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Biomimetic Facade Design Proposal to Improving Thermal Comfort in Hot Climate Region

Güneş Mutlu Avinç
Department of Architecture, Faculty of Engineering and Architecture, Muş Alparslan University, Muş, Turkey

Seda Nur Koç & Semra Arslan Selçuk
Department of Architecture, Faculty of Architecture, Gazi University, Ankara, Turkey

ABSTRACT

The building envelope has an essential role in the energy consumption of buildings and in regulating the energy exchange between the indoor and outdoor environment. Especially in hot climate zones, the temperature increases the cooling loads of the building, while a significant amount of energy is consumed to provide indoor comfort. Much research has been carried out recently to produce responsive and adaptive building envelopes to solve this problem. Nature is a reference for responsive, adaptive building envelope solutions, and the biomimicry approach is utilized. The biomimicry approach suggests using biological models/systems/processes as models/measures/mentors. This research used the biomimicry approach to propose an innovative facade design solution in this context. In this study, where a problem-oriented design approach was accepted, plants were analyzed to find a solution. Plants have evolved to adapt to a particular location's weather, wind, dryness, heat, and light. Buildings, like plants, depend on a specific location. For this reason, arid climate plants were examined in the study. The biological information from analyzing the plants studied was used to develop a design concept. As a result of this study, it is understood that nature has an extensive database and offers many solutions for problems that can be applied in architecture to produce energy-efficient, sustainable, and adaptable designs to indoor and outdoor conditions. The next step for this study is to translate the developed design concept into practice and conduct the necessary analysis.

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Corresponding Author Contact:
snur.koc1@gazi.edu.tr

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1. Introduction

Problems such as changing climate conditions in the global world and the use of non-renewable energy resources affect the building sector. The world's energy resources are limited, and climate change continues to have an impact. The building sector consumes 40% of global energy. In 2015, the energy used for the construction and operation of buildings accounted for 38% of global energy demand, while this rate decreased to 36% in 2020 due to the restriction of the activities of COVID-19 (Hamilton et al., 2020). This consumption also leads to the release of harmful greenhouse gases. Paying attention to the sector's negative impacts, reducing harmful gas emissions and energy consumption, and protecting limited natural resources bring energy-efficient buildings to the forefront (Faragalla & Asadi, 2022). Energy-efficient buildings aim to reduce the energy consumed for cooling by improving natural ventilation, controlling heat conduction, and directing daylight. Energy consumption due to cooling loads is also important in hot climate zones. In hot countries like Egypt, the cooling loads of buildings contribute to approximately 20% of energy consumption (El Ahmar & Fioravanti, 2014).

Thermal regulation in buildings is defined as thermoregulation in nature, and this concept means keeping the body temperature of a living being within a specific range according to external conditions (Farchi Nachman, 2009). Living things in nature adapt to changing environmental conditions with their development adaptations (Abdullah et al., 2018). Adaptations vary according to climate zones. It is provided by many strategies that minimize heat gain or maximize heat loss in hot climate zones. In architecture, designs are made by changing outdoor conditions, like living things in nature, to ensure thermal comfort.

Strategies and adaptations provided by living organisms guide designers toward nature. The evidence found in nature shows nature's evolution, adaptation, and development and is used as a resource in solving design problems. Antonio Gaudi, one of the architects who took nature as a model for himself, emphasized the importance of turning towards nature: "The architecture of the future will be built by imitating nature because this is the most rational, long-lasting and economical of all methods" (Mirat et al., 2018). With its numerous systems, nature offers a database of solutions to many problems. Extracting beneficial and new adaptations from nature brings information about animal and plant morphology, physiology, and behavior.

In the literature, various studies are related to the building envelope where nature is taken as a reference. One of these studies is on the blind systems used in architectural facades. Various hinges are used in these systems. Due to the load acting on these rotating, sliding elements, the hinges tend to wear over time. Periodic maintenance is required due to this situation. To solve this problem, the flexible and elastic properties of plants in nature are examined. Flectofin, produced by I.T.K.E., is a hingeless blinds system inspired by the valvular pollination mechanism in the *Strelitzia reginae* flower (Lienhard et al., 2011).

Building envelopes are a thermal barrier that should be insulated to prevent heat loss and opened to dissipate the heat generated when necessary. In a study of thermoregulation, Badarnah et al. (2010) put forth an evaporative cooling system for building envelopes in arid and dry regions. Drawing inspiration from the osmotic pressure of plant stomata, pinecone deformation due to relative humidity, eyelashes protecting the eyes from sand and dust, and human skin heat transfer, the system's design principles were determined. The system, designed based on the principles of more than one natural system, has been named Stoma Brick.

Aedas Architects designed Al Bahar Towers' double facade system to protect against the hot desert sun. Flowers and mashrabiyas inspired this system. In hot climates such as the Abu Dhabi Desert, where temperatures rise to 49.2 °C, avoiding solar radiation is essential in energy-efficient designs. Radiation, one of the ways of heat transfer, is prevented by the shading method on facades and causes passive cooling. With the facade created, a system that responds to solar movement and reduces solar gain by up to 50% is obtained (URL-9).

Arbabzadeh et al. (2020) analyze the use of thermoregulation in nature through architectural examples. The study evaluates the overlapping features of biomimetic architecture and vernacular architecture. Using different examples, Abdullah et al. (2018) reviewed how thermoregulation in nature can be applied to architecture. In the study, a literature review was conducted and evaluated under the titles of applied projects, experimental models, and design concepts. As seen in the mentioned studies, some studies examine and analyze the use of thermoregulation in nature in architecture. In some studies, model and concept study proposals are presented.

Unlike other studies, this study presents a plant-inspired, energy-efficient, sustainable facade design proposal to provide thermal comfort in hot climate regions. In the design proposal, while the facade modules provide the necessary conditions for the building, a change in the material used according to the ambient conditions is also proposed. The conversion of excess daylight into energy and its utilization for the building also reveal a sustainable design. From this point of view, the following questions have been guiding the creation of an adaptable and responsive architectural shell:

- Can plant systems be considered an example of thermoregulation in the building envelope or facade?
- Can the adaptation strategies of plants be a guide for adaptive and responsive building envelope design?

In this research, firstly, general information about the biomimicry approach is presented. Then, designs created concerning nature are included, and the information obtained from the research on thermoregulation strategies in plants is explained. After the research and analysis, the *Fenestraria aurantiaca* plant, which lives in the deserts of South Africa, was selected for information transfer. The biological information obtained from the plant, also called the window plant, was then transferred to architecture for building envelope design, and lessons learned from natural construction were used. The scope of the study was limited to the thermoregulation strategies of the plants, so a conceptual facade proposal was presented for the selected plant. The facade design, produced with a problem-driven approach, could not be carried out practically due to the possibilities.

2. The Biomimicry Approach

Biomimicry was first published in Janine Benyus' book "Biomimicry: Innovation Inspired by Nature." The concept of biomimicry, which consists of the Greek words 'bios' (life) and 'mimesis' (imitation), enables one to examine, analyze, and apply the order existing in nature to the system as a solution to produce solutions to the problems that people face throughout their lives. Benyus states that "it is a candidate to be a new branch of science that studies models of nature to solve human problems and then adapts them to their systems or is inspired by these designs or processes." He defines it as" not precisely technology or biology; it is the technology of biology" (Benyus, 1997). Biomimicry is a new approach representing a broad field of scientific and technical activities concerned with interdisciplinary cooperation between biology and other areas to solve practical problems for innovation or sustainable development (Chayaamor-Heil, 2023).

The development, adaptation, and evolution that nature has undergone for many years for its survival appear to have biological traces. Humans use nature by following these biological traces to learn and solve their problems. Using the natural world as a source of inspiration and problem-solving has introduced a new term called 'biomimetic' to architectural design. The primary purpose of biomimetic design is to learn from nature and discover the solutions used by nature (Zari, 2007).

The process of learning/inspiration from nature, which includes concepts such as biomimicry and biomimetics, is diversified with concepts such as bio-informed, bio-inspired, and bio-design. Bioinspiration offers a creative approach based on the observation of biological systems (ISO/TC266, 2015), while the concept of bio-informed refers to the use of biological knowledge to generate innovative solutions, sustainable or not, to design problems that people are trying to solve (louguina et al., 2014). Bio-design is an interdisciplinary concept that combines biology, science, and design. Although the primary source of all the concepts expressed is the same, they differ in dealing with that source. For example, while biomimicry emphasizes sustainability, biomimetics emphasizes innovative designs and technologies by learning from nature.

Finding a solution to the problem encountered in nature, guided by it, reveals two basic approaches: problem-driven and solution-driven in the biomimetic design process. The problem-driven approach identifies the problem, and how nature develops solutions to this problem in similar situations is examined. In the solution-driven practice, a feature, behavior, or function existing in nature is identified and transferred to the design.

Researchers express these two basic approaches in different terms. Problem-driven design processes are described by various terms such as design looking to biology (Zari, 2007), biomimetics by analogy (Gebeshuber & Drack, 2008), top-down (Speck et al., 2008), problem-driven biologically inspired design process (Helms et al., 2009), technology pull (ISO/TC266, 2015) (Cohen & Reich, 2016).

The solution-driven process is expressed in different terms such as solution-driven (Vattam et al., 2007; Helms et al., 2009), biology to design (Baumeister et al., 2013), biology push (ISO/TC266, 2015), bottom-up (Speck et al., 2008; Aziz & Sherif, 2016), biomimetics by induction (Gebeshuber & Drack, 2008) (Cohen & Reich, 2016). The steps of these two processes are presented in Figure 1.

In this context, a building envelope/facade design was produced in this study using the "problem-driven approach," one of the biomimicry approach processes.

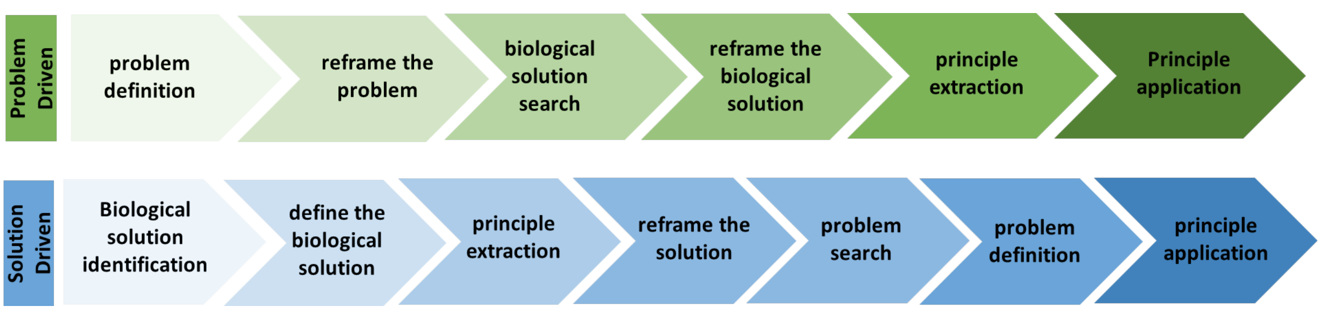


Figure 1 Biomimicry-based design process (Helms et al., 2009)

3. Nature-Inspired Facade Systems

Changing climatic conditions, non-renewable energy resources, and increased consumption also affect the architecture sector. Architectural designs should vary and adapt to these conditions. The envelope, which is most affected by external conditions such as air movement, humidity, temperature, solar radiation, and noise, is the most energy-efficient component of a building. It acts as a thermal shield that needs to be insulated to prevent heat loss and opened to dissipate heat when necessary. It aims to improve the building envelope's performance and minimize energy consumption with adaptable facade solutions according to environmental and climatic conditions (Badarnah, 2017). In this context, building facades should have functions such as directing daylight, controlling heat transmission, improving natural ventilation for ventilation performance, and reducing energy consumption due to cooling loads (El Ahmar & Fioravanti, 2015).

In nature, living organisms keep their body temperatures within a specific range behaviourally, physiologically, or morphologically to survive. Maintaining a constant body temperature is achieved through continuous heat gain and loss. Organisms develop different mechanisms and strategies according to the climate to facilitate heat gain and loss (Badarnah & Knaack, 2010).

Today, nature harbors the critical potential for thermoregulation in buildings with its processes, systems, and strategies. The design of effective building shells that adapt to climatic conditions related to buildings is inspired by nature. From this point of view, the study includes facade designs created by learning from nature.

3.1 Facade Design Inspired by Stoma

Plants facilitate air exchange through pores known as stomata. The opening of these stomata leads to enhanced heat loss, whereas their closure results in reduced heat loss. The research designed by Kalatha (2016) based on thermoregulation strategies in plants

(Figure 2) was inspired by the working principle of stomata. The designed facade has panels that change according to environmental conditions. Panels formed by combining metals with two expansion coefficients change shape according to temperature. By bending or opening the panels, heat transfer and ventilation of the system are provided (Kalatha, 2016).

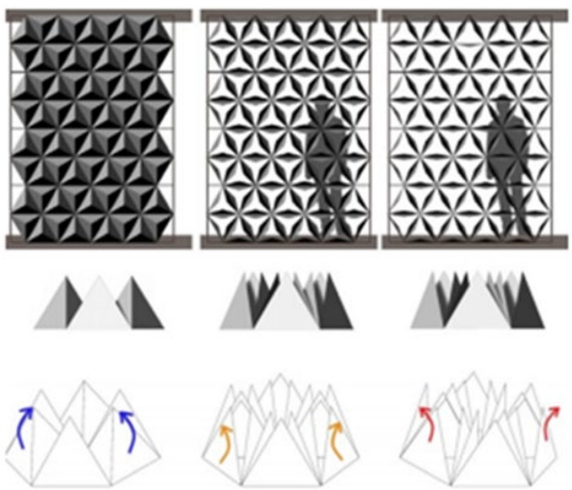


Figure 2 Facade model inspired by the stoma (Kalatha, 2016)

3.2 Shell System Designed Inspired by Durian Fruit

The durian fruit, indigenous to Southeast Asia, is encased in a semi-hard, multi-layered, and spiny shell, safeguarding the seeds inside. The thorns, acting as a protective layer, also prevent the seeds from overheating. As seen in Figure 3, the Esplanade Theatres Building features a shell system with multiple layers that comprises pyramid-shaped modules inspired by the Durian fruit shell. The shell contains sunscreens made of aluminum material. Long sunscreens are on the east and west facades with high sunlight, and shorter sunscreens are on the other facades. In this way, the interior space is prevented from overheating, and the daylight required by the building is taken into the interior space in a controlled manner (Radwan & Osama, 2016).

Figure 3 Durian Fruit and Esplanade Theatres Building (URL-8)

3.3 Facade Design Inspired by Spiny Devil Lizard Skin

Various systems are being developed in arid climates with high temperatures and water scarcity to provide an adequate water supply. The microstructural characteristics of the spiny devil lizard's skin facilitate optimal moisture absorption. The skin scales possess channels that collect water through capillary sensing, as reported by Abdelmohsen and Ibrahim (2021). In this context, the study proposed by Abdelmohsen and Ibrahim (2021) aims to develop facade morphologies using programmable passive actuation (Figure 4). Hygromorphic materials like wood typically exhibit various deformation patterns that affect passive actuation mechanisms. Mimicking the ability of the spiny devil lizard to retain water for a significant period reinforces these mechanisms. The study proposes a two-layer composite containing silica gel and potassium chloride that mimics this behavior in wood composites based on chemical properties (Abdelmohsen & Ibrahim, 2021).

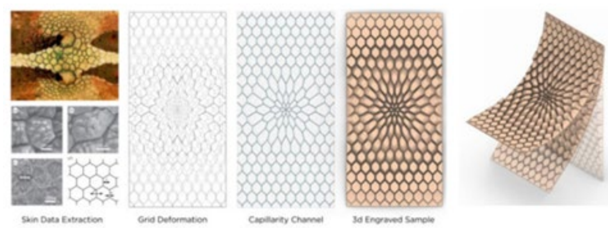


Figure 4 Adaptable facade prototype by imitating the skin of the spiny devil lizard (Abdelmohsen & Ibrahim, 2021)

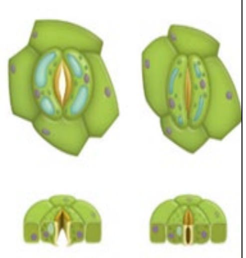
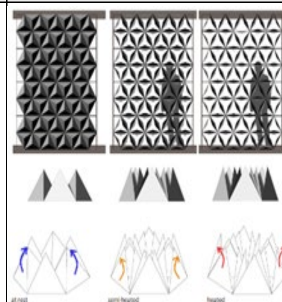
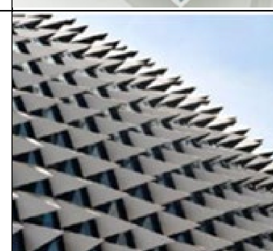
3.4 Facade Designed Inspired by Cactus

The Minister of Municipal Affairs and Agriculture (M.M.A.A.) building design drew inspiration from desert plants thriving in Qatar's arid and unproductive environment. The building is designed to save energy. The windows are equipped with sunshades that are responsive to solar intensity. Taking inspiration from the cactus' ability to retain water by sweating at night, the sunshades adjust to the level of sunlight during the day by opening and closing accordingly (Figure 5). This feature helps to prevent excessive heat and provides passive cooling when the sunshades are closed (URL-10)

Figure 5 The Minister of Municipal Affairs and Agriculture (M.M.A.A.) Building (URL-10)

Information about the studies designed with the data obtained from nature mentioned so far is presented in Table 1. In this context, in the studies examined, the inspired organism, the thermoregulation feature of the organism, the biomimetic shell feature, and the purpose for which they were designed, such as heat gain, heat retention, heat dissipation and heat prevention as a function were analyzed.

Table 1 Architectural examples that utilize thermoregulation strategies found in nature in building envelope design.

	The Inspired Organism	The Thermoregulation Feature of The Organism	The Biomimetic Shell Feature	Architectural Work	Function Of The Architectural Shell
STOMA		When stomata open, heat loss increases, and when they close, heat loss decreases. Stomata that open at night due to osmotic pressure close during the day, thus regulating thermal conditions in plants.	The facade has panels that change according to the ambient temperature. Panels formed by combining metals with two expansion coefficients change shape according to temperature. By bending or opening the panels, heat transfer and ventilation of the system are provided.		Heat Gain Heat Retention Heat Dissipation Heat Prevention
CACTUS		The cactus sweats at night to retain water. In addition, the thorns that cover the cactus reduce the thermal gain due to intense solar radiation, as they draw the hot air away from the outer surface and keep it cool.	The facade has a shading system that adapts to the amount of solar radiation and the outside temperature, like cactus spines. Inspired by the principle that the cactus sweats at night to retain water, the sunshades open and close according to the sun's intensity during the day.		Heat Gain Heat Retention Heat Dissipation Heat Prevention
DURIAN FRUIT		Durian fruit has spines on its surface that protect the inner seeds from high temperatures.	The facade is made of aluminum inspired by the thorns of the durian plant. The building envelope is connected to an intelligent shading system that connects to photoelectric sensors to adapt to the sun's movement.		Heat Gain Heat Retention Heat Dissipation Heat Prevention

3. Method

In regions with hot climates, buildings are exposed to more daylight. For this reason, more energy is spent on cooling loads to keep the indoor temperature comfortable. This situation has led to the problem of "exposure of buildings to excess daylight and an increase in cooling loads in hot climate zones." The source utilized to produce solutions to this problem is nature. Plants in nature are immobile, like buildings, and remain attached to a specific place. Accordingly, they have developed unique protection methods against extreme wind, drought, cold, heat, and light (URL-1).

For this problem, problem-driven process steps were followed, one of the biomimicry approaches and starting with the issue. Firstly, the problem was defined, and then the problem was placed in a biological framework. Afterward, a biological solution was searched for, and the biological solution was examined in detail. After the principle was obtained from the biological solution, it was transferred as an architectural facade solution in the last step. However, there was continuous feedback during this process. The stages of the process are presented in Figure 6.

Figure 6 Design process (created by the authors following the problem-driven process steps defined by Helms et al.,2009)

In the biomimetic design process, the domains that exist to address the problem intersect, and the potentials of domains such as function and morphology form the principles necessary to solve the problem. The principles reached in this study can be seen in Figure 7.

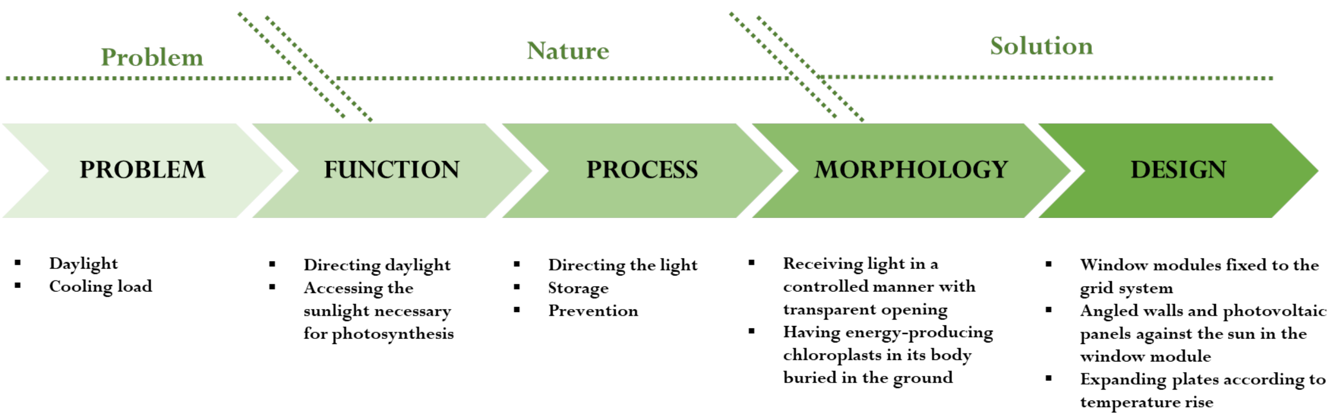


Figure 7 The design process followed based on the *Fenestraria* plant (adapted from Zari, 2007 and created by the authors)

4. Case Study: Biomimetic Building Shell Design for Hot Climate Regions

In this section, the research conducted with problem-driven process steps, which is one of the biomimicry processes, is presented.

4.1 Problem Definition

Buildings constitute a significant portion of total energy consumption in developed countries. Changing climatic conditions and increasing consumption of limited resources have brought energy-efficient buildings to the forefront. Building shells are effective in regulating energy exchange between indoor and outdoor environments. By improving natural ventilation, controlling heat conduction, and directing daylight with building shells, the cooling loads required for the building are reduced. In hot climate regions, the temperature increases the cooling loads of the building, and a significant amount of energy is consumed to provide indoor comfort. For this reason, thermoregulation of the building envelope in these regions constitutes a significant design problem.

4.2 Reframe the Problem

In nature, thermoregulation refers to the adaptations that organisms develop according to variable temperatures. Living organisms have developed physiological, morphological, and behavioral adaptation strategies for survival. Living organisms have various methods to maintain their thermoregulation. According to climatic conditions, organisms use techniques such as heat gain, conservation of existing heat, dissipation of excess heat, and prevention of overheating (Yazıcıoğlu & Selçuk, 2019).

Plants, for example, have evolved over generations and developed various adaptations in response to the ever-changing environment. The basis for the success of plants depends on their ability to compete with their environment and physiological development. One of the most critical applications of physiological principles is the study of plants, climate, physical and physiological environmental factors, and the relationships between them. From this point of view, the problem statement, which was determined to be the thermoregulation of buildings in hot climate regions, is re-asked in this section as what kind of strategies living things develop for thermoregulation in nature.

4.3 Biological Solution Search

In Asknature, plants such as ice flower, cactus, and *fenestraria aurantiaca* are obtained in the research on biological strategies and thermoregulation of plants. The ice flower has small water vesicles on its surface to meet the water needs of the climate and maintain its thermal balance. On the other hand, the cactus has spines on its surface and folds in its stem to help regulate its temperature in hot climates. You can find a panda plant on another website about plants (URL-4). In the panda plant, thermoregulation is achieved by a layer of feathers covering the surface of the leaves. The feather layer is used to direct daylight and control water loss.

The information obtained shows that plants in arid climates are exposed to intense sunlight in the region where they grow. Plants growing in this region develop different strategies to protect themselves from sunlight. The leaves of some plants are covered with wax or hairs that reflect light. Some plants photosynthesize with their green stems and maintain water balance with the thorns on them.

The panda plant (Figure 8) is a wild plant from Madagascar. It has a woody base. The plant can grow up to several meters long. The velvety appearance of the leaves is caused by the villus that covers them. These hairs, which appear in the trichomes, help to direct light and limit transpiration (URL-4).

Figure 8 Panda Plant (URL-3)

The ice plant (Figure 9) is found in South and East Africa. The plant gets its name from the tiny, transparent sacs covering its leaves, making them appear covered in frozen dew. These tiny sacs are a variation of the hair-like structures that cover the surface of plants. These sacs provide the plant with water during drought (URL-5).

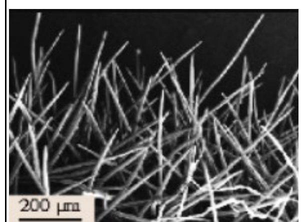
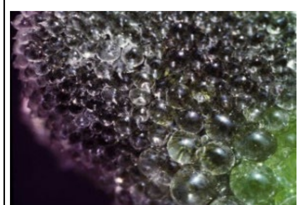
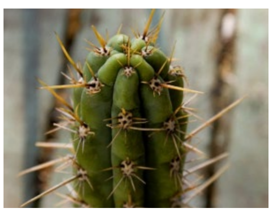
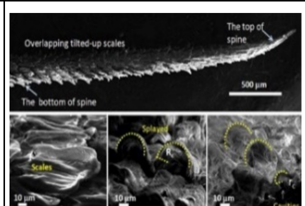
Figure 9 Ice Plant (URL-5)

The hills and hollows surrounding the thick stems or branches of the cactus (Figure 10) protect them from overheating and drying out. The uneven surfaces control the amount of sunlight reaching the plant. In the desert heat and in times of rainfall, the curved surfaces of the cactus change. In addition, cactus thorns minimize the surface area and reduce the perspiration rate (URL-6).

Figure 10 Cactus (URL-6)

In this section, the data obtained about the plants is presented in Table 2. The thermoregulation feature of the investigated plants, microscope images of the feature, and morphological, physiological, and behavioral aspects of their adaptation to nature are analyzed.

Table 2 Thermoregulation methods of plants in nature

	Plant	Improved Thermoregulation Method	Microscope Image	Adaptation		
				Morphological	Physiological	Behavioral
PANDA PLANT	 (URL-3)	The leaves are covered with villus. These villus help to direct light and limit transpiration (URL-4).	 (1)			
ICE PLANT	 (URL-5)	The leaves are covered with tiny transparent sacs. These sacs are used for storage during drought and high salinity (URL-5). The plant uses rainwater to open and release its seeds (2).	 (3)			
CACTUS	 (URL-6)	The amount of solar heat reaching the plant is controlled by the uneven surfaces formed on the cactus stem. Cactus spines reduce the transpiration rate by keeping their surface area minimal (URL-6).	 (4)			

4.4 *Define the Biological Solution*

Fenestraria aurantiaca grows in the Namib Desert in South Africa. The plant has a stem of about 4 cm (1.5 inches) and buries its stem in the sand. The plant has lenticular tops that direct light inwards (Figure 11). These lenticular protrusions allow the photosynthetic cells in the stem to capture daylight without burning (URL-2).

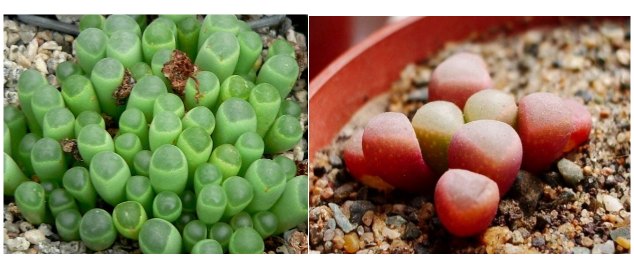


Figure 11 *Fenestraria aurantiaca* (URL-2)

In the working principle of the plant (Figure 12) (right), light enters through transparent protrusions at the tip of each leaf. The incoming light travels along the leaf. This ensures the plant has access to daylight without burning in extreme heat. The plant absorbs light through the transparent opening at the top (Figure 12) (left), which is why it is also called a 'window plant' (Heil & Belkadi, 2017).

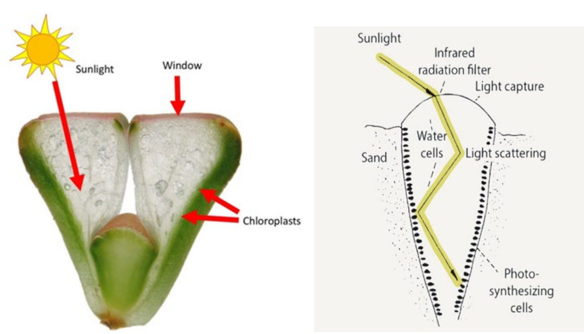


Figure 12 Section of a Fenestraria plant (URL-11) (left); Working principle of *Fenestraria Aurantiaca* (Heil, Belkadi,2017) (right)

Fenestraria Aurantiaca continues its lifecycle with the characteristics developed following the region and the warm climate. The most important feature is that it has transparent, window-like protrusions. In hot and dry climates, the plant buries its stem in the ground to prevent damage, and these transparent protrusions allow the daylight necessary for photosynthesis to pass through.

The *Fenestraria Aurantiaca* plant was identified because it grows in hot climates, and the window feature in its structure is practical. The transparent window structure, designed to suit the climatic conditions, protects the plant from extreme heat while allowing it to receive the daylight it needs.

4.5 *Principal Extraction*

The plant receives the daylight it needs through its transparent, window-like projections. Based on this structure, a window module is proposed for the facade. The module, which has a transparent layer like a plant, provides the daylight needed by the building, while the panels on the concave walls of the module aim to convert excess sunlight into energy (Figure 13).

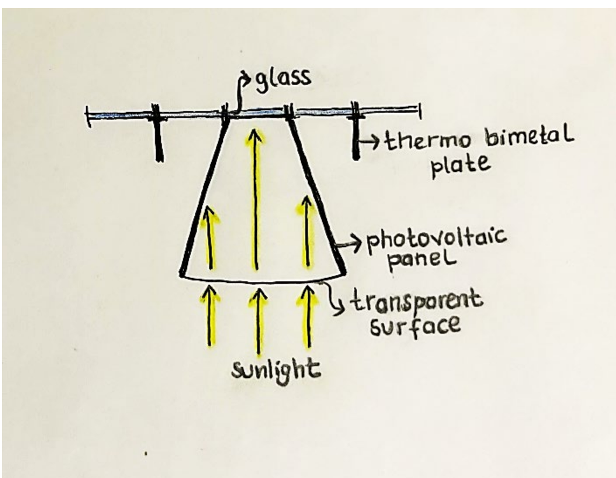


Figure 13 Sketch of design principle

In hot and arid climates, plants bury themselves in the ground to prevent damage to their leaves and reduce the surfaces exposed to daylight. Inspired by this principle, the aim is to reduce the areas exposed to direct sunlight as the temperature of the facade rises. This minimizes the thermal comfort of the building and the energy required for cooling.

4.6 *Principal Application*

The design aims to create a facade that does not compromise the need for daylight, reduces heat gain, and minimizes cooling loads. The design idea is inspired by the physiological and behavioral characteristics of the window plant, which grows in warm climates. The transparent openings in the plant provide the necessary daylight for the plant's energy needs, whose leaves are buried (Figure 14).

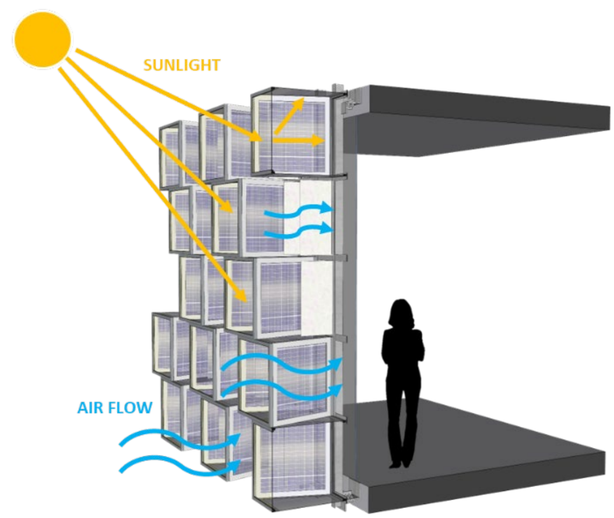


Figure 14 Perspective View of the Designed Facade

We designed a fixed horizontal and vertical frame system to mount the modules. There are gaps in the frame that allow natural airflow. Thermal bimetal plates were placed next to the gaps in the facade to protect against hot air and excessive daylight (Figure 15). Thermo-bimetal plates are formed by joining two metals with different coefficients of expansion.

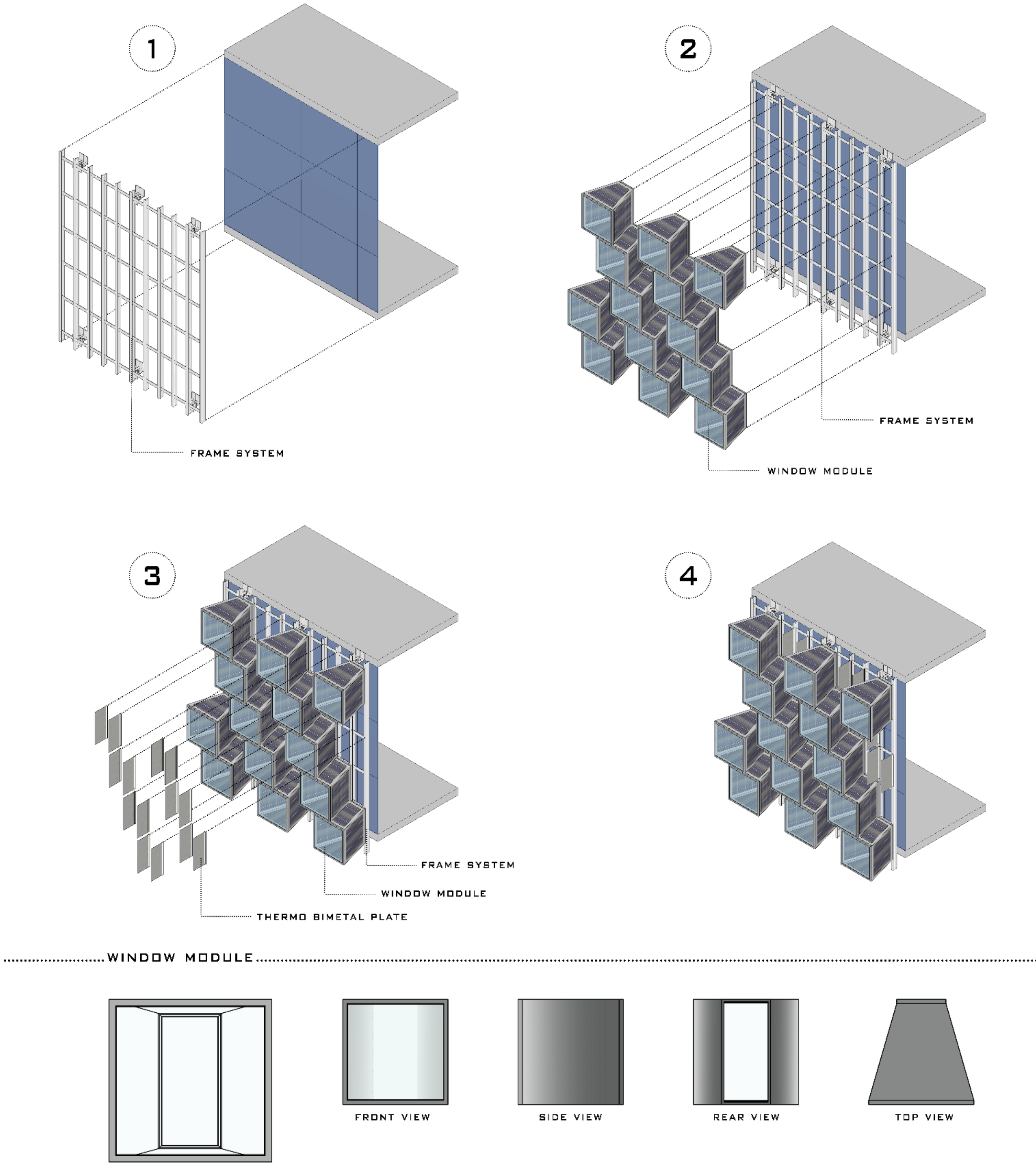


Figure 15 Facade Design Diagram

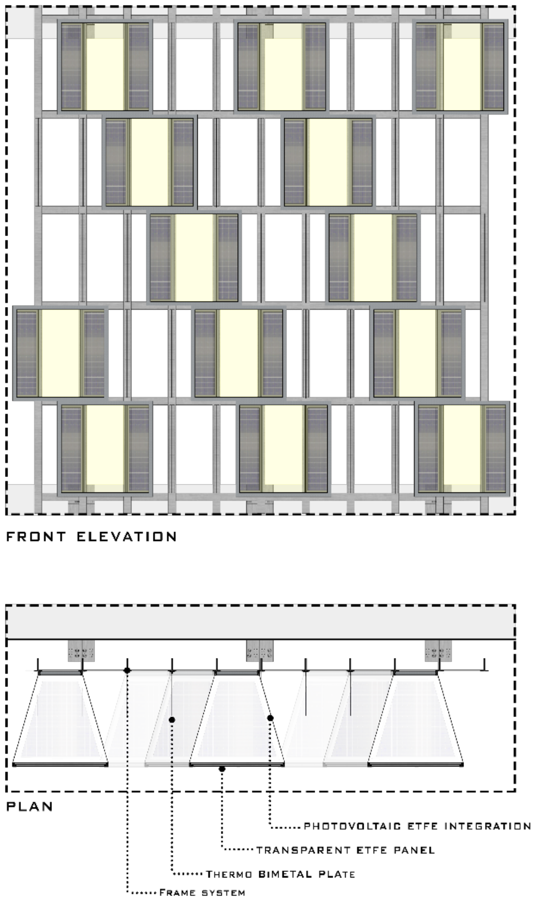


Figure 16 System Plan and Elevation

The designed modules and panels were used to create a facade. The fixed window modules in the facade meet the daylighting requirements of the system and convert excess daylight into energy in the panels on the side faces. Gaps are left in the facade to allow natural airflow through the building. Thermo-bimetallic plates fixed to the sides of these gaps expand as the temperature rises (Figure 17). The expanding plates reduce the gaps in the facade and ensure that the heated air reaches the building at a minimum level (Figure 18).

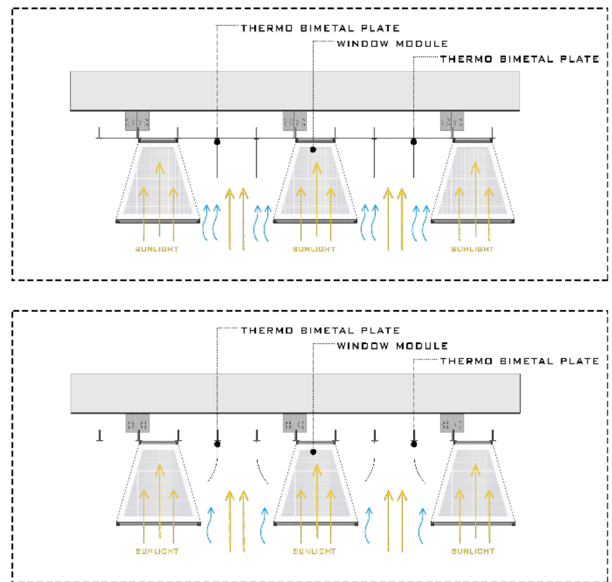


Figure 17 Thermo bimetal plates on the facade that expand according to temperature

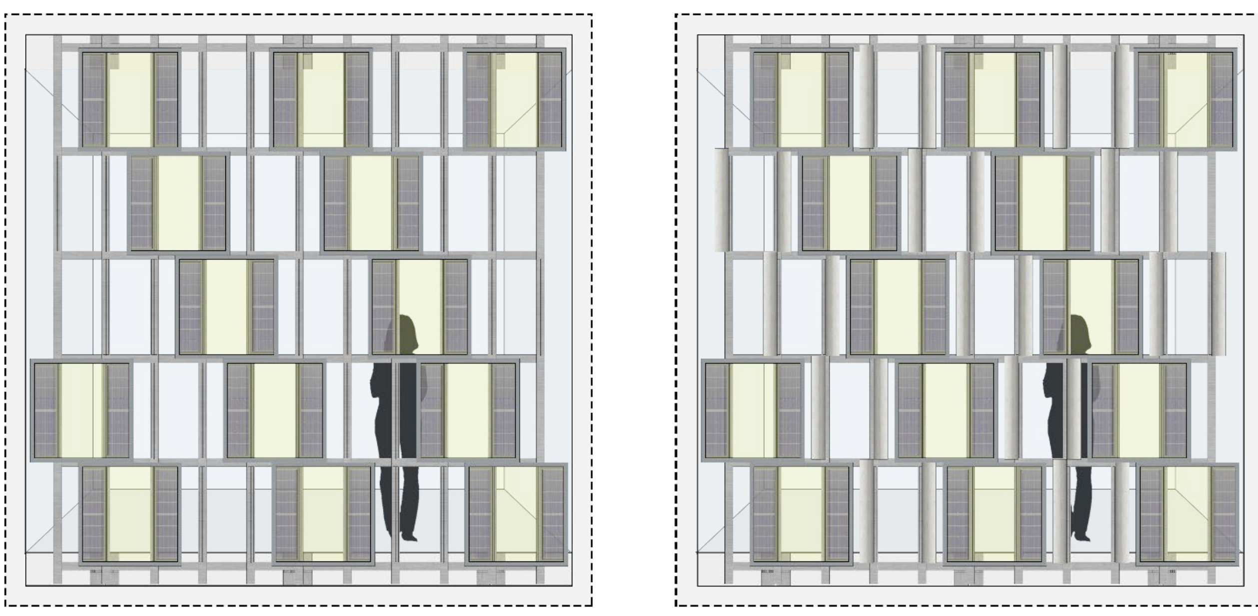


Figure 18 Facade change due to expansion of plates according to temperature change.

5. Conclusions

Changing climatic conditions, increasing energy consumption, and limited energy resources have highlighted the importance of energy-efficient buildings. The building envelope is one of the most critical components of energy-efficient buildings. The design of building envelopes aims to improve natural ventilation, control heat conduction through direct daylight, and reduce energy consumption for cooling.

In this context, nature offers a unique resource for solving the problems we encounter in our designs. The resource it offers guides us towards sustainable solutions. Plants in nature are stationary elements exposed to various environmental factors, such as buildings. Plants have developed different adaptations to survive according to their climate. With the same approach, buildings can be designed to be sustainable and energy efficient without harming their environment.

In this study, plants are analyzed to provide a solution to the problem of excessive daylighting and increased cooling loads of buildings in hot climates. A problem-driven design process was followed, and Arid climate plants were investigated to solve the problem. *Fenestraria aurantiaca*, a desert plant, was used as an inspiration. Window modules were created by mimicking the plant's ability to receive daylight through its transparent windows and provide the energy it needs. These modules are supported by thermo-bimetallic plates and transformed into a facade system. In the system created, the openings in the facade are reduced with thermo-bimetal plates that expand as the temperature rises. The window modules ensure that the daylight required by the building is always available and that the energy needed for the building is obtained by converting excess sunlight into energy.

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