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In Transizione: sfide e opportunità per l'ambiente costruito

In Transition: challenges and opportunities for the build heritage

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Fabio Fatiguso, Francesco Fiorito,
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A biomimetic approach for climate reactive building envelopes inspired by plants adaptive strategies

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Abstract
Due to climate change, traditional building envelope solutions cannot longer ensure optimal regulation of variable external environmental flows. This requires the use of energy-intensive technical solutions. To reduce the environmental impact of the building sector and achieve the Sustainable Development Goals proposed in the 2030 Agenda, a change in the building's design methods is requires. In recent years, attention to climate-responsive solutions for the building envelope has increased. Nature provides a database of adaptive and responsive solutions that can be mimicked by the biomimetic discipline and translated into building envelope technologies using innovative materials and techniques.
This paper aims to investigate and emulate the adaptive and responsive strategies of plants in desert and mediterranean climates, to propose bio-inspired solutions for climate-reactive building envelopes. To survive survive in different ecosystems, plants respond to biotic and abiotic factors through morphological, physiological, and behavioural mechanisms activated by their integumental tissues. Buildings, like plants, are also located in a specific climatic-territorial context and interact with the external environment through the building envelope which acts as a filter.
In this study, the field of plants is investigated using the bio-Adaptive Model, a biomimetic and problem-based approach that allows moving from nature to technology and proposing different solutions for the building envelope that vary according to the climatic context and are able to respond to specific climatic challenges. As a result of this study, four responsive functions inspired by the adaptation strategies of Mediterranean and desert plants are proposed. Furthermore, this approach can help architects and engineers to design biomimetic and adaptive building envelope inspired by nature.

Keywords: biomimetic, environmental, adaptive envelopes, plants adaptation strategies, bio-inspired design

1. Introduction

The built environment is responsible for a high rate of energy consumption and greenhouse gas emissions into the atmosphere [1] with consequent alterations in the climatic state. In particular,

the building sector account for 40% of energy-related CO_2 [2], [3]. In order to promote adaptive and sustainable solutions in this scenario, in line with the various European instruments such as the 2030 Agenda [4] and the related Sustainable Development Goals, a change in the approach to building design is required.
The relationship between the building and the environment is through the building envelope, which is not only the separating element between indoor and outdoor spaces, but also the filtering element responsible for regulating energy exchange [5]. When it interacts with different environmental factors such as solar radiation, temperature, air flows, wind and noise, it could promote indoor comfort and reduce energy consumption and environmental impact. Conventional envelope solutions are not always efficient to deal with the accentuated weather changes, varying from the time scale of the second to the daily or seasonal one. Furthermore, conventional building envelopes improve performance through solutions with static components, such as thermal insulation or energy-efficient glazing, but are unable to respond to climate changes throughout the day and over the years [6], [7]. Therefore, it is necessary to direct the design towards technological solutions able to guarantee the regulation of environmental flows in relation to different climatic conditions. It follows the need to review the characteristics and requirements of the building envelope [8].

1.1. Theorical background

To respond to the new challenges of climate change, the concept of adaptive building envelope has emerged in recent years as a resilient way to reduce building energy consumption, limit CO_2 emissions and ensure indoor comfort [9], [10]. Loonen [11] introduces the concept of adaptive building skins (CABS) as an element that have the "ability to repeatedly and reversibly change some of its functions, features, or behavior over time in response to changing performance requirements and variable boundary conditions, to improve overall building performance". Definitions of adaptive envelope are varied [12]–[14], as are the terminologies in which it's declined. The most recent classification is the one proposed by Tabadkani et. Al [15] in 2021, which gives an overview of the different declensions of the adaptive envelope: active, passive, biomimetic, kinetic, intelligent, interactive, movable, responsive, smart, switchable. The advantage of evolvability is recognized in adaptive envelopes as a feature that allows the envelope itself to cope with changes even in the long term [10], [11]. Most of the building envelopes made to date are mainly characterized by kinetic solutions that are activated by sensors and actuators, performing, in most cases, a shielding function from solar radiation. These solutions involve the use of sensors and actuators which involve energy consumption, as well as high management and maintenance costs. Therefore, passive solutions, capable of responding to climatic stimuli autonomously and without added energy, are configured as privileged. Combining the concept of adaptive envelope with that of self-activating smart materials [16] is one of the challenges of the world of scientific research in recent years. The application of responsive materials, such as shape memory materials, is also limited to the prototype scale but foster the potential to react to environmental stimuli in a passive way like natural organisms. In this direction, nature is configured as a teacher and as a privileged way to propose bio-inspired solutions to the functioning of natural organisms themselves. Nature has always been an inspiration source for architects and engineers, who have reproduced its shapes and structures [17] to create interesting architecture. The imitation of forms, typical of biomorphism, or the use of nature in architecture (bio-use or bio-utilize) such as green roofs and green walls, are not the only possibilities of bio-inspired design, but it is also possible to emulate the functioning mechanisms of natural organisms and transform them into technologies through the biomimetic discipline [18]. In fact, unlike formal emulation, typical of biomorphism, the biomimetic discipline (from the Greek bios, life and mimesis, imitation), aims to emulate the functional strategies of nature to transfer them into dynamic and adaptive architectural technologies. Nature offers numerous examples of adaptation strategies activated by natural organisms, classified into morphological, physiological and behavioural, to survive and adapt to the biotic and abiotic factors and environmental stresses that characterize the habitat in which they live. Janine Benyus outlines biomimetics as a new direction capable of linking sustainable and innovative solutions [19]. This concept also underlies that of saving resources and sustainability, in fact the Biomimicry Institute specifies that “biomimicry is about valuing nature for what we can learn, not what we can extract, harvest, or domesticate” [20]. The combination of the concept of biomimicry with that of adaptive envelope therefore allows to define a biomimetic adaptive envelope solution capable of reacting to environmental stimuli and adapting to it passively, without using additional energy resources, just as occurs in nature.

1.2. Aims and scope

The aim of this paper is to explore the bio-adaptive model by examininv the mechanisms of adaptation of plants to different environmental conditions in order to highlight the parallels between natural functions and the functions of buildings. In this way, “nature-inspired” [21] facade solutions are proposed. Applying the functional strategies of plants to the building envelope creates a “living envelope” that is able “to adapt to the changes arising in the surrounding environment in order to maintain a comfort state for its occupants” [22]. This study can facilitate the subsequent stages of the design process to propose adaptive nature-inspired solutions and define sustainable and innovative built environments. The present work is divided into three macro-sections: the first concerns the methodology used, the second the theoretical implementation of the bio-adaptive model with a biological study of the strategies of plants in desert and Mediterranean climates and the associated adaptive solutions for adaptive casing. The third part presents the results and conclusions that underline the potential of the defined approach, the biomimicry discipline in the context of the building envelope technologies sector and the coherence of this discipline with the short and long term goals of climate neutrality and reduction of energy consumption in the building sector.

2. Methods: the bio-adaptive model

This section shows presents the methodology used in this study. After defining the objectives of the following article, the study analyses the strategies of natural organisms in order to provide indications of replicable and transferable solutions in the field of building envelope technologies. Among all natural organisms, the focus of this study is on plants, which, like buildings, are stationary but still activate adaptation strategies, which are divived into morphological, ethological and behavioral strategies. In addition, energy exchange between plants and their surrounding environment takes place through the integumental tissues whose actions can be analyzed and emulated in architecture.

So, because the aim of the biomimetic discipline is the transfer of the functions of natural organisms in the field of building technologies, and to make this happen, it is necessary to define a methodology for this transfer. The application of the biomimetic approach to identify the potential of the nature's functional strategies for implementation in the field of Architecture, Engineering and Construction (AEC) has increased in recent years [23]. Unfortunately, many of the biomimetic methodological approaches present in the literature define in a generic way the steps to emulate the functioning of biological organisms without specifying the field of application. In this study, we consider the problem-based approach called the bio-Adaptive Model [18] which explores the three basic steps to move from the problem to building technologies by nature, as shown in Fig. 1.

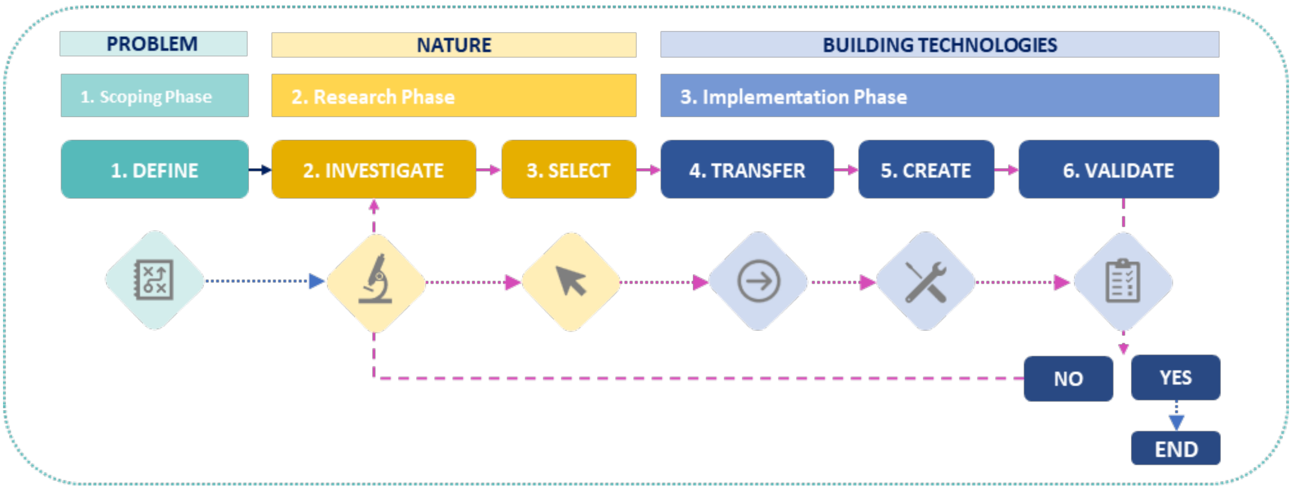

Fig. 1. General framework of the bio-Adaptive Model (bio-AM) – © 2022, Sommese et al. [18].

The first step of bio-AM, called "scoping phase", is to define the problem or challenge to be addressed. For this step, analysis of the geographical context and available environmental resources is crucial, as a solution for one context may not be valid in another context. In the second step – the "research phase" – the question "how does the nature react?" must be answered in order to understand how biological organisms meet the climatic challenges and which adaptation mechanisms they activate for survive. In the third phase, the biological strategies, identified in the previous phase, are transformed into architectural technologies using dynamic-reactive systems or self-responsive materials. If the result of this phase is positive, the adaptive biomimetic envelope model is obtained; if the result is negative, one has to return to phase two to identify a new strategy to imitate.

3. Current problems and challenges for buildings

Recent government reports, as well as the scientific literature, highlight the main issues and challenges facing the built environment, and buildings in particular, due to climate change [3]. Every ecosystem is composed of a number of biotic (living) and abiotic (non-living) factors, which vary in scale and quantity depending on the geographical location. Abiotic factors are the non-living parts of an environment, such as sunlight, temperature, wind, water and soil, as well as natural events, such as storms or volcanic eruptions. Biotic factors, on the other hand, are the living parts of the environment, such as plants, animals and microorganisms. Ordinary environmental parameters are being altered and often exacerbated by the ongoing climate crisis. Thus, on has to deal with high temperatures, excessive solar radiation, air (often not very pure and polluted) and the water that has to be extracted from the water bombs in order to preserve it and use it during long periods of drought. So, the main factors that pose a problem for buildings are synthesized as temperature, water and sun. As a result these have negative repercussions on indoor comfort and user welfare. Therefore, the challenge for the building envelope is precisely to ensure an adaptive and passive response to these climate stimuli and to address this challenge in a resilient and sustainable way. The study of nature, which is always the master of adaptive solutions, is configured as a proactive solution from which strategies can be derived for imitation.

4. Biological investigation: plants adaptation strategies

In biology, the concept of adaptation implies changes in organisms as environmental conditions vary. In particular, refers to the ability of organisms to change their anatomical, physiological and behavioral processes to adapt to the conditions of the environment in which they live, through response mechanisms to regulate abiotic factors, including water, air, and sunlight [24]–[26]. The set of biotic and abiotic factors that make up an ecosystem affect the life of natural organisms that must adapt, with mechanisms varying from the daily to the seasonal scale [24].
In the case of plants, the interface with the external environment is represented by the integumental lining and protection tissues. The epidermis represents one of the primary external integumental tissues, constituting the outermost layer of the leaves; its functions are to limit water loss, protect internal tissues from mechanical damage and excess heat caused by irradiation, build a barrier against fungi and bacteria [27]. In addition to these main functions, the epidermis also performs other functions such as participation in movement mechanisms and the perception of biotic and abiotic stimuli [27], [28]. The gas exchange between the internal and external environment takes place through the stomata, which represents the key to investigating the response and adaptation of plants to environmental conditions. Stomata are made up of guard cells (similar in shape to the lips) which increase their turgor by absorption of water, while when there is a decrease in turgor the cells will narrow the stomatal opening until it closes again [28]. The epidermis is also made up of trichomatous formations, characterized by hairs, trichomes, papillae, scales or emergencies [27].
The movement of the plants is induced by the microscopic swelling of the cells. Plants regulate their morphology and physiology in relation to the variability of the boundary conditions. The dynamic interactions between their morphology and the environment contribute to the adaptability of the plant system. Some environmental factors greatly affect the development and growth of the plant. Light is an indispensable factor for the existence of plants: most plants can activate some physiological functions only in the presence of light. Temperature is also crucial. In winter, for example, high temperatures prevent plants from carrying out various physiological processes that will go into a stupor until spring. Light and temperature also affect the flowering of plants. Obviously, individual plant species

react differently about variations in light, temperature and all other climatic factors such as rain, wind, humidity, etc. This justifies the fact that, depending on the climatic conditions of a given location, plant organisms take on different aspects and characteristics.
The ability of plants to respond and regulate themselves to the surrounding environment is manifested in the change of the growth pattern through the modification of the size, shape, and structure of the various vital systems. Darwin [29] was among the first to observe and describe some plant movement responses to the variation of environmental parameters. The movements of the plants can be divided into tropisms, nastie and nutations. Tropisms involve a modification of the growth pattern of the plant by changing the orientation of the plant in the direction of the stimulus; the nastie do not depend on the direction of the stimulus but are due to the variation of turgor or growth of the cells; nutations, on the other hand, are oscillatory or rotatory movements of the organs caused by a different type of cell growth on opposite sides of the organs themselves [30]. In particular, the movements of plants are divided into spontaneous, when they are autonomous and activated for reasons internal to the organism, and induced movements, when they are caused by a stimulus. The Tab. 1 shows the abiotic and abiotic factors and the main plant movements induced by environmental stimuli. The movements of plants and their orientations in space imply a behavioral adaptation [30], but there are also two other types of adaptive mechanisms that plants can activate: morphological (appearance/form) and physiological (metabolic properties). Morphological adaptation implies a perennial or temporary structural or geometric modification, which improves survival functions. Shape, volume, and structure change according to the plant's response to environmental factors. Cacti are an interesting example of this type of adaptation. Their accordion stems are water tanks, they expand and contract according to the water content, the ribs ensure self-shading by reducing the temperature of the airflow around the cacti; the leaves of the cacti are transformed into thorns to limit the number of stomata responsible for transpiration and evaporation. Physiological adaptation is linked to the metabolic changes of organisms. For example, the CAM type metabolism (typical of Crassulaceae), according to which the stomata open at night when the humidity is higher and the temperatures are lower, to reduce water losses.

Environmental factors			Adaptive induct movements		
Level	Biotic	Abiotic	Level	Sub-level	Stimulus
Physical	Solar energy	Plants	Tropism	Phototropism	Light
	Temperature	Animals		Gravitropism	Gravity
	Atmospheric pres-sur	Micro-organi-sms		Hydrotropism	Water
	Rain			Tigmotropism	Contact
Chemists	Water		Nastia	Termonasty	Temperature
	Oxygen			Seismonasty	Shaking
	Minerals			Hydronasty	Water
	Water salinity			Tigmonasty	Contact

Tab. 1. Biotic and abiotic factor and adaptive induct movements of plants.

4.1. Mediterranean climatic context

A type of vegetation typical of the Mediterranean regions are the plants of the so-called Macchia Mediterranea, whose species have had to adapt to environmental conditions characterized by mild and humid winters and hot and arid summers. Mediterranean plants are shrubby or bushy species. Especially due to the summer dryness, Mediterranean plants have activated adaptation mechanisms aimed at reducing the loss of water through transpiration; many species have small, leathery leaves with thick, shiny cuticles, often with hair or waxy substances on the surface. The thick cuticles define robust and resistant leaves against excessive loss of water due to transpiration. Fig. 2 shows some of the plants of the Mediterranean climate, classified according to the functional strategy in response to the environmental stimulus with static mechanisms. For example, *Salvia officinalis*, has leaves with a silvery coating to protect the epidermis from excessive insolation and autonomously reflect the sun's rays; or *Rosmarinus officinalis* and *Myrtus communis*, have small leaves to reduce the surface exposed to evapotranspiration.

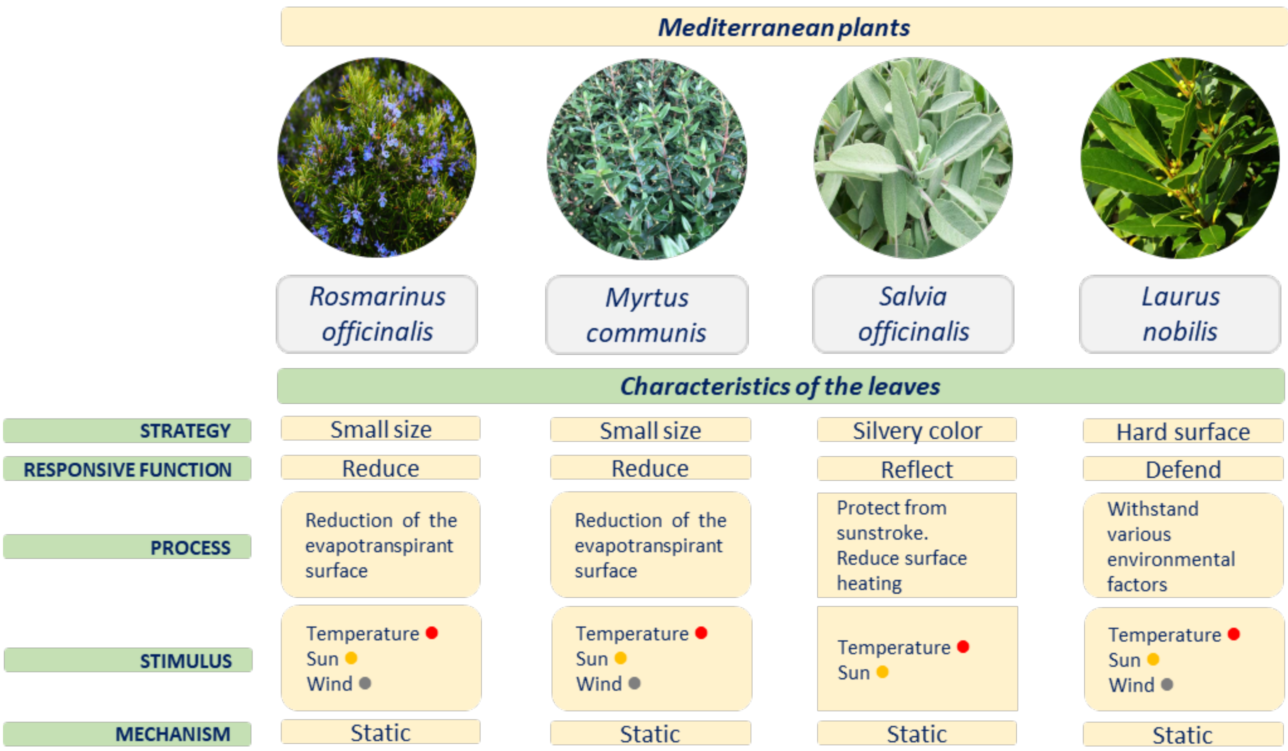

Fig. 2. Characteristics of some Mediterranean plants – © 2023, Francesco Sommese.

4.2. Desert climatic context

Arid and semi-arid areas make up about 30% of the earth's surface and are characterized by the scarcity of water [31][32]. Due to global warming, in semi-arid and arid regions the tendency to dry out is increasingly accentuated [33]. In these climatic zones, rainfall is very rare, temperatures are high, and temperature variations are very accentuated.

The typical plants of arid and sunny areas must limit the surface exposed to the sun to avoid

excessive transpiration which would lead to water loss; in fact, they tend to reduce the surface of the leaves, as well as the organ through which much of the body's liquid content evaporates. The leaves of these typical plants of arid, xerophilic contexts, are small and hard because they are protected by a thick superficial cuticle and often turn into thorns. In many cases, the stem of xerophytes swells and turns into a water reservoir that allows the plant to withstand long periods of drought.
The protective hairs, generally dead and filled with air, shiny and whitish, can guarantee total reflection of light, protecting from solar radiation and defending the plant from excessive transpiration. The intertwining of hairs, characteristic of plants in arid environments, causes stagnation of air, which, in contact with the epidermis, becomes full of moisture. Fig. 4 shows some of the plant species typical of arid climates and their adaptation strategies.

Desert plants

	Oreocereus celsianus	*Agave americana*	*Crassula ovata*	*Echinocactus grusonii*
	Characteristics of the leaves			***Characteristics of the stem***
STRATEGY	Hairy lining	Silvery color	Waxy coating	Hard surface
RESPONSIVE FUNCTION	Absorb Store Reflect	Reflect Shield Regulate	Regulate Reflect	Store Shield
PROCESS	Retain water or moisture Protect from cold and sunlight Reflect solar radiation	Reduce surface heating by reflection	Barrier to water loss	Store water Self shading
STIMULUS	Temperature Sun Wind Water	Temperature Sun	Temperature Sun	Temperature Sun Water
MECHANISM	Static	Static	Static	Dynamic Static

Fig. 3. Characteristics of some desert plants © 2023, Francesco Sommese.

5. Biomimetic responsive envelope: a proposal

The third step of the bio-Adaptive Model involves the transfer of nature's strategies into technologies for architecture through the implementation phase, characterized by 3 sub-phases: transfer, create and validate. In this study, only a few proposals are presented to the reader, which need further investigations, especially for their validation through simulation tools for performance evaluation.

The previous analysis of the adaptive solutions of plants allows us to conclude that the movements induced by external stimuli occur autonomously without further use of energy. It is about the exploitation of intrinsic abilities, which involves an autonomous modification of the morphological or physiological conformation of the organism. In the previews Fig. 2 and Fig. 3 the adaptation mechanisms have been classified into static and dynamic. According to the various definitions of literature [11], [18], the mechanism is static when the adaptation takes place due to aesthetic and morphological characteristics, while the mechanism is dynamic when they occur through a visible formal modification. An example of dynamic adaptation is given by *Echinocactus grusonii* which expands and contracts depending on the water content it possesses. It is therefore a question of adaptive solutions that concern surface coatings. These replicated mechanisms in the building field allow us to propose facade solutions or, more generally, building envelopes, capable of adapting to external stimuli independently [34].

The adaptive characteristics of plants find a strong analogy with those of the adaptive or responsive envelope. In fact, in the literature, they are classified on the basis of various factors including: the response time, which varies from daily to seasonal or annual scale [11]; the static or dynamic mechanism [35], the responsive function [18]. The responsive function of the adaptive envelope, in response to environmental factors, consequently, entails conditions of indoor comfort (Tab. 2). Establishing parallels between the responsive functions of plants and those of the envelope allows you to emulate innovative and sustainable adaptive strategies. The scale of application can vary from facade system to component or material.

The analysis of Mediterranean and desert plants makes it possible to recover the main strategies of these particular plant species and to associate them with a specific function that could be replicated in the context of technological design to propose solutions for facades or, more generally, for the building envelope. Below are four main proposals for horizontal and vertical elements of the building envelope, deriving from the analysis of the strategies of the plants performed in the previous steps:

i. Coat roofs and walls with light colored materials or coatings (silver or white) to reflect solar radiation and protect the elements of the building envelope from aging by the sun's rays (Fig. 4a).
ii. Create a dynamic cladding characterized by "pores" that allow the elements of the cladding to breathe in order to prevent overheating of the cladding itself or of the cavity (in the case of ventilated or double-skin facades); the same pores, if made with suitable materials, I can facilitate the collection of rainwater, conserve it and reuse it for other purposes serving the building (Fig. 4b).
iii. Similar to the hair that covers succulent plants, create facade cladding with light-colored microporous structures capable of retaining the water or humidity present in the surrounding environment, to promote self-evaporation of heat from the vertical and/or horizontal elements of the building envelope; in particularly humid conditions, collect the water and reuse it for other purposes serving the building (Fig. 4c).

iv. To create a double-skin facade which, similar to some succulents that expand and contract, or some flowers that open and close, is able to expand and contract when stimulated by thermal factors, to favor a self-regulated and passive facade shading (Fig. 4d).

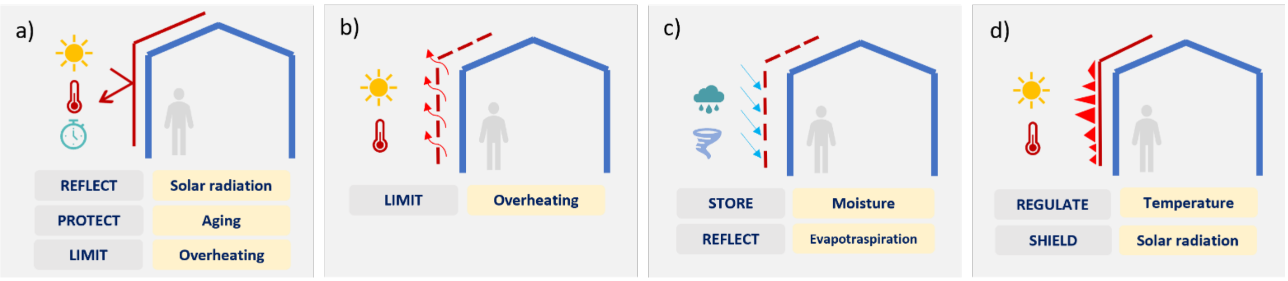

Fig. 4. Responsive function of the building envelope inspired by Mediterranean and desert plants © 2023, Francesco Sommese.

6. Smart materials for responsive surfaces

To develop these solutions it is necessary to associate different materials and above all to investigate which ones are suitable. If many studies are advanced in terms of light-colored and reflective coatings, the studies on self-responsive materials, especially in the architectural field, are still limited.
In recent years, various materials to be associated with facade technologies are being investigated to propose responsive and adaptive solutions. In this context, intelligent materials have an important role, thanks to their intrinsic properties, which lead to a modification of the physical or morphological characteristics, when stimulated by certain environmental factors [36].
To date, these materials find a limited application on some components of building facades. Unlike traditional materials which are mainly static, smart materials are characterized by an immediate response and reaction capacity, they are self-activating and selective. Among the various smart materials, the most cited and known ones are the shape memory materials (SMM), which are activated exclusively thanks to the modification of intrinsic characteristics. Like plants, they perceive the stimulus, respond to it and return to their original state when the stimulus ends. [15].
An interesting example that integrates the biomimetic approach with smart materials, in particular with Shape Memory Alloys (SMA) is represented by Air Flow(er): a ventilation device that regulate airflow and internal temperature using the shape memory allow wire [37]. In the case in question, the alloy deforms when subjected to low temperatures by opening the four doors of the device and favoring the circulation of the air flow; on the other hand, when the alloy is subjected to higher temperatures, the doors of the device close, blocking the flow of air. This movement emulates the thermonastic behavior of crocus flowers, which open when the temperature rises and close when the temperature decreases, thus responding to day-night thermal variations [30].
Several literature studies [16], [35], [38], [39], propose a classification of smart materials capable of self-activating if stimulated by environmental factors that can be very useful in this phase, to propose solutions to be tested and evaluated. The main classification is based on their response to

environmental stimuli: materials responsive to light, temperature, CO_2, water or humidity. Among the main temperature-reactive materials are thermo-bimetals, liquid crystal elastomers and thermochromic polymers; among those reactive to light stimuli there are light-sensitive polymers, photochromic coatings, shape memory polymers. Among those reactive to water and humidity present in the environment, there is hydrogel and those based on wood which, although not considered smart materials, are candidates to become so by exploiting their hygroscopic properties. Among the various CO_2-reactive coatings, there are those based on Titanium Dioxide which self-activate in the presence of UV radiation or diffused light [16], [40].

7. Conclusion: biomimetic building solutions and climatic goals

On the one hand, the building envelope provides protection from external influences such as water, wind, sun and extreme temperatures; on the other hand, it is the element that connects the occupants and the external environment by regulating energy flows and ensuring indoor comfort [41]. By analogy with natural tissues, such as human skin or plant tissues, the building envelope is often referred to by the word “skin” to illustrate its role as a barrier and interface. Both the building envelope and the natural envelope are responsible for controlling environmental factors such as water, sun, air and water [42].
The integration of biology with adaptive technologies implies a new paradigm in design that draws on the large database of mechanisms and strategies of living organisms. In order to achieve the goal of climate neutrality by 2050, defined in the European Green Deal, it is necessary to act on the energy consumption of the different sectors, in order to limit or eliminate greenhouse gas emissions, which are considered one of the main causes of climate change. In the construction sector, buildings are responsible for 40% of energy consumption.
In the present work, the adaptive functions of plant organisms were investigated, focusing on movements triggered by external environmental stimuli. The bio-Adaptive Model was studied with the aim of dimostrating the potential of biomimicry and the possibilities of expanding this discipline in the AEC sector to propose innovative and highly sustainable solutions, capable of limiting environmental impacts. This research, using the bio-adaptive model, that defines the main stages of the transition from nature to building technology, provides a useful and reproducible tool for researchers in the building field to propose solutions inspired by nature. Establishing clear parallels between nature and architecture for knowledge transfer could facilitate the development of environmentally adaptive building solutions [18] [43]. Applying a biomimetic approach to create adaptive and responsive building envelopes favours solutions that can limit environmental impacts by proposing technologies with low or no energy consumption. Automated systems are eliminated, and environmentally friendly solutions are defined.

Fig. 5. Sustainable development goals met with the biomimetic approach.

The biomimetic approach and its application are in line with many of the Sustainable Development Goals of the 2030 Agenda (Fig. 5), as by mimicking natural strategies and using responsive materials and low-tech solutions, it is possible to reduce environmental impacts by promoting climate action (SDG 13) and creating sustainable cities and communities (SDG 11). The use of self-activating materials also limits resource waste and pollutant, promotes the generation of affordable and clean energy (SDG 7) and thus creates more sustainable urban spaces that benefit health and well-being (SDG 3). At the same time, biomimetic application steers design towards the circular economy and responsible consumption and production (SDG 12); in particular, it favours the blue economy, which, unlike the green economy, is based on physical principles and uses techniques such as biomimicry, to define a sustainable ecosystem based on the nature's principles. Finally, it promotes multidisciplinary and partnership approaches (SDG 17).

Author contributions

Francesco Sommese: conceptualization, methodology, writing, editing and visualization. Gigliola Ausiello: Supervision.

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