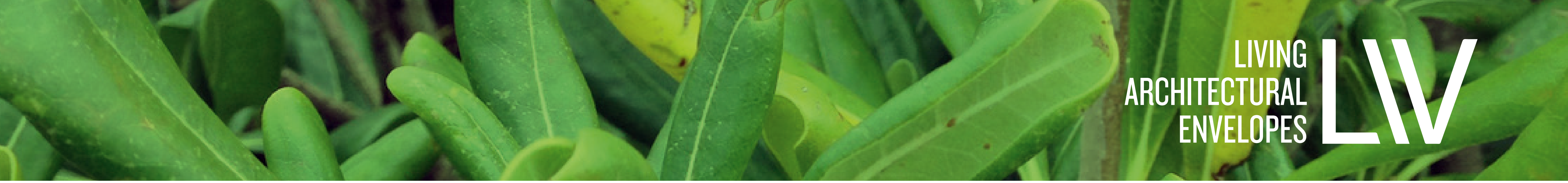


IDENTIFICATION OF PROBLEM

STATIC BUILDING ENVELOPES

Façades have an important role in the regulation and control of energy waste, since they act as intermediary filters between external environmental conditions and inside users and functional requirements.

The multiple environmental and climatic characteristics of the area are variable parameters, while those concerning internal comfort in buildings are largely static; so, we use large amounts of energy to pump heating, or cool, ventilate and light our buildings between quite well defined limits, while external environmental factors can change considerably. The existing solutions to these problems tend to have a static building envelope and dynamic building services. Therefore conventional solutions for façades are not designed for optimum adaptation to contextual issues and needs.

CHALLENGE

ADAPTATION

"Adaptation is the evolutionary process whereby an organism becomes better able to live in its habitat or habitats"
(Dobzhansky et al., 1968)

Biological solutions to adaptation are often complex, multifunctional and highly responsive. As opposed to our buildings, which remain inert, living objects respond to the environment and they are able to adapt to the changing weather conditions.

An adaptive architectural envelope is one that responds to changing environmental conditions both interior and exterior while managing the indoor environment. Adaptive architectural envelopes should have adaptation strategies to anticipate exterior environmental variations as well as interior activities and their interactions with inhabitants.

LIVING ARCHITECTURAL ENVELOPES THAT INTERACT WITH THEIR ENVIRONMENT

Naturalizing design

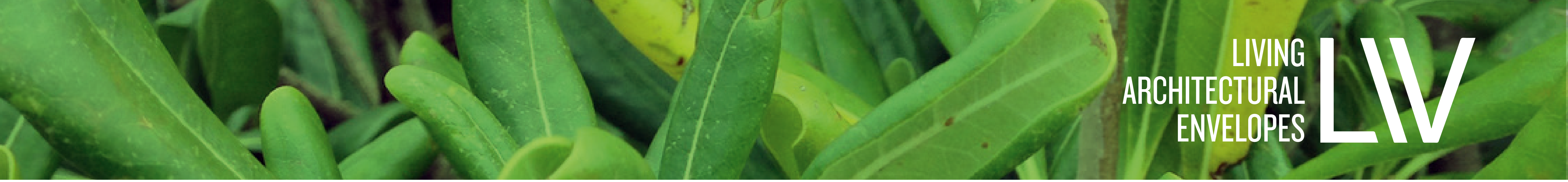
Through technological innovation and new manufacturing techniques, the application of biomimetics to the development of adaptive architectural envelopes is being investigated.

We are very interested in applying our basic research done in active building envelopes. We have developed a strategy inspired by stomata to optimize building energy consumption.

Nature is studied in order to create this kind of living envelopes and we focus on the adaptations of plants to the environment. The plants, due to their immobility can not be protected from the weather and have developed protective strategies to survive. These adaptations are the base of this research, and the goal is the creation of a living architectural envelope that adapts to the surrounding environment and interact with it, as the leaves of plants do through their stomata or regulation pores.

LIV is a living envelope, that breathes and regulates various functions, e.g. absorb, dissipate, exchange or filter according to internal demands and changing external conditions of the moment.

The fields of application are the construction and materials sectors.



THIS RESEARCH ONLY FOCUSES ON THOSE ADAPTATIONS TO ENVIRONMENT SHOWN BY PLANTS

Plants, like buildings, lack of movement and remain subject to a specific location, so they have to resist weather conditions that affect them at all times.

Plants, unlike buildings, have adapted to the environment, through processes of evolution over millions of years.

ADAPTATION IN PLANTS

The basis of the success of plants is the ability to compete in their environment and it depends mainly on their physiological evolution and adaptation to the environment. They have developed special means of protection against changing environmental issues such as light, humidity, rainwater, fire, temperature, freezing, air movement or air quality. These adaptations develop over time and generations as a response to the ever changing environment.

FROM NATURE → TO ARCHITECTURE

In this research several techniques abstracted from plants that respond to different environmental issues are discussed for possible application in adaptive systems for building envelopes that respond to changing environmental conditions.

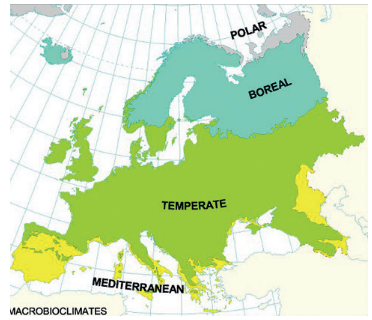
Current work is about the transfer of plant adaptation strategies into technology for innovation.

Taking as a reference the Worldwide Bioclimatic Classification System, we focus on Europe, where we can see four of the five broad climate types defined: Mediterranean, Temperate, Boreal and Polar. Through these different climate areas we study the different strategies and mechanisms to adaptation.

In order to classify and compare the wide range of plant adaptation examples that can be found in nature, we define a Data Collection as well as make easier the application or transfer solutions from nature to architectural solutions. We establish a classification of plant adaptations to their environment: dynamic mechanisms and static strategies. Once several plant adaptations examples have been studied for their possible application to adaptive architectural envelopes, we have found stomata of leaves of particular interest.

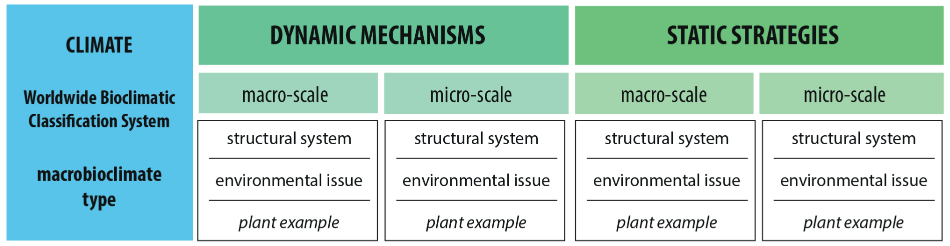
FROM PLANT ADAPTATION PRINCIPLES TO LIVING ARCHITECTURAL ENVELOPES

01 ANALYSIS → DISCOVER NATURAL MODELS

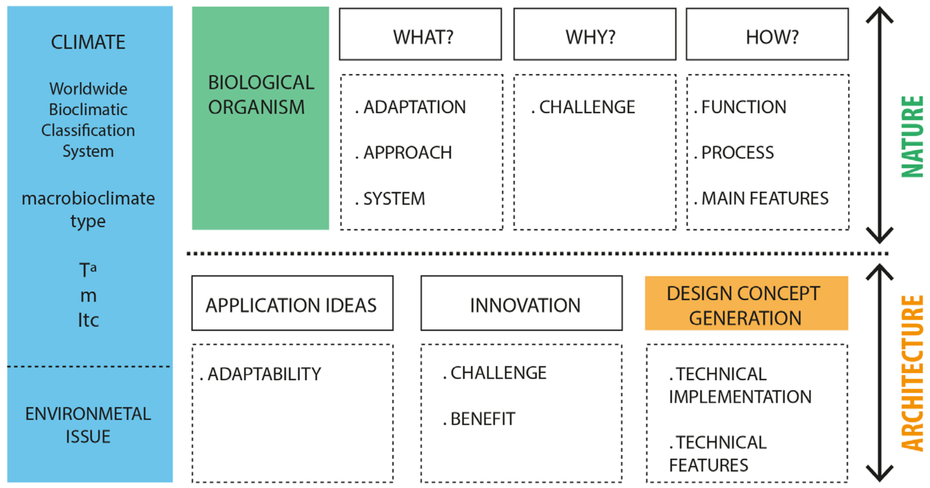


MACROBIOCLIMATE	BIOME
Polar	Tundra
Boreal	Taiga
Temperate	Temperate and Coniferous forest
Mediterranean	Mediterranean forest

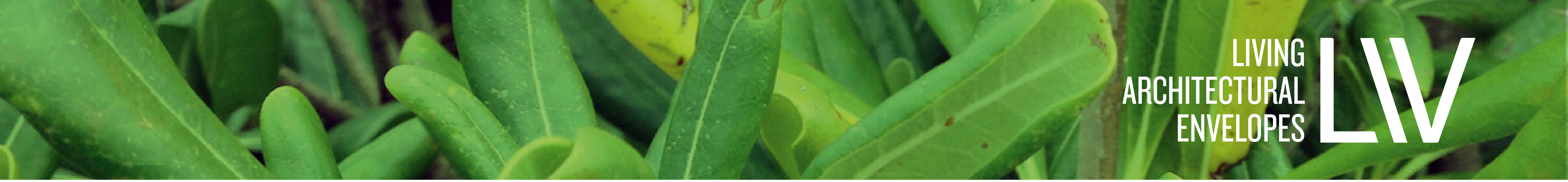
02 SYNTHESIS → DATA COLLECTION OF ADAPTIVE SOLUTIONS IN PLANTS



03 EVALUATION → POTENTIAL APPLICATIONS



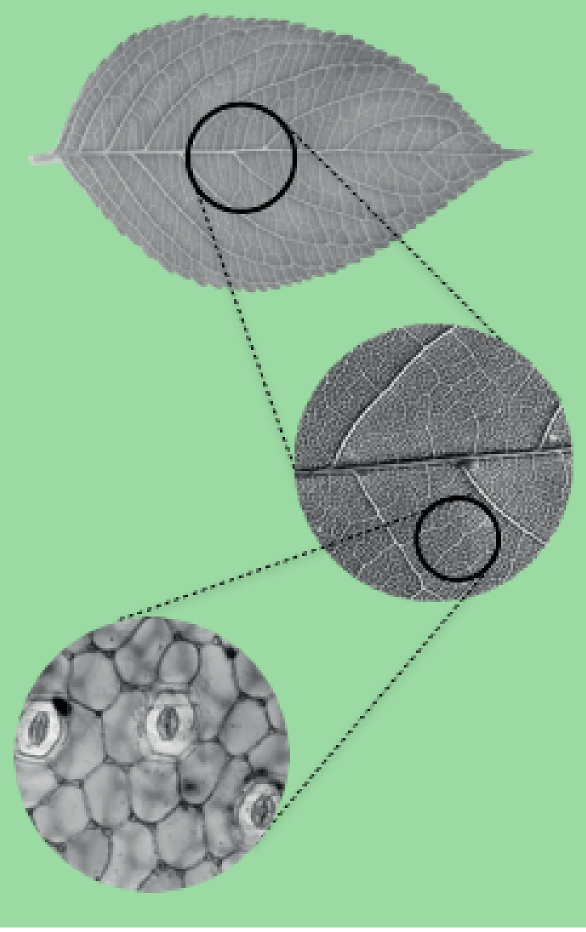
04 TECHNICAL IMPLEMENTATION



STOMATA

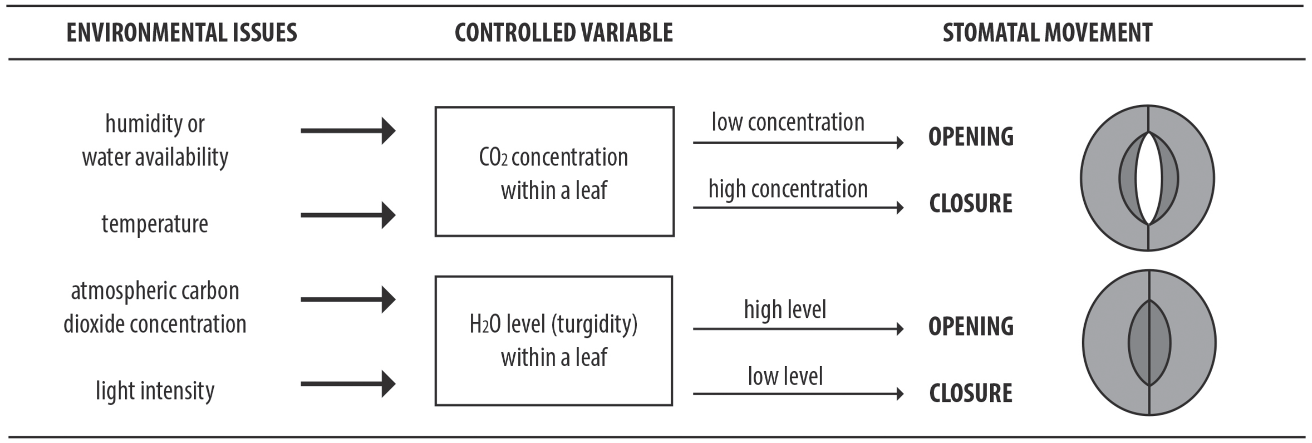
Stomata are pores, found in the epidermis of leaves used to control gas exchange. These pores are bordered by a pair of specialized parenchyma cells known as guard cells that perceive and process environmental stimuli to trigger cellular responses resulting in stomatal opening or closure.

We have chosen stomata because they exist in all terrestrial plants and they are a key experimental tool to investigate how plants respond to and drive environmental factors. Moreover, stomata are an example of dynamic mechanisms and, at the same time, static strategies, and thus demonstrate that the classification proposed is not exclusive and therefore stomata are specimens with an exceptional value in the process of biomimetic inspiration.



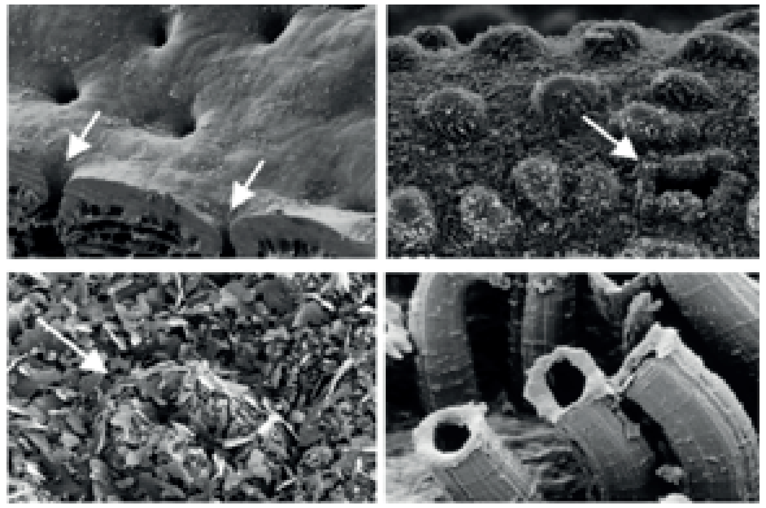
STOMATA AS DYNAMIC MECHANISMS

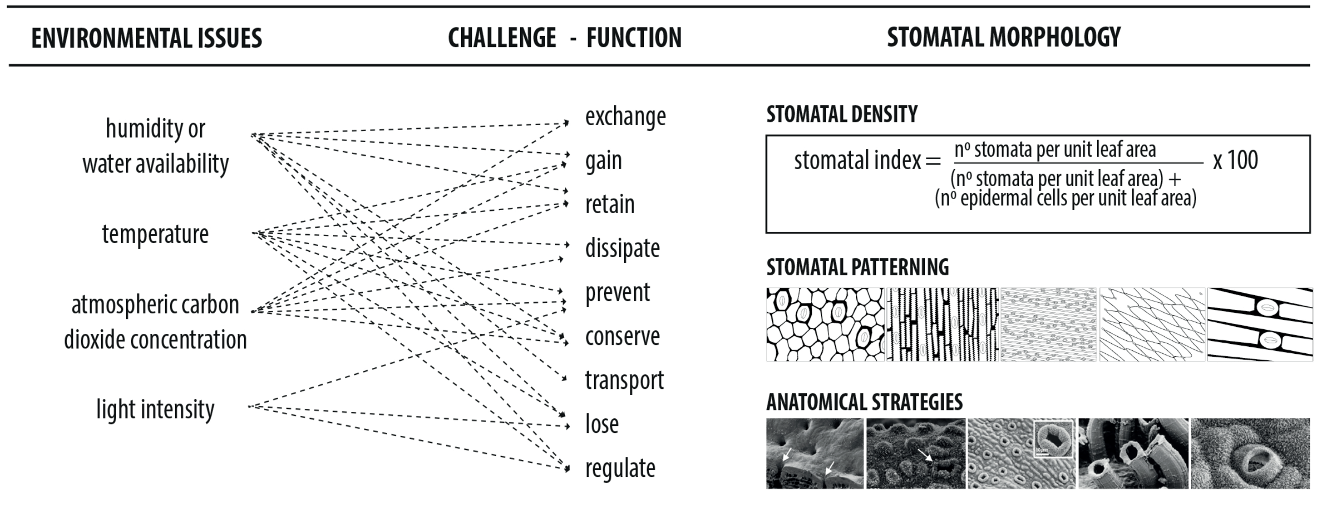
Stomata are considered as dynamic mechanisms due to their valve movements in response to water and carbon dioxide interchanges. Functions of stomata include: interchanging of gases, avoiding lack of water, transpiration and interchanging of temperature. Stomata open in response to a decrease in concentration of dioxide carbon, as well as respond directly to light. Temperature provides another stimulus, at higher temperatures, stomata commonly open, responding to increased carbon dioxide consumption and as close responding to the higher level of carbon dioxide. Finally stomata respond to water or high humidity through guard cells that increase their turgidity and the stomata open. The control of stomatal movements depends on the controlled variable within leaf (carbon dioxide concentration and water level) and the external inputs (humidity, temperature, carbon dioxide and light).

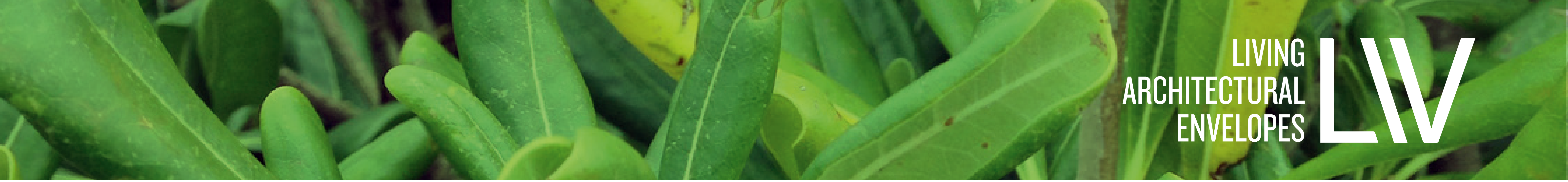


STOMATA AS STATIC STRATEGIES

Stomata are considered as static strategies because of their great variability on surface structures around these valve cells, due to functional adaptations to environmental conditions. According to the different challenges at different climate zones, plants have been developed different stomatal morphologies, and these are the key of their environmental adaptations. It is important to understand these principles of adaptation solutions and transferring them into artificial systems for adaptive architectural envelopes rather than simply copying them. We organize this information according to three main concepts: stomatal frequency or density; stomatal patterning or distribution geometry; and anatomical strategies such as wax morphologies or hair structures to reduce the evaporation of water, or dense coverage with airfilledhairs to reflect visible light and temperature control.







ADAPTIVE BEHAVIOURS

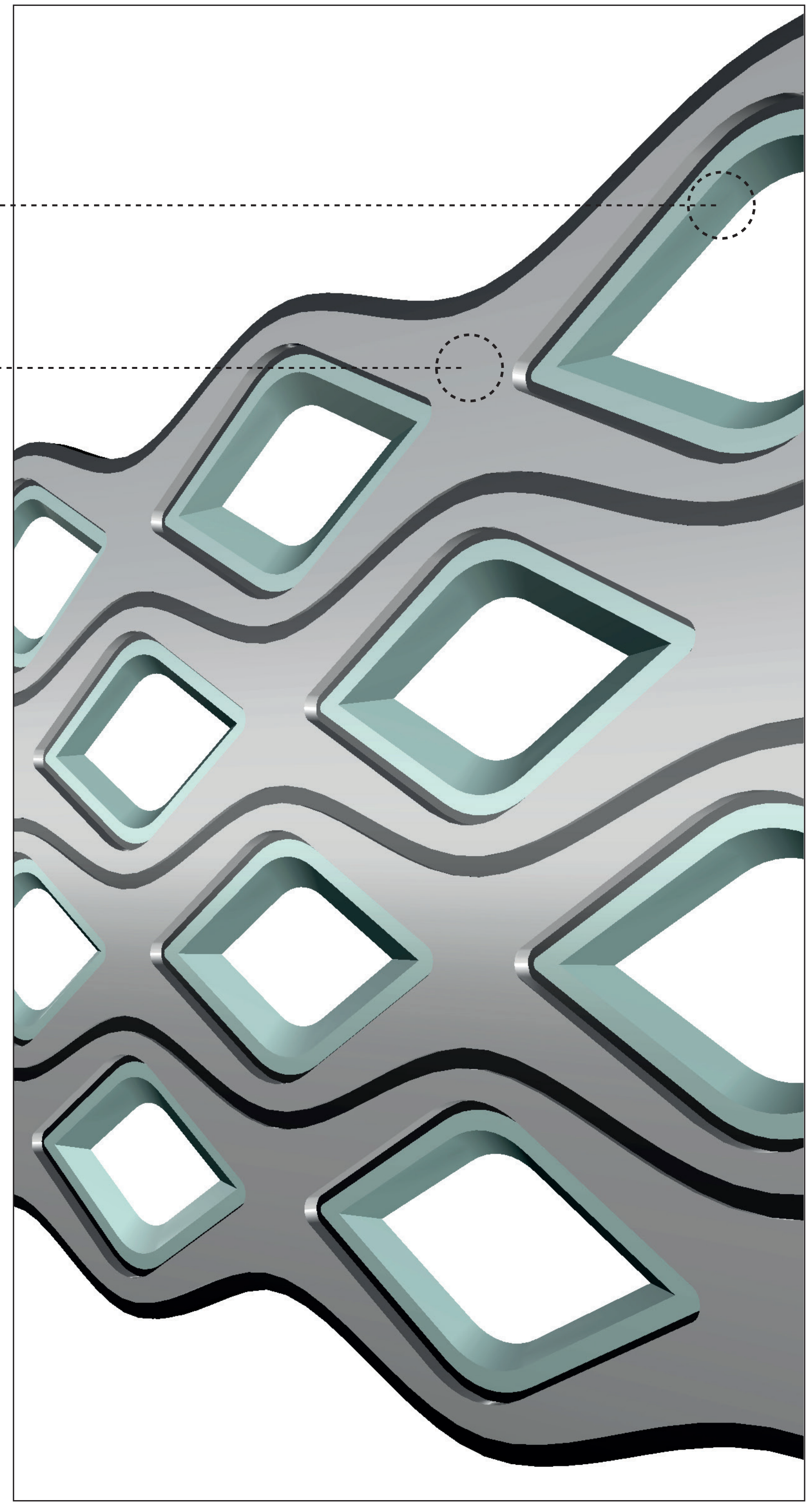
Transforming the biological inspiration into technical implementation.

Some adaptive behaviours are suggested to concept designs for architectural adaptive envelopes. Functions defined suggest two kinds of adaptability: adaptive behaviour through dynamic mechanisms or adaptive behaviour through static strategies.

DYNAMIC MECHANISMS

STATIC STRATEGIES

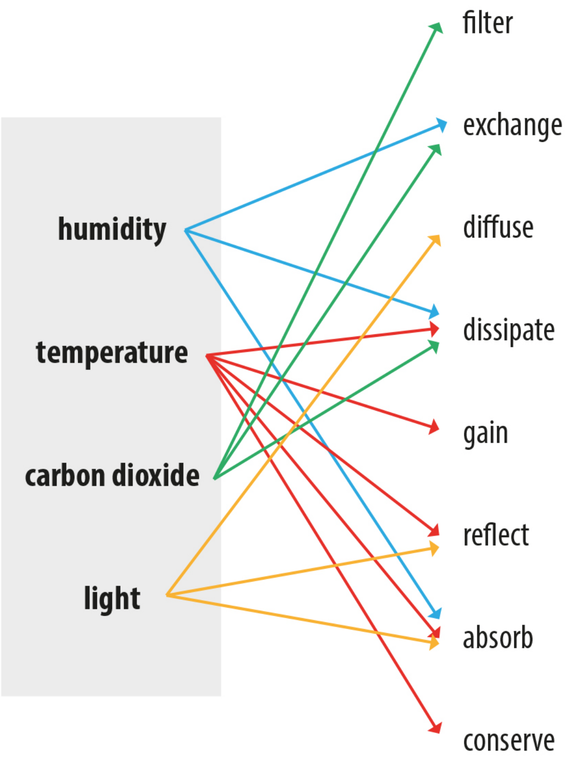
DESIGN CONCEPT GENERATION



CLIMATE DATA & USER DEMANDS	ENVIRONMENTAL ISSUE	CHALLENGE & FUNCTION	ADAPTIVE BEHAVIOUR

CLIMATE
Worldwide Bioclimatic Classification System

USER DEMANDS INSIDE THE BUILDING
standard regulations for buildings according to level and type of activity
ASHRAE / CTE



DYNAMIC MECHANISM

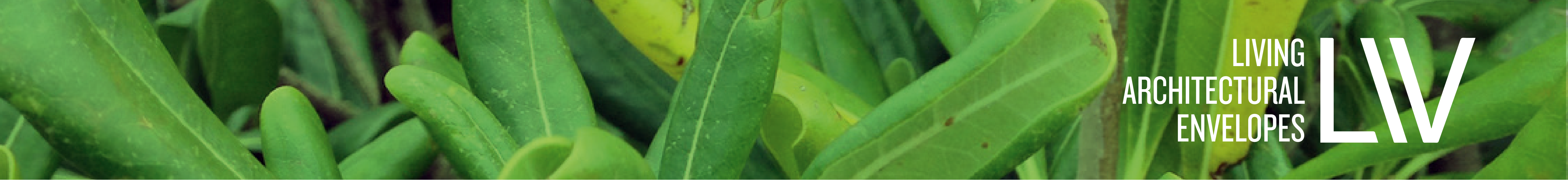
A certain kind of observable motion is present, resulting in changes in the envelope configuration via moving parts.

Folding, sliding, expanding, creasing, hinging, rolling, inflating, fanning, rotating or curling.

STATIC STRATEGY

Adaptability is manifested via morphological features, such as desnsity, patterning or geometrical strategies, also changes in specific properties of materials.

Reflection, absorption or exchange of energy from one form to another.



ACTIVE MATERIALS

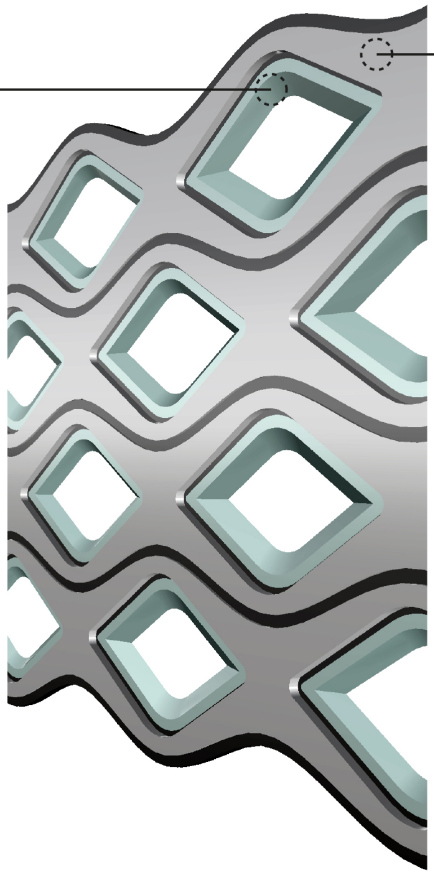
Active materials, with kinematic behaviours for a better performance that shrink, fold or expand responding to changes and, at the same time, remain stable in their different configurations. We look into active materials that are selfactuating responsive materials with innate characteristics, behaviour and performative capacity to react to environmental changing conditions. These atmospheric conditions act as "green" triggers on active materials with reversible changes.

ACTIVE MATERIALS FOR DYNAMIC MECHANISMS

ACTIVE MATERIALS FOR STATIC STRATEGIES

DYNAMIC MECHANISMS

FILTER	
carbon dioxide	CO2 responsive polymer
EXCHANGE	
humidity	wood / cork hydrogel
carbon dioxide	-------
DIFFUSE	
light	textile light responsive polymer
DISSIPATE	
humidity	wood / cork hydrogel
temperature	thermo-expansive polymer thermo-bimetal shape memory
carbon dioxide	-------
GAIN	
temperature	thermo-expansive polymer thermo-bimetal shape memory



STATIC STRATEGIES

DISSIPATE	
humidity	hydrogel
temperature	phase change (PCM)
carbon dioxide	-------
GAIN	
temperature	phase change (PCM)
REFLECT	
temperature	thermochromic polymer
light	photochromic polymer-dyes
ABSORB	
humidity	hydrogel
temperature	thermochromic polymer phase change (PCM)
light	photochromic polymer-dyes
CONSERV	
temperature	phase change (PCM)

EXPERIMENT 01

ADAPTIVE BEHAVIOUR

CLIMATE: Mediterranean, Temperate, Boreal, Polar
CHALLENGE: to control the interchange of gases between the interior of the leaf and the atmosphere
PLANT ADAPTATION : dynamic mechanism: stomatal opening-closing
FUCNTION: to allow the CO2 entry and the water vapour to exit.

ADAPTIVE ARCHITECTURAL ENVELOPE
MECHANISM: to dissipate or gain heat, according to climate area data.

CLIMATE: Mediterranean ($T<25^{\circ}C$)
CHALLENGE: to cope with high temperatures
PLANT ADAPTATION : dynamic mechanism in CAM plants: stomatal closing during the day (high $t^{a}>30^{\circ}C$) and opening during the night (low t^{a}).
FUCNTION: to reduce water loss

ADAPTIVE ARCHITECTURAL ENVELOPE
MECHANISM: reflect sunlight in order to reduce temperatures inside buildings through a closing-shading system

ACTIVE MATERIAL EXPERIMENT

MATERIAL: thermo-expansive polymer
COMPOSITION: UHMWPE + PU
ADAPTIVE BEHAVIOUR: dynamic mechanism
ENVIRONMETAL ISSUE "GREEN TRIGGER": temperature
MECHANISM: shape change: thermal deformation (expand and bend) under heating.
NEXT RESEARCH: to reduce temperature range necessary for deformation ($<50^{\circ}C$)

EXPERIMENT 02

ADAPTIVE BEHAVIOUR

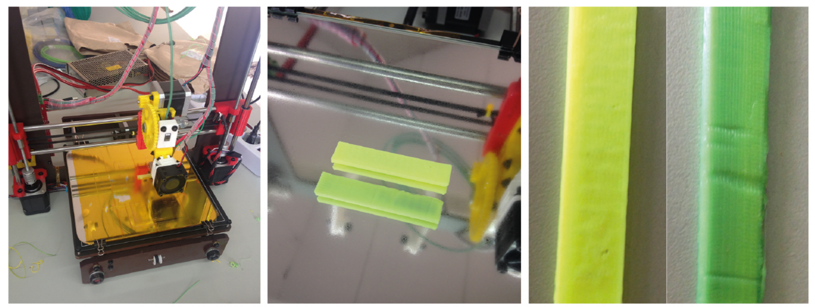
CLIMATE: Mediterranean ($T<25^{\circ}C$)
CHALLENGE: to cope with drought, excessive sunlight and high temperatures
PLANT ADAPTATION : static strategy: white waxy cuticles on leaves around stomata
FUCNTION: to reflect sunlight and reduce water loss

ADAPTIVE ARCHITECTURAL ENVELOPE
STRATEGY: to reflect sunlight in order to reduce temperatures inside buildings

CLIMATE: Boreal ($T<6^{\circ}C$ - $T<0^{\circ}C$)
CHALLENGE: to cope with low temperatures
PLANT ADAPTATION : static strategy: dark colours
FUCNTION: to absorb more solar heat

ADAPTIVE ARCHITECTURAL ENVELOPE
STRATEGY: absorb sunlight in order to retain more solar heat and maintain/increase temperatures inside buildings

ACTIVE MATERIAL EXPERIMENT



MATERIAL: thermochromic polymer
COMPOSITION: PLA + additive
ADAPTIVE BEHAVIOUR: static strategy
ENVIRONMETAL ISSUE "GREEN TRIGGER": temperature
MECHANISM / STRATEGY: property change: colour change at certain temperature, in this case $37^{\circ}C$
NEXT RESEARCH: to experiment polymer from dark opaque to transparent and to reduce temperatures until $29^{\circ}C$ to change colour.