LIVING ARCHITECTURAL ENVELOPES THAT INTERACT WITH THEIR ENVIRONMENT
Naturalizing design

STOMATA
dynamic mechanisms
static strategies

FROM PLANTS TO ARCHITECTURE
Biomimetic principles for the development of adaptive architectural envelopes

Photo: SEM of a stoma on a leaf of Cruciferae plant (mag 3192x) by SCT-UB
**LIVING ARCHITECTURAL ENVELOPES THAT INTERACT WITH THEIR ENVIRONMENT**

**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.

**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 cannot 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.
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 adaptation strategies based on plant behavior and 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.
**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: stomat 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.
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

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 STRATEGIES

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

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

DYNAMIC MECHANISMS

FILTER
- carbon dioxide: CO₂ responsive polymer

EXCHANGE
- humidity: wood/cork, hydrogel
- carbon dioxide: ... 

DIFFUSE
- light: textile, light responsive polymer

DISSIPATE
- humidity: thermo-expansive polymer
- temperature: thermo-bimetal shape memory
- carbon dioxide: ... 

GAIN
- temperature: phase change (PCM)

REFLECT
- temperature: thermo-chromic polymer
- light: photo-chromic polymer-dyes

ABSORB
- humidity: hydrogel
- temperature: thermo-chromic polymer
- light: phase change (PCM)

CONSERV
- temperature: phase change (PCM)

ACTIVE MATERIALS FOR STATIC STRATEGIES

STATIC STRATEGIES

DISSIPATE
- humidity: hydrogel
- temperature: phase change (PCM)
- carbon dioxide: ...

GAIN
- temperature: phase change (PCM)

REFLECT
- temperature: thermo-chromic polymer
- light: photo-chromic polymer-dyes

ABSORB
- humidity: hydrogel
- temperature: thermo-chromic polymer
- light: phase change (PCM)

CONSERV
- temperature: phase change (PCM)

EXPERIMENT 01

ACTIVE MATERIALS EXPERIMENT

- Material: thermo-expansive polymer
- Composition: UNW/P = PU
- Adaptive Behaviour: dynamic mechanism
- Environmental Issue: “green trigger”: temperature
- Mechanism: shape change, thermal deformation (expand and bend) under heating
- Next Research: to reduce temperature range necessary for deformation (<50°C)

EXPERIMENT 02

ACTIVE MATERIALS EXPERIMENT

- Material: thermo-chromic polymer
- Composition: PLA + additive
- Adaptive Behaviour: static strategy
- Environmental Issue: “green trigger”: temperature
- Mechanism: strategy: property change: colour change at certain temperature, in this case 37°C
- Next Research: to experiment polymer from dark opaque to transparent and to reduce temperatures until 29°C to change colour.