Bio-inspired passive kinetic solar shading device for a responsive architectural envelope

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Research Keys

- Actuation systems in plants as biomimetic translation
- Shape memory alloys (SMAs) are used for activating kinetic devices
- Energy efficiency and responsive envelopes using SMAs to support biomimetic application

Overview of the research

- Background of Study/ Context
- Research Questions/ Design Problem
- Hypothesis/ Approach
- Methodology
- Design Development
- Discussion
- Acknowledgement

Background of Study

- We make the state of arts for traditional kinetic solar shading devices
- We have discovered that these solutions involve complex mechanical components and with high-energy consumption
- Some case studies of traditional kinetic façade for responsive building envelope

Case Studies

Figure 1: Some examples of kinetic façades: (a) Arab Institute Paris (b) Aegis Hyposurface (c) Aldar Central Market, Abu Dhabi

Research Questions

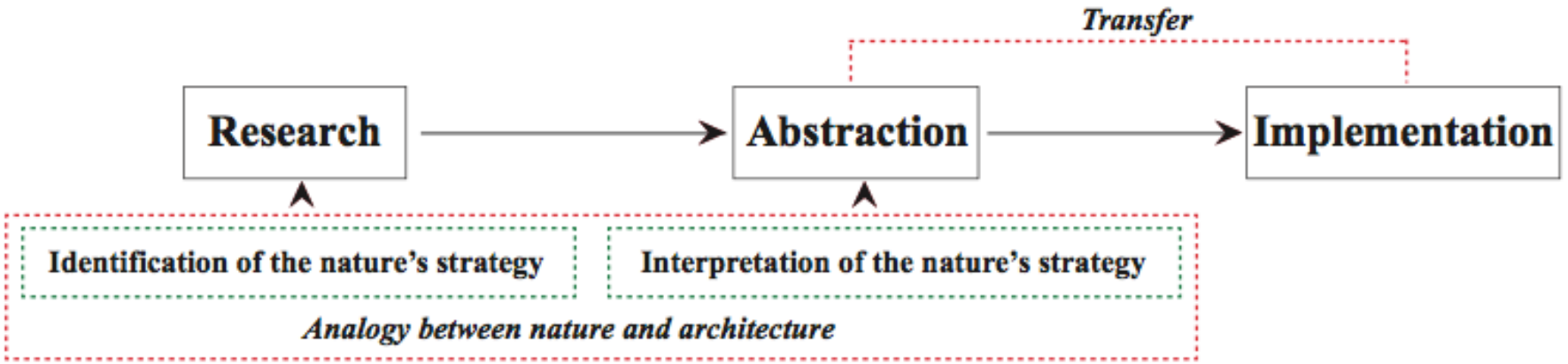
Developing a new type of kinetic solar shading device…

- Autonomously respond to external factors using local environmental factors as stimuli
- Require no complex mechanical parts, electronics or sensors
- Responsive yet passive system

Hypothesis

- Biomimetic Approach

Biomimetics is defined as the "abstraction of good design from nature" (Vincent)

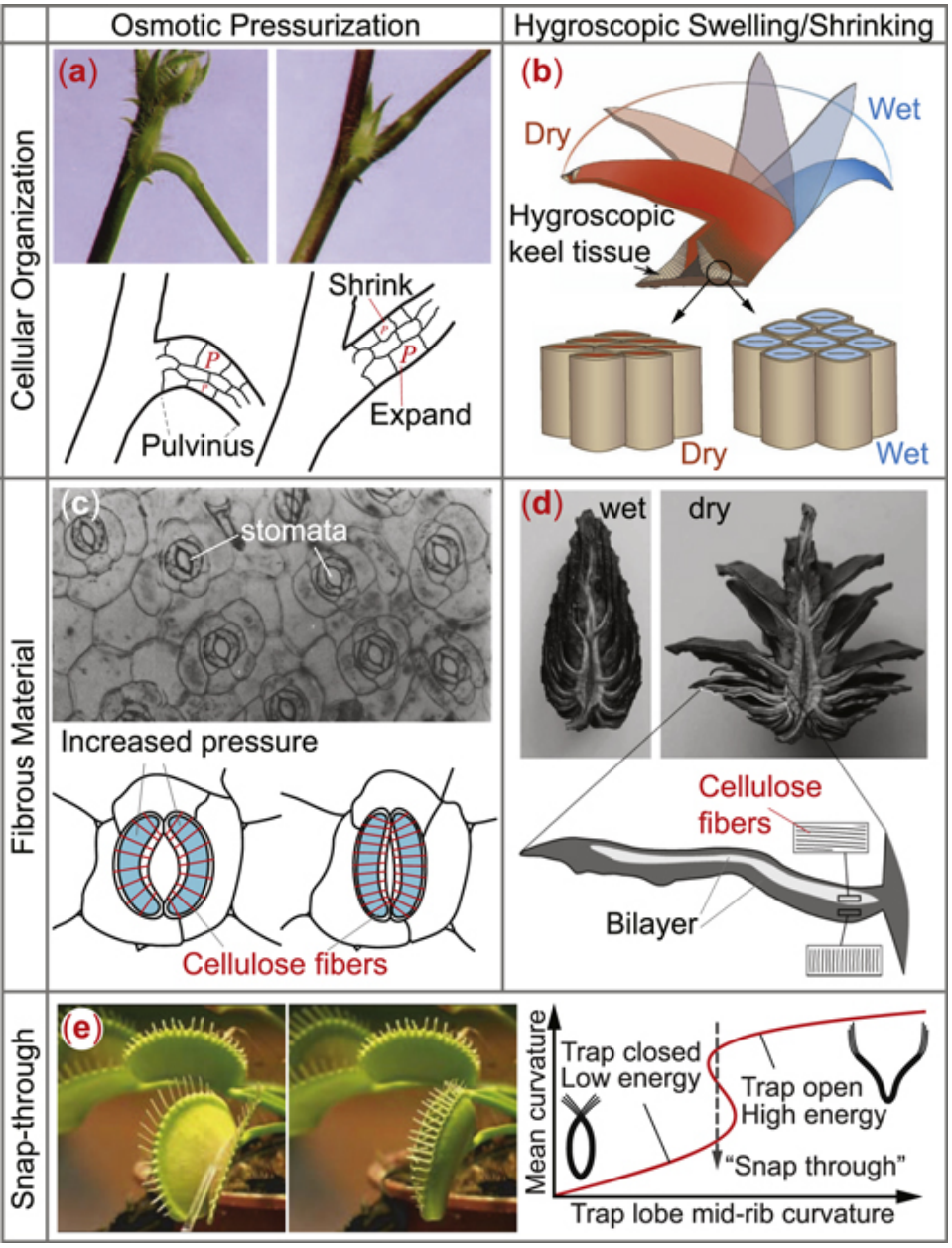


The theory of cognition of biomimetic design process, signified this process in 3 steps (Bionik als Wissenschaft: *Erkennen* → *Abstrahieren* → *Umsetzen*, Werner Nachtigall, 2003)

Nature model

- Actuation systems in plants as prototypes for bio-inspired devices
- Not only looking at the actuations as sensors themselves but also in relation with the morphology and the movement of the plants
- How physical property change at the micro scale affects the mechanical change at the macro scale

Actuation systems in plants



Mimosa
biomechanics and cell arrangement aspect

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Smart materials

- Programmable material

'*Programmable matter is linked to the concept of a material which inherently has the ability to perform information processing'*

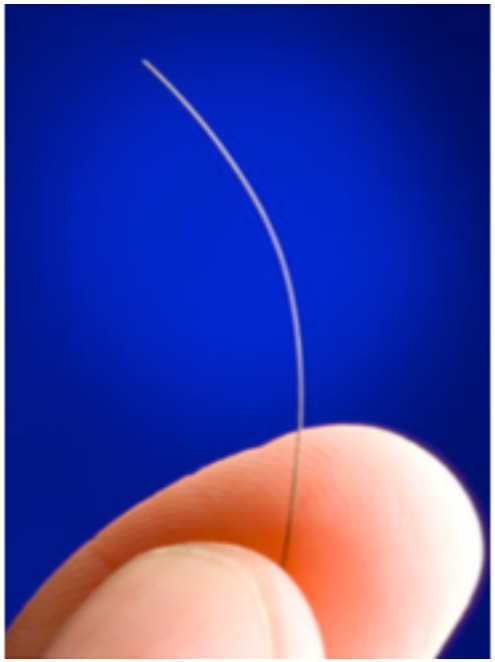
- Shape memory materials (SMMs)

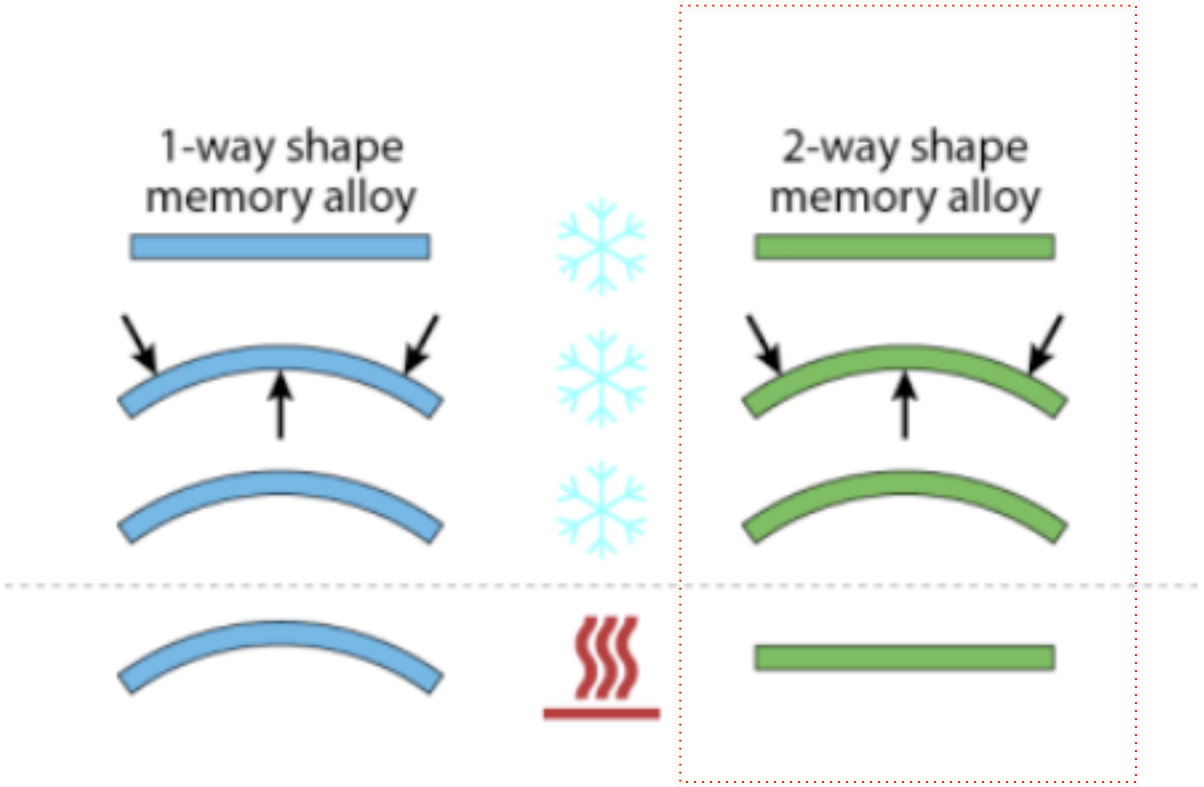
'SMMs are part of programmable material technologies. Programmable matter allows the system to be autonomously changed according to various factors (water, light, UV ray, heat, touch and etc.)

- Shape memory alloys (SMAs)

'SMAs are part of the SMMs. The SMAs are able to 'remember' a shape constituted in advance. This shape is the permanent shape. SMAs sense an external stimulus and respond to it by changing their physical properties, which results in a deformation or deflection of the structure'

Shape memory alloys (SMAs)





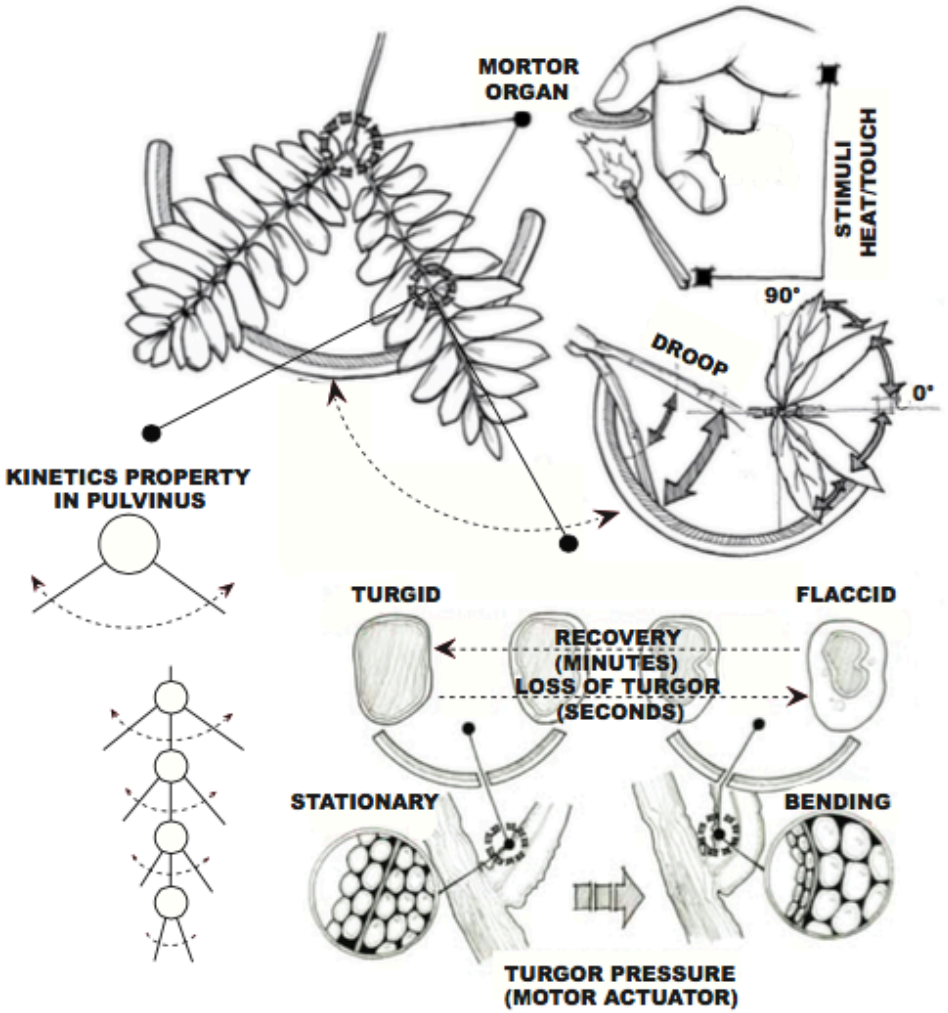
A shape-memory wire, one-way and two-way shape memory effect.

Methodology

How to turn inspiration into a working method?

- **1. *Understand the organism:*** The Mimosa Pudica is studied with special attention given to the movements exhibited by the plant. The study involved understanding the reactions causing the nastic movements and the processes happening simultaneously at the leaf level.
- **2. *Abstract:*** To understand mechanical means of movement, actuation system, analogy between biology and technology (actuation methods and material study). This part of the study incorporates simple experiments to generate the collapsing movements similar to the leaflets in comparison with the shape change of shape- memory alloy (SMA). This phase involves creation of the working model that could be applied to an architectural function.
- **3. *Design realization and application*:** The prototype is designed to replicate the turgor change at the micro scale, which impact the kinetic movement of Mimosa leaves at the macro scale according to the stimuli. It is decided that the device would function as a shading device that has its own capacity to adjust itself for the thermal and visual comfort for the interior of the building according to intensity of the sun radiation.

Mimosa
biomechanics and cell arrangement aspect



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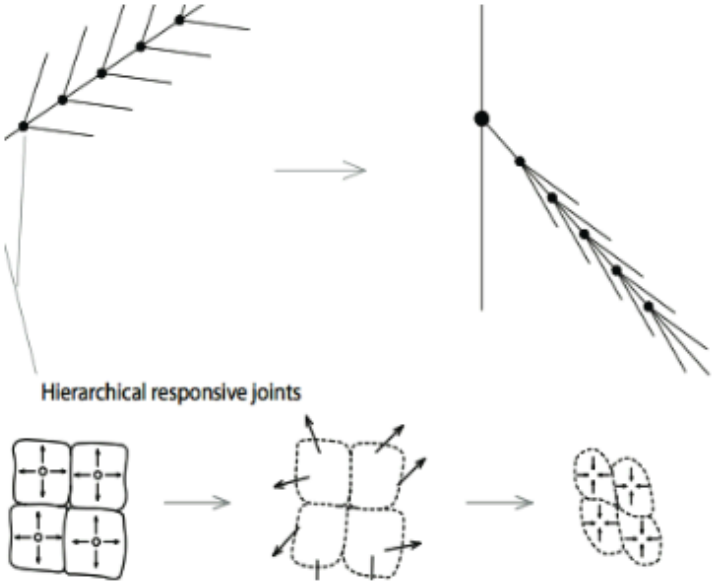
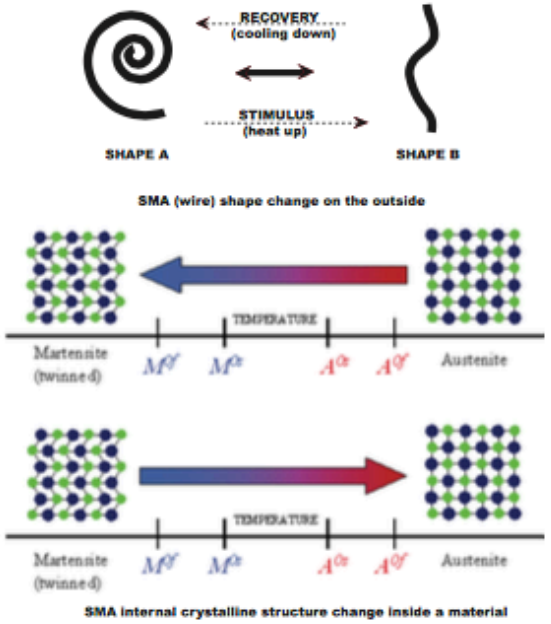
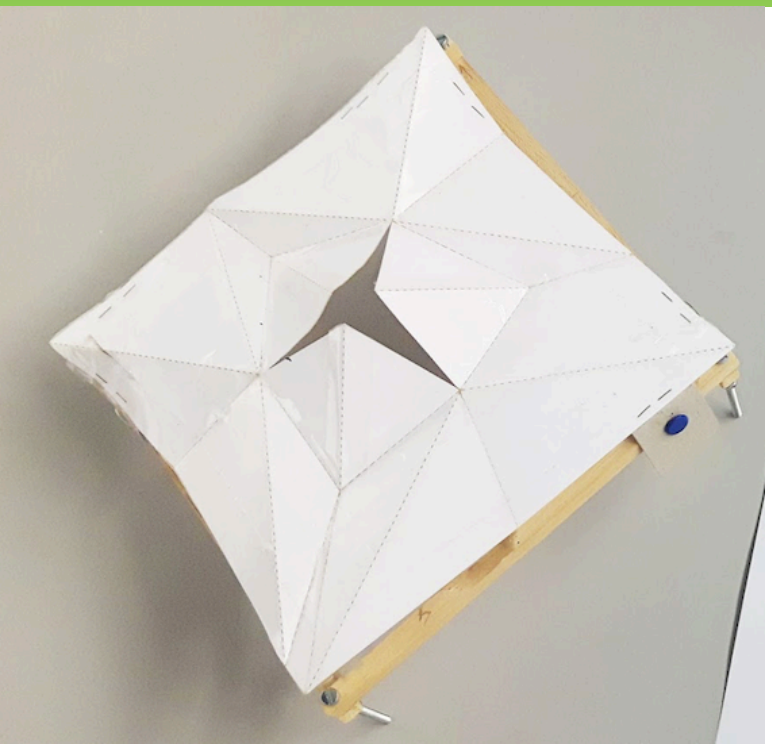
Methodology





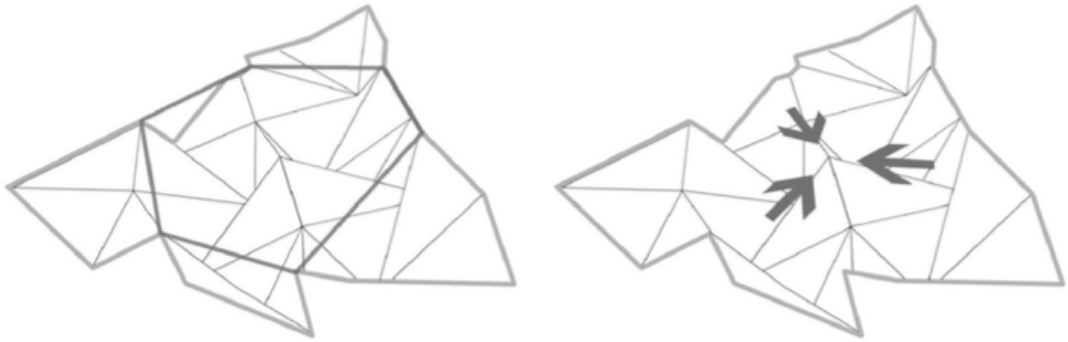
The comparison of mechanical change at macro scale and physical property change at micro scale between Mimosa Pudica leaves and the Shape memory alloy wire.

Design development



Kinetic behaviour of Origami geometries

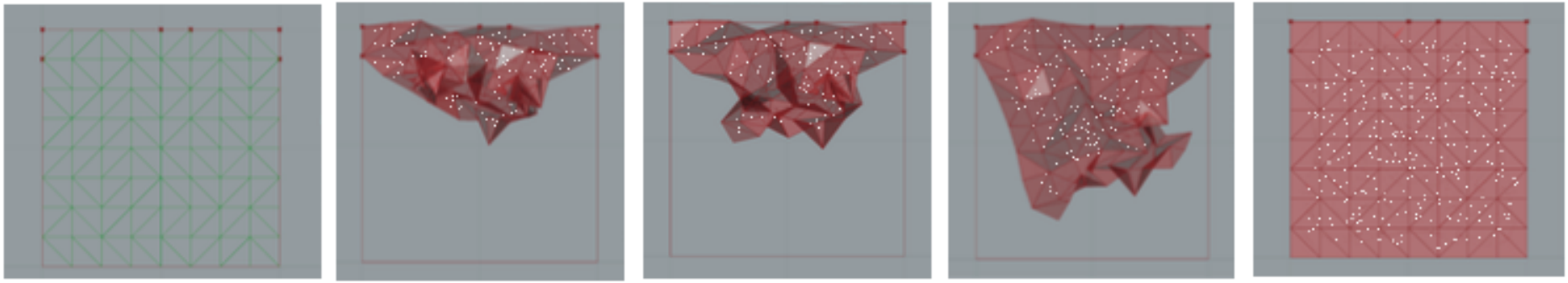
The paper brings the attention to the kinematics potential of Origami creased patterns, investigating how those geometries can be modelled so as to optimize the surface displacements.



The embedded SMA wires define the direction of deployment

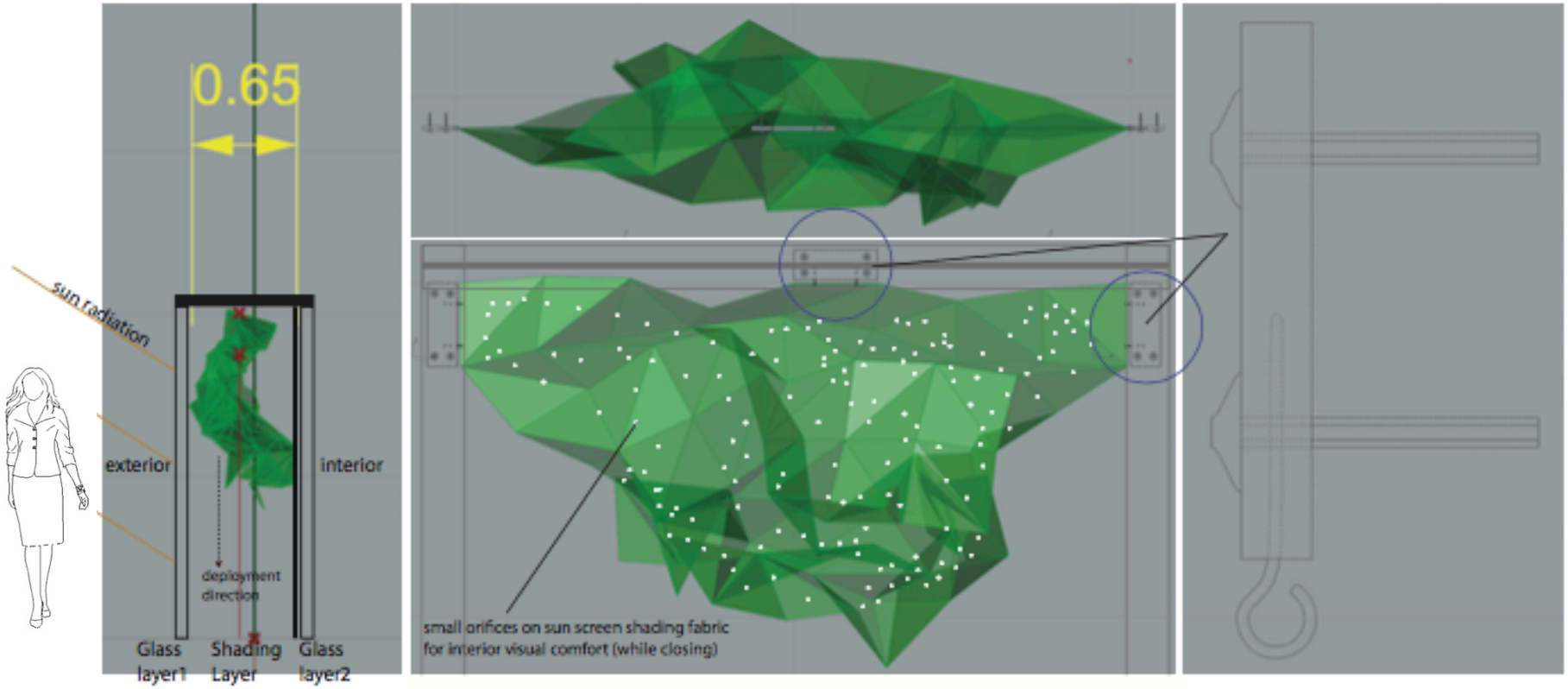
Reference: Kinetic solar skin: a responsive folding technique, 2015

Design development



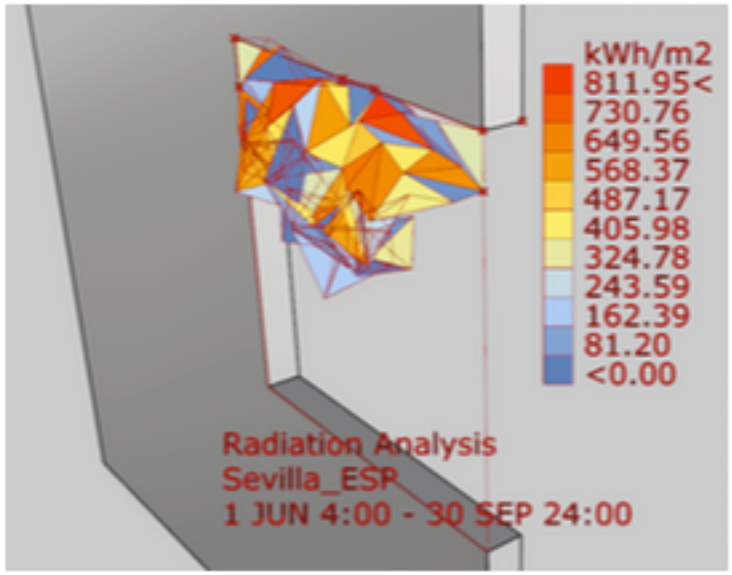
(From left to right): The original origami crease pattern where SMA actuators are placed and the sequenced simulation of the passive kinetic shading device is deployed and activated by the sun radiation stimulus.

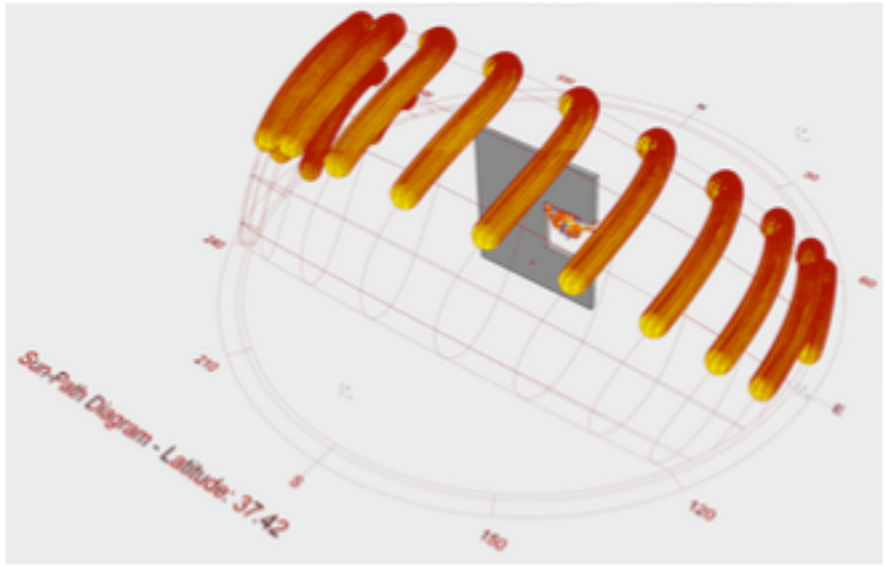
Design development



Details of Bio-inspired design shading device

Design development

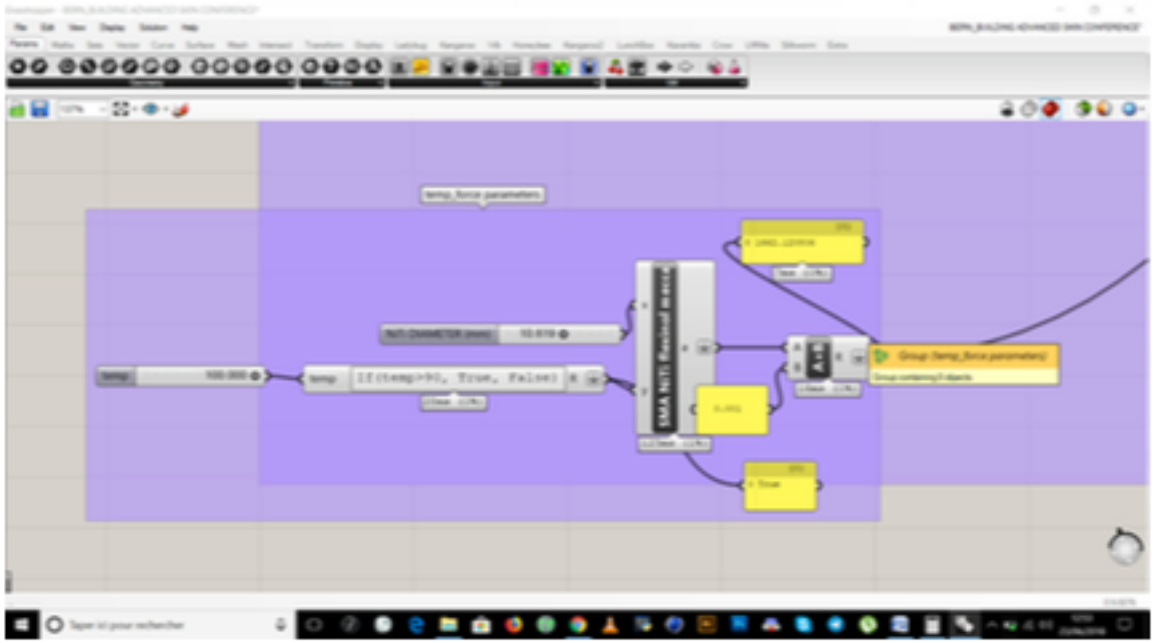




(left) Sun radiation analysis interacts with shading device area from 4::00h to 24:00h on August 1st

(right) Sun path in Seville, Spain during summer period (June-September).

Design development



SMM NiTi Flexinol Mecca: a custom subroutine written in Grasshopper's Python editor, uses the (2ax2))*c = F(x) pull force formula and combines it with Grasshopper's Unit Vector components to turn the values into proper vector form to enable the physical simulations

Discussion

Today's envelopes are mostly passive systems and are largely exhausted from an energy efficiency point of view. They can neither adapt to changing environmental conditions related to daily and annual cycles nor to changing user requirements. Current energy efficient design strategies like biomimetics and technologies of building envelopes have led to significant building energy saving. In recent years, an increasing number of researchers started to think about smart materials as a way to perform adaptation leading to an environmental responsive envelope. Shape memory alloy wires, springs and plates have been extensively tested and studied in a variety of fields; therefore, on the base of their applications they currently remain within the most suitable materials for shading applications. The combination of a flexible structure with the properties of an active material can embed awareness into contemporary buildings and adapt architecture to its environment.

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