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Elastic Instability for Adaptive Building Screens

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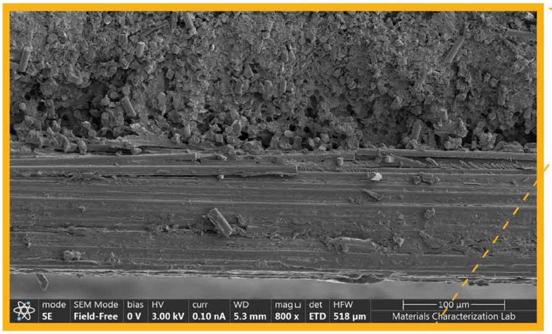
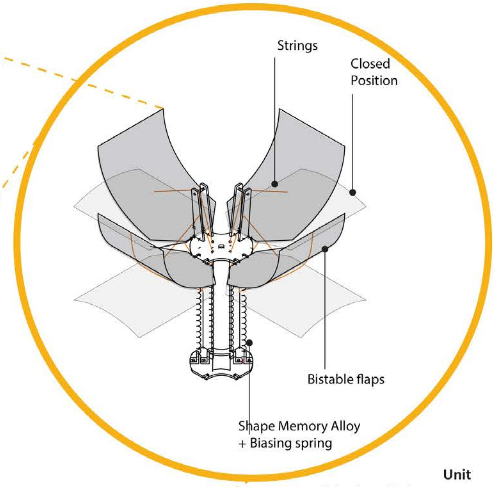
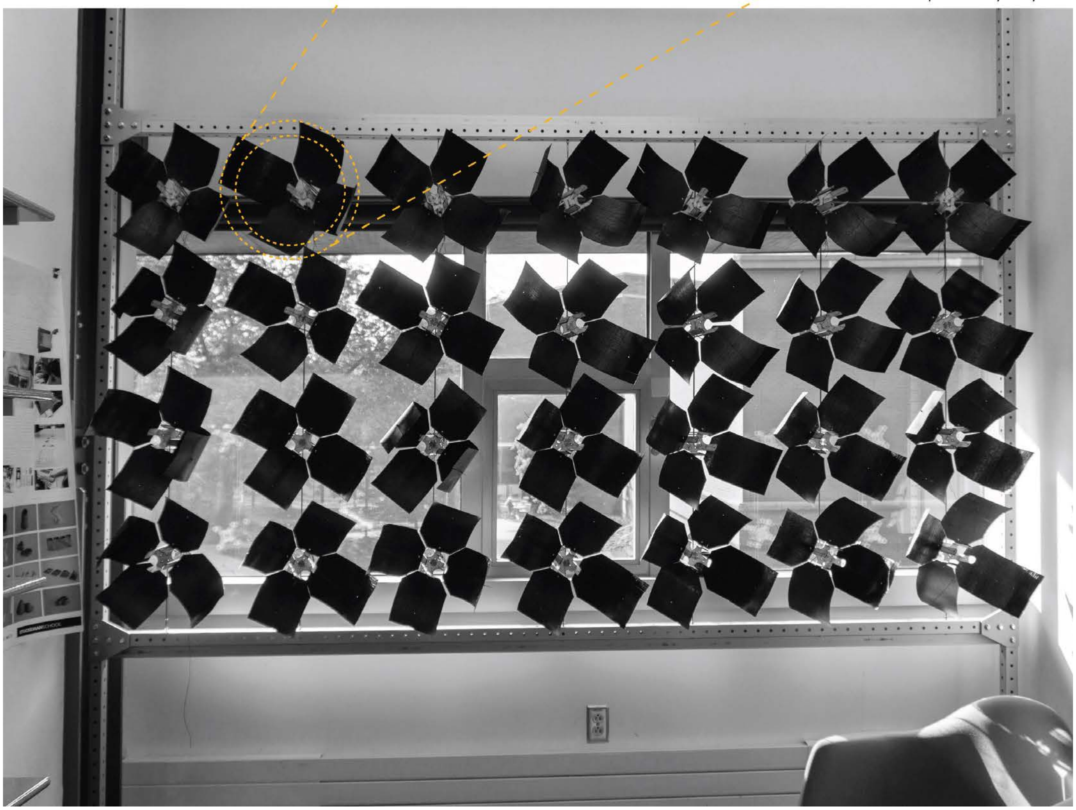
Anisotropy
SEM image of bistable composite showing the two layers with orthogonal fiber orientation





Full scale
A prototype of a adaptive bistable screen for a small office.

Unit
Design of the bistable laminates actuated with Shape Memory Alloys



The building envelope controls energy interactions between the inside and outside, regulating the heat exchange while managing daylight control and radiation. Although outdoor temperatures and sky conditions can fluctuate throughout the day, most building envelopes are designed to be static. Natural systems, in contrast, are often more complex and highly adaptive and can inspire biomimetic facades that adjust their morphology in response to changing environmental conditions (Lopez et al. 2017). However, a closer look at plant movement reveals that these organisms present significantly slow speeds measured in hours and days if they rely solely on passive hydraulic actuation (Poppinga et al., 2020). To achieve more considerable deflections and fast actuation, building envelope designers can turn to elastic instability—a phenomenon seen in one of the fastest organisms in the plant kingdom, the Venus Flytrap (Forterre et al., 2005). The Bistable Skins project is an example of a building screen application that relies on elastic instability.

The Bistable Skins project explores the use of thin laminates that present two stable states: opened and closed. In recent years, researchers have leveraged the elastic instability behavior of bistable structures for novel modes of functionality (Lee & Inman, 2018). The bistable laminates are fabricated by stacking unidirectional carbon fiber prepregs in layers with orthogonal fiber orientation, followed by a curing process. Anisotropy, the condition of having different properties in different directions, is present in several smart materials for façade design, from thermo-bimetals with a differential thermal response to hydro-active wood printed with differential layers (Sung, 2016; Correa et al., 2015). In the Bistable Skin, the orthogonal layering and the subsequent curing process create an anisotropic condition that imprints the bistable behavior in the laminates. However, a second smart material is needed to snap the bistable laminates from their open to closed positions.

Bistable laminates can snap into their second state by hand or using smart materials. Because the laminates are very thin, they only require a small force to actuate (~2 N for the bistable laminates in this project). Once that force is removed, the laminates retain their shape and remain stable until triggered again to transition to the other state. The low actuation force required makes bistable laminates very energy efficient. Shape Memory Alloys (SMA) that contract when heated ‘remembering’ their martensitic state were selected as actuators for the full-scale prototype due to the commercial availability and relatively low cost (Figure 1). The bistable laminates snap into either of their two stable states with the SMA actuators in only 5 seconds.

The snapping sound that the laminates make when opening and closing evoke the elastic instability of the screen. Elastic instability allows for the rapid movement of the bistable screen and is also responsible for significant shape transformations. Because of the flexibility of the bistable laminates, one can also speculate embedding other thin, flexible smart materials to expand the screens' functionality, such as PV systems for energy harvesting. Developing elastic bistable systems using low-carbon materials, such as some wood species with high tensile strength, might also be a fruitful area for future work. While instability might not have been a desirable feature of past architectural archetypes, it is a concept that can help design the kinetic structures of the future which are adaptive and energy efficient.

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