AIA UPJOHN - FINAL REPORT

1. Project name:

Adaptive Envelopes for a Changing Climate: Exploring Bistability for Building Envelope Design

2. Individual in charge of the project:

Jose Duarte and Elena Vazquez

3. Date: June 2022.

4. Scientific report:

The project aim was to test a large-scale kinetic shading system using bistable carbon fiber laminates, actuated with smart materials. The study set out to develop and test novel designs for bistable adaptive building envelopes. We have met the project goal of building and testing a full-scale prototype of a bistable kinetic screen, experimentally measuring its daylight performance. The following lines describe the main project outcomes.

We have conducted a series of prototypes for a bistable building shade device made with two elements: bistable flaps and shape-memory alloys. Our accomplishments were fivefold: (1) explorations of different geometric configurations to identify the most appropriate one; (2) building of single units of four flaps and testing test them for actuation (Figure 1); (3) building a working prototype of the selected unit and optimize it for efficiency in terms of kinetic actuation (Figure 2); (4) building a full-scale prototype of a shading screen with several units to collect data on its daylight performance (Figure 3); and (5) building of a shading screen with several working units actuated by column. The next step is to get all the units in this screen to be actuated at the same time, not just by column.

The full-scale prototype allowed us to collect data on the kinetic envelope's energy performance. We developed a digital model and compared simulation and experimental data to validate the model. The data collection was performed using daylight sensors located in a test room with a bistable kinetic screen. The results indicate that the bistable kinetic skin helps control daylight throughout the day (Figure 4).

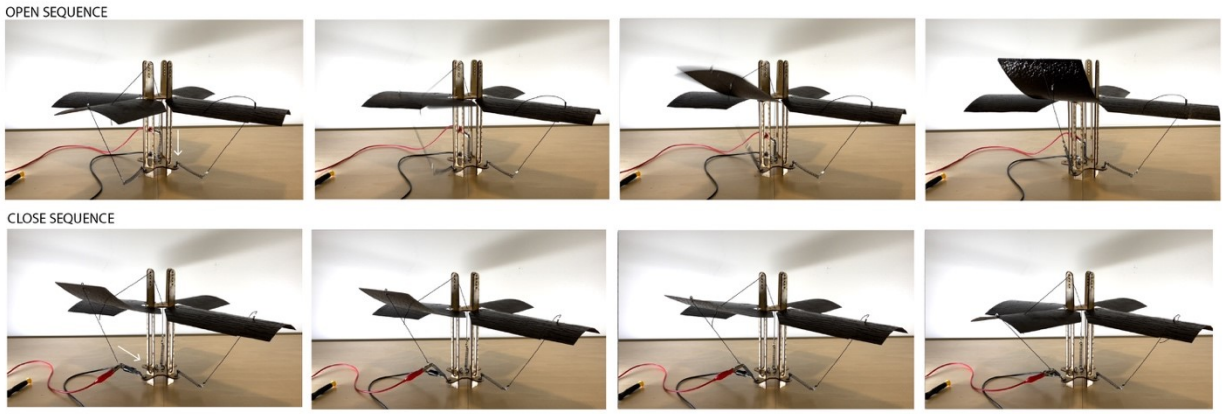

Figure 1: Prototypes for testing actuation

Figure 2: Actuation detail of kinetic system using Shape Memory Alloys.

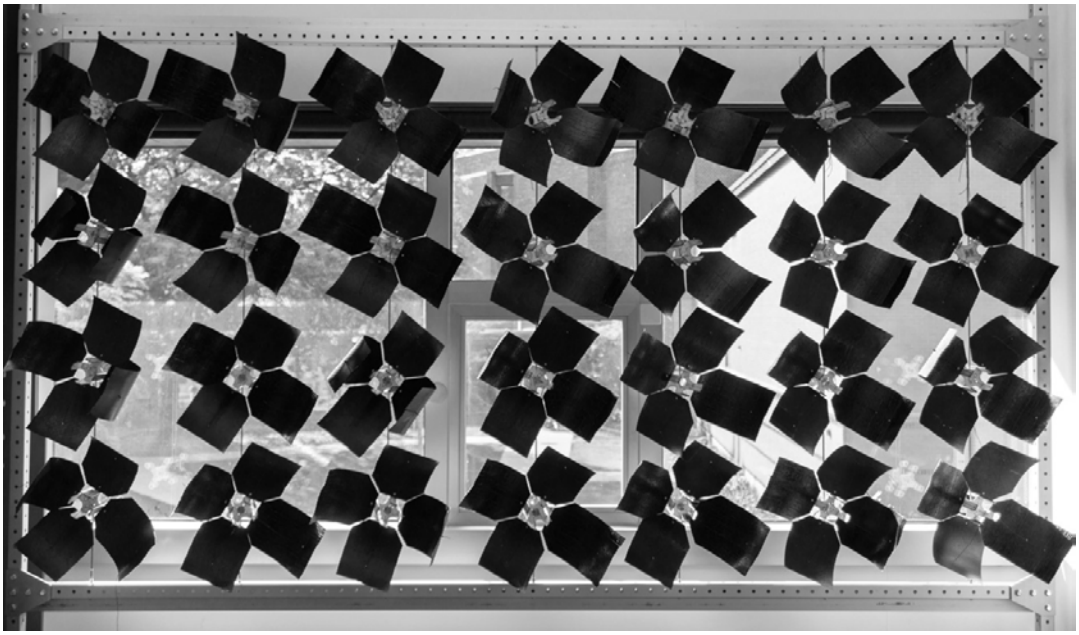

Figure 3: Full-scale test

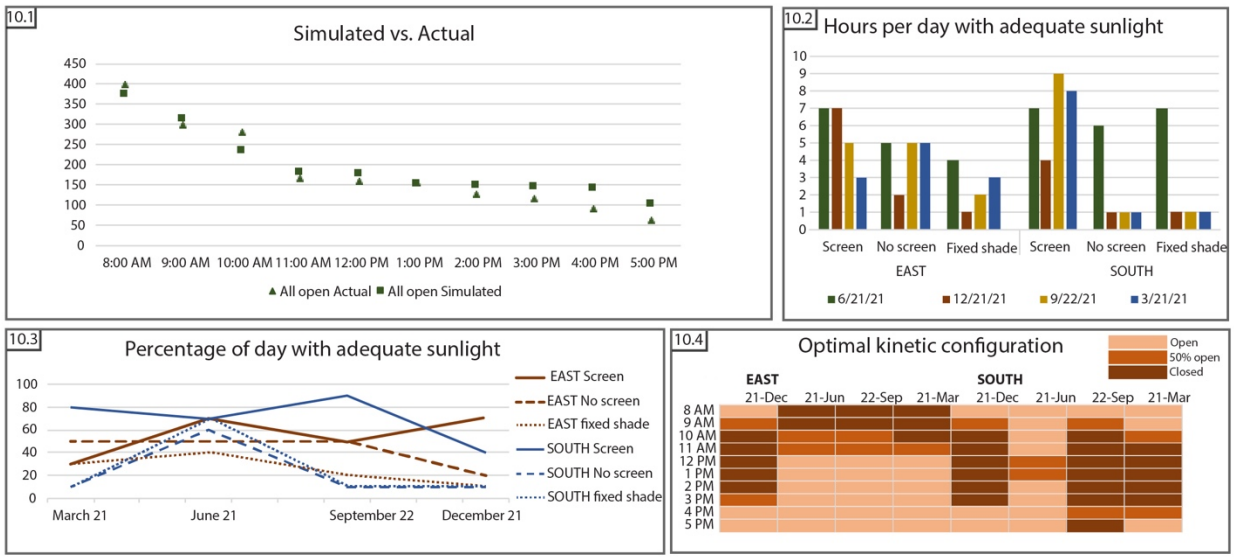

Figure 4: Comparing experimental and simulated daylight data.

5. Project outcomes.

Publications

We have published one manuscript based on the specific work supported by this grant:

- Vazquez, E., & Duarte, J. P. (2022). Bistable kinetic shades actuated with shape memory alloys: prototype development and daylight performance evaluation. Smart Materials and Structures, 31(3), 034001.

We also published three manuscripts related to this grant:

- Vazquez, E., & Duarte, J. (in press). Snap-through carbon fiber laminates: Exploring bi-stability for kinetic building shadings. Journal of Facade Design and Engineering. (Manuscript accepted on June 14th, 2022).

- Vazquez, E., Ounaies, Z., & Duarte, J. P. (2022). Kinetic bistable flaps actuated with magneto-active elastomers. In Behavior and Mechanics of Multifunctional Materials XVI (Vol. 12044, pp. 18-25). SPIE.

- Vazquez, E., Evrim, B., & Duarte, J. (2021). Towards a Digital Workflow for Designing Bistable Kinetic Façades. In Stojakovic, V and Tepavcevic, B (eds.), Towards a new, configurable architecture - Proceedings of the 39th eCAADe Conference - Volume 1, University of Novi Sad, Novi Sad, Serbia, 8-10 September 2021, pp. 365-372 http://papers.cumincad.org/cgibin/works/Show?ecaade2021_330

We have one submitted manuscript going through peer review process:

- Farrokshiar, P.; Vazquez, E.; Duarte, J. Bistable skins: finding optimal configurations based on daylight performance in Rangel, B.; Guimarães, A.S.; Moreira da Costa, J.; Martins, J.P. (eds.) Building Research: Design, Construction, and Technologies. Berlin, Germany: Springer. (Submitted on May 1, 2022)

Exhibitions

- "Kinetic snapping skins: Envisioning climate-adaptive environments" has been selected to be a part of the online publication for the Lisbon Architecture Triennale Millennium Universities Award. (https://www.trienaldelisboa.com/programme/triennali). Our proposal showcases the technology we developed in the context of this grant.
- "Snap through-architecture" was exhibited in the *Penn State Creates* virtual exhibition at the Palmer Museum of Art. The exhibition shows a manually actuated bistable structure, developed as part of this project: https://tinyurl.com/2uaymf5k

Media coverage

- *Four research projects advancing climate action, from earthen materials to embodied carbon calculators.* https://archinect.com/news/article/150261718/four-research-projects-advancingclimate-action-from-earthen-materials-to-embodied-carbon-calculators
- *Stuckeman School researchers receive interdisciplinary research grant.* https://news.psu.edu/story/640617/2020/12/02/academics/stuckeman-school-researchersreceive-interdisciplinary-research

Education

We worked with undergraduate and graduate researchers to develop multiple parts of the project, promoting interdisciplinary research at the school, and providing research opportunities for students. These are some of the students involved in the project:

- Paniz Farrokhsiar is a PhD student in architecture. She worked on finding optimal configurations for the bistable kinetic screen.
- Andrew Smith is an electrical engineering major. He worked on developing the circuit installation for the kinetic screen.
- Ethan Latesta is a material science major. He studied actuation mechanisms for bistable flaps using other polymer-based smart materials. He will develop his honors thesis on the subject.
- A team of 5 engineering students worked on spring 2021 on actuating bistable flaps with magnetoactive smart materials. They developed their capstone project on the subject.