Sustainable Design of Multi-Functional, Multi-Material Parts for AM

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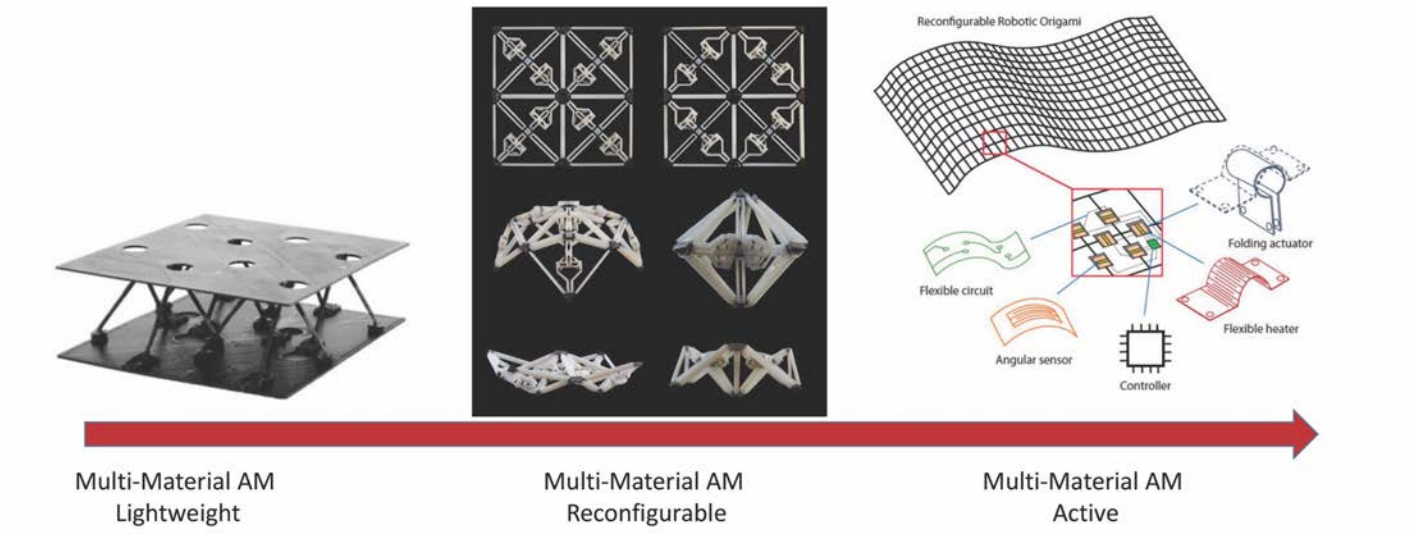
Goal of the Project

- Digitally design and 3D print lightweight, reconfigurable and active structures and robots.
- Use less material, require no assembly, and use fewer different materials to ease recyclability.
- Adapt to the environment and task thus prolonging lifespan and exhibit increased durability for industrial relevance.



Work Packages

1. Material characterization and design of multi-material joints and hinges **(LNM + RRL)**

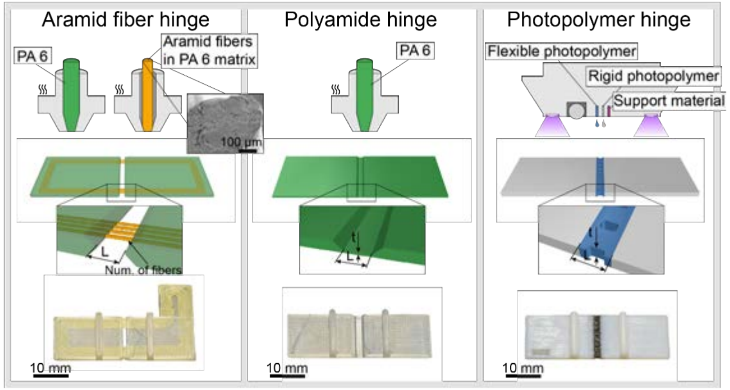
2. Design of sustainable, lightweight, multi-material structures and parts **(CMASLab)**

3. 3D printed and “drop in” actuation systems for distributed, active surfaces and structures (**RRL**)

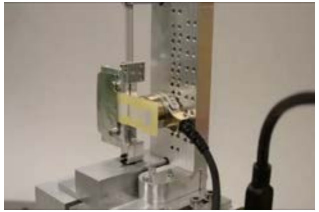
4. Computational design and optimization methods for 4D printing (**EDAC**)

1. Material characterization and design of multi-material joints and hinges **(LNM + RRL)**

Characterization of flexural properties to determine the important design parameters for 3 types of hinges produced by AM



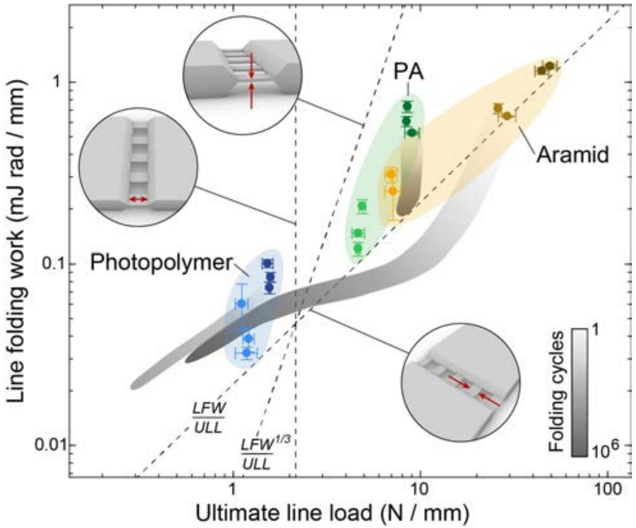
Hinge materials and fabrication



Static test setup

Fatigue test setup

Developed a guideline for the design of flexural hinges



M Wagner, JL Huang, P Okle, J Paik, R Spolenak, "Hinges for Origami-Inspired Structures by Multimaterial Additive Manufacturing", *Materials & Design* (2020): 108643.

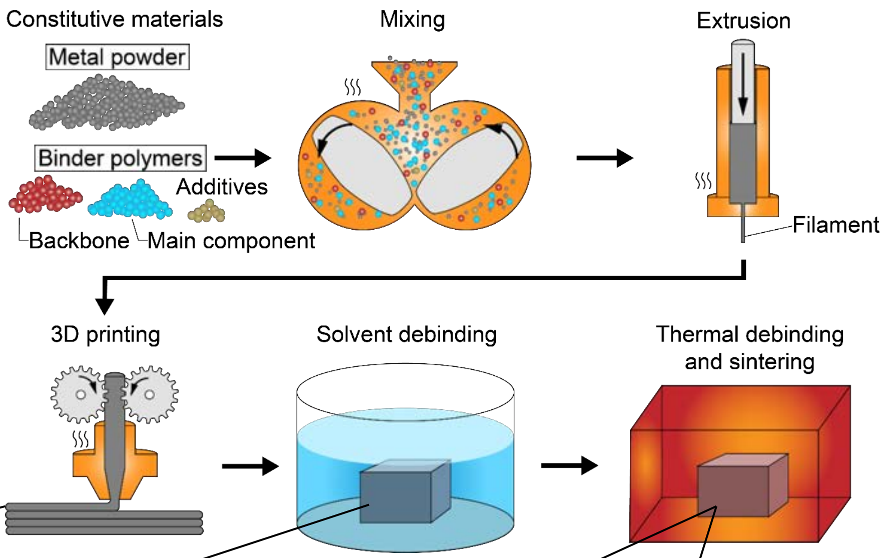
3D Printing of Shape Memory Alloys **(LNM)**

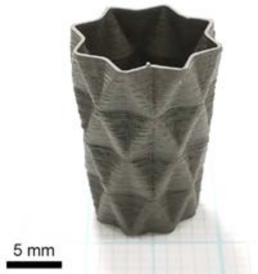
Current project status:

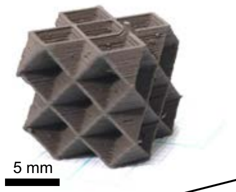
- The process was established and characterized for 316L stainless steel

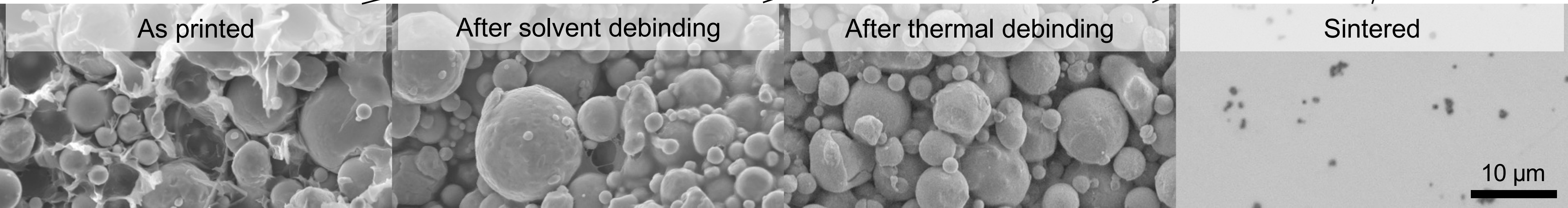
Next:

- Substitution steel with NiTi shape memory alloy powder
- Characterization of material properties
- Fabrication of actuators





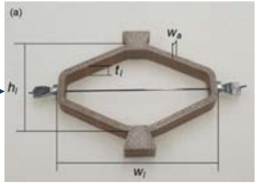




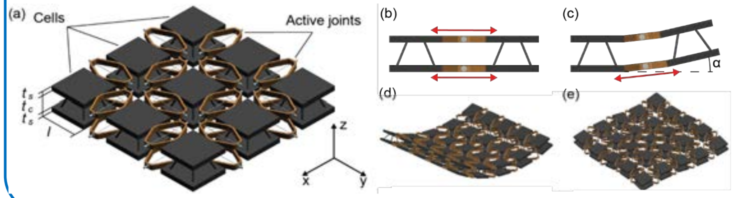
2. Design of sustainable, lightweight, multi-material structures and parts **(CMASLab)**

Shape-adaptable sandwich panel with distributed actuation

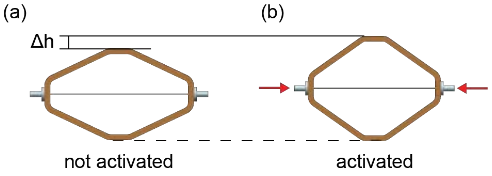
Active joint



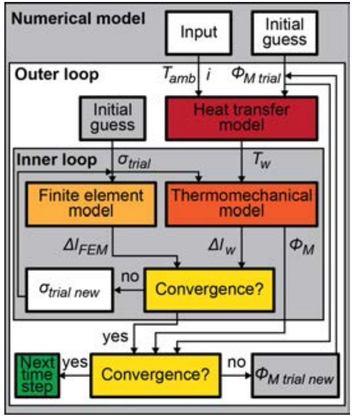
Shape Adaptation mechanisms



Active joint: Working principle

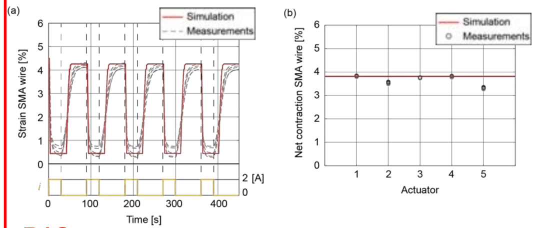


Numerical model

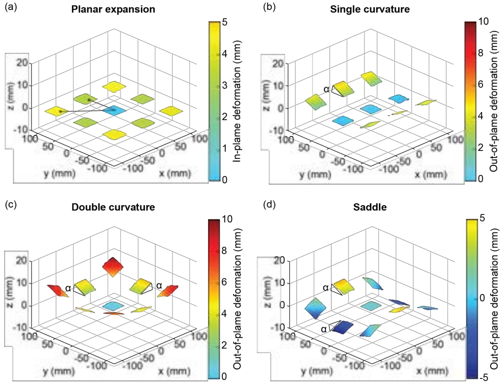


Results

Simulated/measured SMA-strain



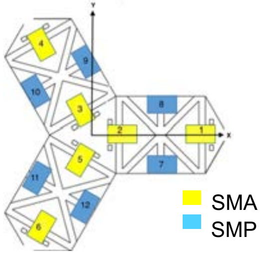
DIC measurements



O. Testoni, S. Christen, S. Bodkhe, A. Bergamini and P. Ermanni, "A novel concept of a modular shape-adaptable sandwich panel with distributed actuation", *Journal of Intelligent Materials Systems and Structures*, 2022

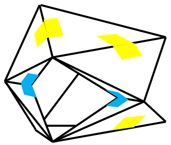
3. 3D printed and “**drop-in**” actuation systems for distributed, active surfaces and structures (**RRL+LNM**)

Characterization and modeling of a tunable stiffness 3D printed origami wrist



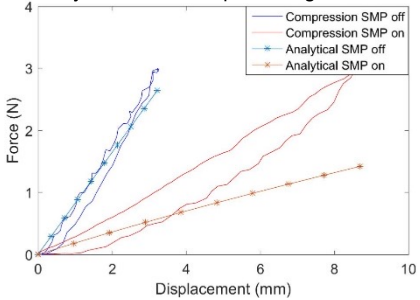
2D design

Fold-up

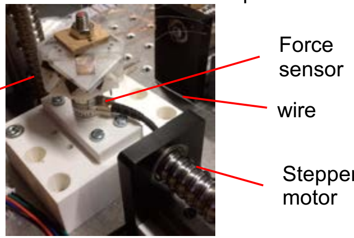


3 DoFs origami wrist

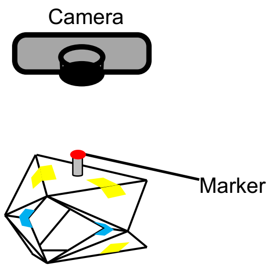
Analytical model for predicting stiffness

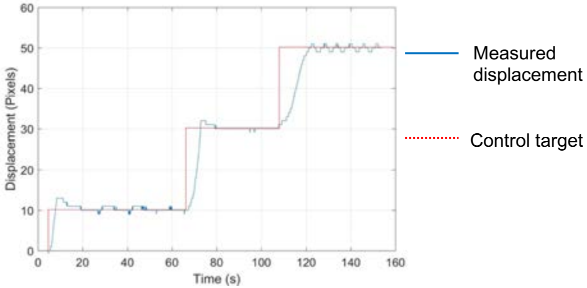


Characterization setup

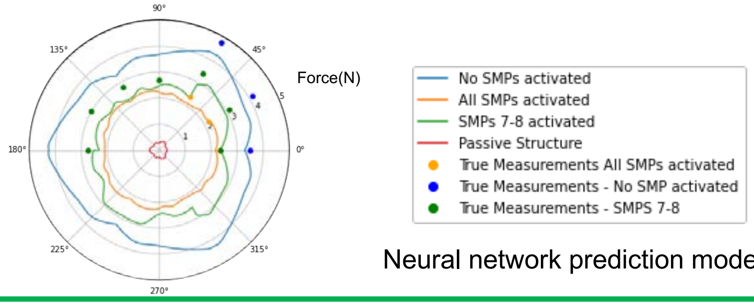


Control algorithms for 3D printed active structure





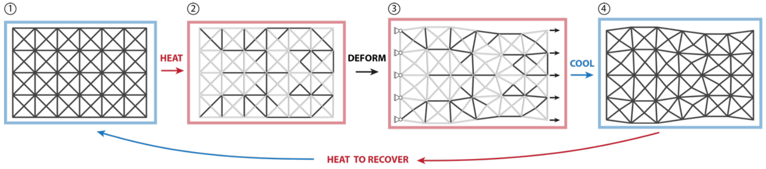
Computer vision-based closed-loop control

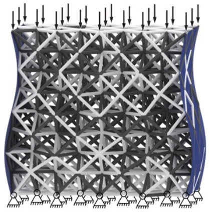


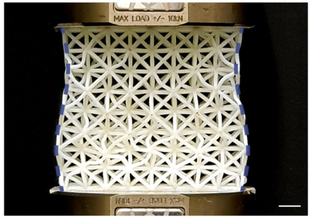
Neural network prediction model

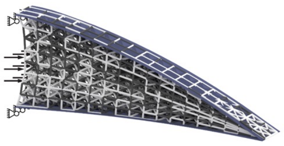
4. Computational design and optimization methods for 4D printing (**EDAC**)

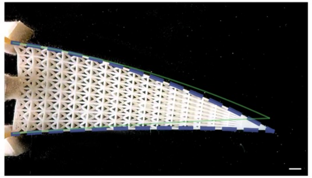
Lattice structures actuated by temperature





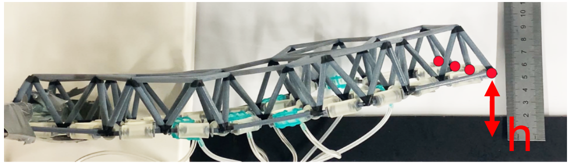


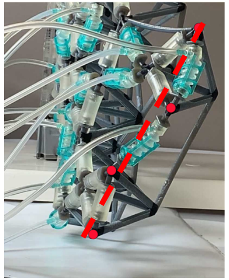




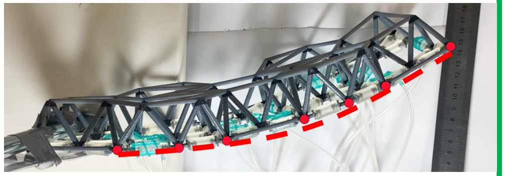
T S Lumpe, K Shea, "Computational Design of 3D Printed Active Lattice Structures for Reversible Shape Morphing", *Journal of Materials Research*, 36(18): 3642-3655, 2021.

Lattice structures actuated by pressure





Hinging due to optimized actuator placement within a lattice



Linear and parabolic deformation induced by pneumatic actuators

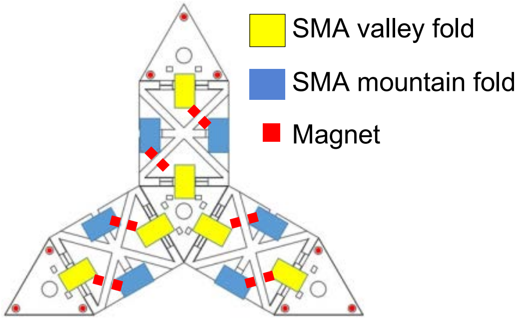
C du Pasquier, K Shea, "Actuator placement optimization in an active lattice structure using Generalized Pattern Search and verification", *Smart Materials and Structures, vol. 30: no. 11, pp. 115007, 2021.*

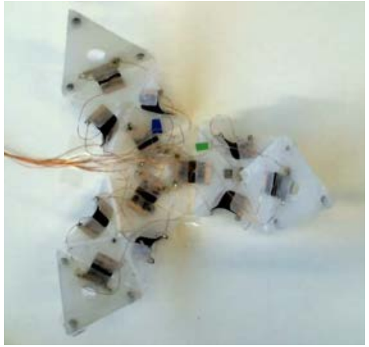
Case study - 1: An adaptable robotic origami gripper

Concept: An adaptable robotic origami gripper that generates **multiple modes** of actuation for pick-and-place of objects with variable shape

By changing the configuration of the functional components, we can achieve:

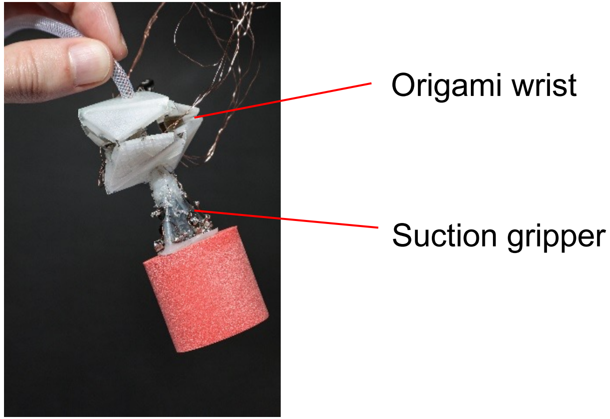
- Variable stiffness
- Variable range of motion
- Resistance for external loading
- Self-assembly





4D printed self-assembly origami wrist

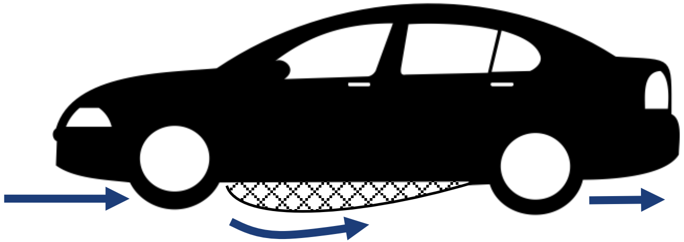
Achievable properties	
Max. orientable angle	37°
Max. lifting load	5 N
Stiffness changes	250%~300%

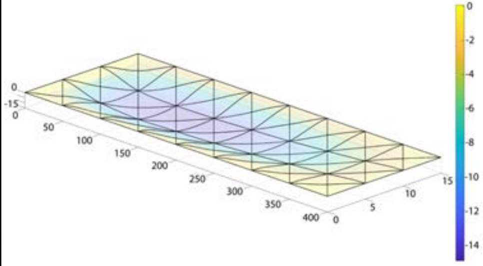


Case study - 2: Deformable underbody for an automobile *(Collaboration with Autoneum)*

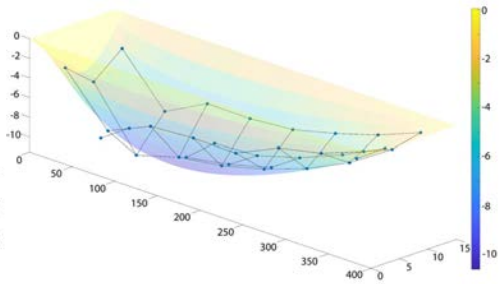
Concept: Overlay the underbody of a car with a **varying stiffness** mesh to optimize it's deformation at **different speed thresholds for aerodynamics**

Desired Properties	
E-Modulus Range	Tension: 450 - 1400 MPa Bending: 200 - 1100 MPa
Temperature Range	-20 ^{o}C to 60 ^{o}C
Panel Area	0.88 m^2
Panel Weight	800 g
Panel Dimensions	**1500 x 570 x 40 mm**





Simulated target deformation



Tested target deformation

Test rig modelling pressure with distributed weights; pictured: 150g

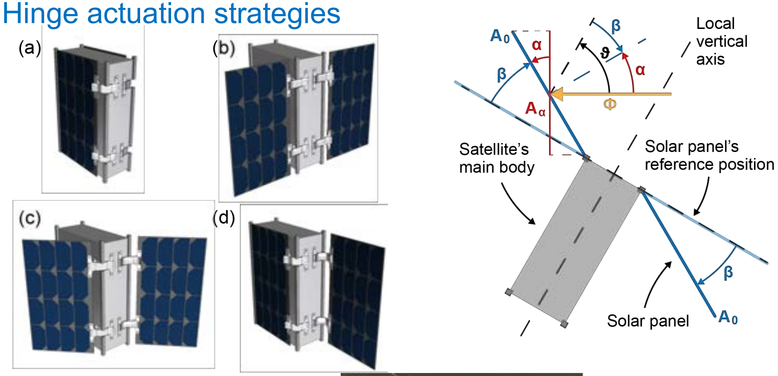
ETH zürich

Case study - 3: Active compliant hinges for reconfigurable solar panels

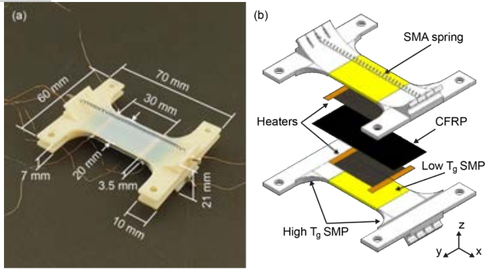
(Collaboration with Orbitare)

Active compliant hinges for gradual deployment and reconfiguration of a solar panel

Hinge actuation strategies



Hinge design

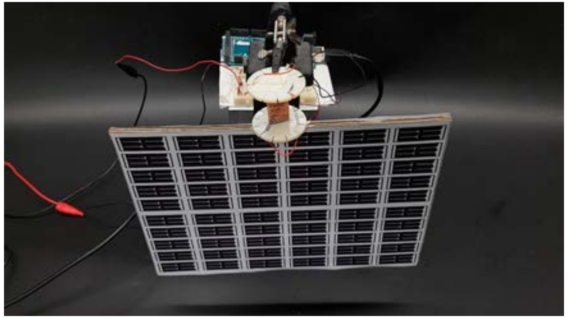


Results

Energy collected, consumed, net energy gain and allowable actuation time for the considered actuation strategies

	Collected energy	Consumed energy	Net energy gain	Allowable actuation time
Fixed	116 kJ	0 kJ	0 kJ (+ 0%)	-
Sun-tracking	217 kJ	37.8 kJ	63.2 kJ (+ 54%)	-
Three steps	198.5 kJ	9.0 kJ	73.5 kJ (+63 %)	1740 s
Five steps	212.5 kJ	13.2 kJ	83.3 kJ (+72%)	870 s

Prototype: Rotation with solar panel (video)

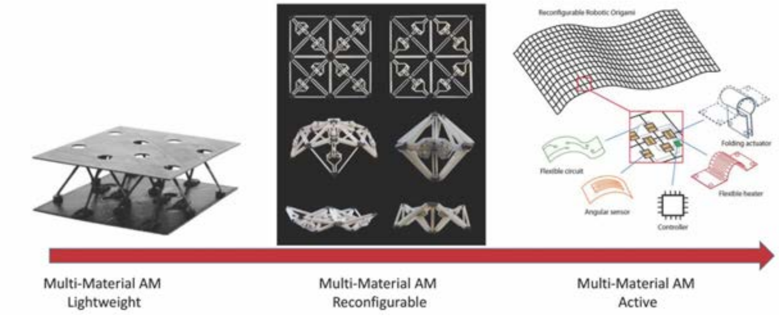


O. Testoni, T Lumpe, J.L. Huang, M. Wagner , S. Bodkhe, Z. Zhakypov, R. Spolenak, J. Paik, P. Ermanni, L. Muñoz and K. Shea, "A 4D printed active compliant hinge for space applications using shape memory alloys and polymers", Smart Materials and Structures, 30(8):085004, 2021.

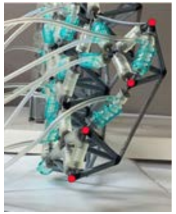
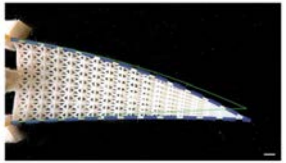
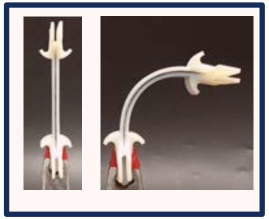
Summary

- Several approaches investigated for 3D/4D printed, multi-material active structures and robots
- Effective collaboration between the groups resulting in three, joint journal papers
- Active involvement and support from industry partners
- Deep-dive workshop conducted with industry partners – Autoneum, Orbitare, and PKNM solutions conducted between 25.02.2019 – 01.03.2019

Proposed



Attained:
Focus on Active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