
Programmable anisotropy with pressure: nonlinear effects in homogenization of cellular solids

Paul Lacorre^{*†1}, Louison Fiore¹, Jean-Marc Linares¹, and Loïc Tadrict^{‡1}

¹Institut des Sciences du Mouvement Etienne Jules Marey – Aix Marseille Université, Centre National de la Recherche Scientifique, Centre National de la Recherche Scientifique : UMR7287 / UMR6233 – France

Abstract

When flowers or other plants with soft stems lack water, they lose the rigidity that allowed them to stand upright. These important changes in stiffness are mainly caused by variations in osmotic pressure within the intracellular liquid. Through a bio-inspired approach, we designed a large artificial plant tissue and assessed its capabilities as a resilient actuator. In our prototype, plant cells are represented by cubic or spherical cavities within a massive polymer block. The air pressure in each cell is controlled individually through small tubes connected to an air tank.

The effective mechanical properties of the medium are obtained by periodic homogenization of a representative volume element (RVE). Our finite element simulations take into account geometric and material nonlinearities. Custom boundary conditions are implemented to allow "periodic expansion" of the RVE. The elasticity tensor is reconstructed to track the evolution of material coefficients as a function of pressure and wall properties. The anisotropy of the tissue can be controlled by changing the distribution of pressure. Counter-intuitively, the apparent Young's modulus decreases with increasing pressure. A linear analytical model shows this is mostly due to volume changes upon inflation while the "actual" stiffness remains constant.

Due to the large number of individual cells, the actuator retains its stiffness even if one or more cells are damaged (i.e. punctured). We study the impact of spatial distribution of defects on mobility reduction.

This artificial tissue is a programmable metamaterial that can serve as a resilient actuator for robotics. Moreover, it provides insights into how plants are able to move without muscles.

*Speaker

†Corresponding author: paul.lacorre@univ-amu.fr

‡Corresponding author: loic.tadrict@univ-amu.fr