Computational Design of Auxetic Metamaterials

PhD (3 years) / PostDoc (1 year)

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Context

Recent advances in digital fabrication and material science raise thrilling new research challenges in computer science with applications to product design, architecture, medicine, and art. One of them relies on the fact that 3D printing technologies, coming along with increasing computational capabilities, nowadays allow to realize more complex geometries and even control the deformation behavior.

An example are metamaterials that gain their extraordinary properties from rationally designed geometric structures rather than their constituting material. Metamaterials enable obtaining exotic mechanical properties from common materials by tailoring the small-scale geometry. For example, a rigid wooden plate or an aluminum sheet can be made very flexible by cutting notches, see Figure 1.

Figure 1: Examples of metamaterials: their mechanical behavior is governed by their geometric structure and not by the material they are fabricated of.

Research Goal

In this project, we focus on a class of metamaterials, called auxetics [1]. Auxetic materials have a counter-intuitive deformation behavior: instead of becoming thinner when stretched, they become thicker. The top row in Figure 1 shows examples of such metamaterials, Figure 2 shows an example of a 3D auxetic polyurethane foam. Auxetic materials are known to exhibit properties important in applications as diverse as biomedical engineering, aerospace industry, or protective sports gear, among others.

We have developed complementary approaches for generating 2D planar auxetic networks, either by pruning a dense network [6], or by conducting a parametric growth process [3][4][5]. This project aims to extend our previous results for constructing 3D structures and porous surfaces with tailored mechanical behavior, with an emphasis on auxeticity. Optimization of shape parameters and numerical simulations are part of the project in order to test and optimize the elastic response of the developed geometric structures. An existing numerical simulation code developed in [6] will have to be extended to 3D. Great care will be taken to control the mechanical properties' directional characteristics rigorously. Once the new structure (metamaterial) is computed, it can be used as a mesoscale structure and fill a 3D geometric object with it.

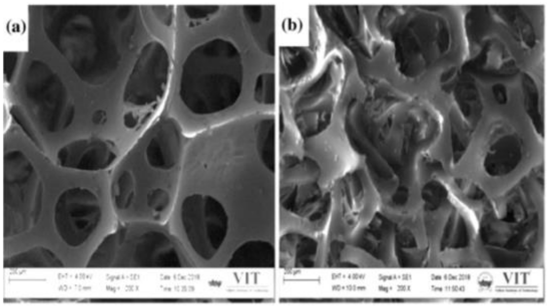

Figure 2: (a) conventional polyurethane foam, (b) auxetic polyurethane foam [2]

Required skills

We are looking for a candidate with a combined math-informatics profile interested in geometric algorithms, data structures, graphical programming and taste for mechanics and simulation. The candidate should have a good knowledge of geometric modeling or computational geometry and good skills in numerical methods, algorithmics and programming (C/C++, Python). Curiosity and enthusiasm are essential.

Information for applicants

The PhD/PostDoc will be collocated at INRIA Nancy and INRIA Grenoble and is part of the European FET OPEN project ADAM2 (https://www.adam2.eu). The candidate will benefit from an international research environment.

References

[1] Auxetic mechanical metamaterials, H. Kolken, A. Zadpoor, RSC Advances, 7 (9), 5111-5129, 2017
[2] Fabrication and testing of auxetic foams for rehabilitation applications, V.C. Vinay, D.M. Varma, J. Indian Inst Sci 99, 2019
[3] Random Auxetic Porous Materials from Parametric Growth Processes**,** Jonàs Martínez, Computer-Aided Design, Elsevier, 139, 202, 2021
[4] Star-shaped metrics for mechanical metamaterial design, Jonàs Martínez, Mélina Skouras, Christian Schumacher, Samuel Hornus, Sylvain Lefebvre, and Bernhard Thomaszewski. ACM Trans. Graph. 38(4), 2019
[5] 3D periodic cellular materials with tailored symmetry and implicit grading, Semyon Efremov, Jonàs Martínez Sylvain Lefebvre. CAD 140, (2021)
[6] Geometric construction of auxetic metamaterials. Georges-Pierre Bonneau, Stefanie Hahmann, Johana Marku. (Eurographics 2021), Computer Graphics Forum 40 (2), pp.291-303, 2021