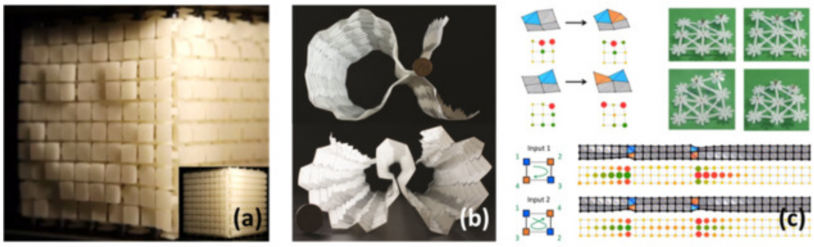
1) Non-Abelian Metamaterials.

Mechanical metamaterials are structured, flexible materials with unprecedented collective properties. In this project, we aim to design and create metamaterials that have memory, and whose state depends on the sequence of input signal. More simply: Consider an ordinary elastic material, and two types of mechanical input, say pushing in location A and B. In linear response, the order in which A and B are applied is irrelevant. However, in strongly nonlinear, multistable materials, first applying A, then B, may lead to a different final state that first applying B, then A. In that case, we call the material non-Abelian. We recently have studied a few theoretical models for such behavior. To realize this experimentally, we propose to create metamaterials where the linear response is suppressed, and nonlinear, multistable behavior is build in.

In this project you will start by creating very simple quasi 1D metamaterials by use of either 3D printing or moulding/cutting of rubber samples. The first goal is to demonstrate non-Abelian behavior experimentally for the first time. Then, we will investigate if there is a critical non-Abelian length scale that, for example, sets a maximum distance between signals A and B before they start to commute. If time permits and depending on interests, extensions to 2D models, computer modeling or theoretical modeling can also be made part of the project.

The research will be carried out at the University of Leiden and/or institute AMOLF in Amsterdam.

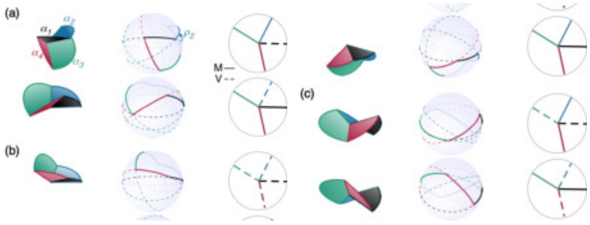
An earlier example of non-Abelian mechanics: Physical Review Letters, 113, 175503 (2014)
For a review on mechanical metamaterials see: Nature Reviews, Materials, 2, 17066. (2017)
For information, contact Martin van Hecke: mvhecke@gmail.com



Recent and future work on mechanical metamaterials in our group. ***(a)*** *Programmable Shapeshifter (**Nature 2016**)* ***(b)*** *Multishape Origami (**in prep**)* ***(c)*** *Non-commuting Metamaterial* ***(You?)***

2) Non-Euclidean Origami.

The science – and art – of origami concerns the folding of flat, 2D structures into 3D shapes. Here we propose to investigate the folding of quasi-2D structures that are not flat. As an example, consider a 4-vertex, consisting of 4 rigid plates connected by straight folds that meet at the center. For a flat, Euclidean vertex, the sum of the sector-angles of the plates adds up to 2π; but here we propose to use vertices where these angles add up to more or less than 2π. We have recently studied the folding of individual non-Euclidean 4-vertices, and are currently also working on using such vertices as logic gates.in this project we wish to explore origami patterns consisting of multiple non-flat vertices.



Non-Euclidean origami building blocks

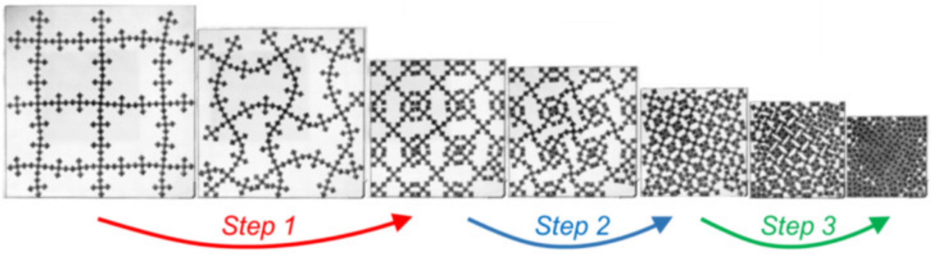
Preliminary explorations suggest that such structures, which we can create by e.g. 3D printing, display highly unusual folding behavior, including folding into different shapes, with folding branches connected in bizar ways that we do not understand. You will create such samples and explore their foldability. If time permits and depending on interests, computer modeling or theoretical modeling can also be made part of the project.

The research will be carried out at the University of Leiden and/or institute AMOLF in Amsterdam.

An earlier example of our work on origami: Physical Review Letters 114, 055503 (2015)
For a review on mechanical metamaterials see: Nature Reviews, Materials, 2, 17066. (2017)
For information, contact Martin van Hecke: mvhecke@gmail.com

3) Self-folding Metamaterials

Multi-step pathways, constituted of a sequence of reconfigurations, are central to a wide variety of natural and man-made systems. Such pathways autonomously execute in self-guided processes such as protein folding and self-assembly, but require external control in macroscopic mechanical systems, provided by, e.g., actuators in robotics or manual folding in origami. We recently designed the first shape-changing mechanical metamaterials, that exhibit self-guided multi-step pathways in response to global uniform compression. Their design combines strongly nonlinear mechanical elements with a multimodal architecture that allows for a sequence of topological reconfigurations, i.e., modifications of the topology caused by the formation of internal self-contacts.



*A three-step self-folding metamaterial (**Nature 2018**)*

In this project we propose to explore metamaterials that can follow different pathways depending on the mechanical forcing supplied; e.g., horizontal forcing should lead to a different pathway than vertical folding. You will design and create such samples and explore their mechanics – creativity is essential for this challenging project. If time permits and depending on interests, computer modeling or theoretical modeling can also be made part of the project.

The research will be carried out at the University of Leiden and/or institute AMOLF in Amsterdam.

Our recent work on self-folding: Nature accepted (2018)
For a review on mechanical metamaterials see: Nature Reviews, Materials, 2, 17066. (2017)
For information, contact Martin van Hecke: mvhecke@gmail.com