Electronic Supplementary Material (ESI) for Soft Matter.

Supplementary Information for the paper: Tunable sequential pathways through spatial partitioning and frustration tuning in soft metamaterials

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This document provides numerical results obtained via Finite Elements with the commercial software ABAQUS 2020 (Dassault Systèmes Simulia Corp) by applying a uniform confining strain to even rows of the metamaterial, followed by a uniaxial compression-decompression cycle. Unless mentioned, gravity is included in the analyses.

S1. Mechanical response of a perfect lattice

This section examines a perfect lattice (free from soft inclusions). S1.a shows the force-displacement curve obtained for $\varepsilon_x = 0.12$ where snapping events (1)-(5) and (6)-(10) triggered by compression and decompression respectively correspond to geometric changes displayed in S1.b. We can see that geometric frustration, in a perfect lattice, first induces the formation of a domain wall across the lattice domain. Then, due to gravity and under continuous compression, a sequential change of polarization occurs along the loading axis from the bottom clamped edge to the specimen top edge. At unloading, deformation propagates from the location of the unloading force to the clamped bottom edge. Due to the large size and periodicity of the domain, the deformation sequence is not predictable and is highly sensitive to imperfections especially for the first state change. Such behaviour motivated the implementation of partitioning strategy which aims to provide more order in the lattice because the deformation becomes localized in small domains.

Figure10link

S2. Mechanical response of the equally spaced layer partition

This section examines the biholar lattice with embedded equally spaced soft inclusion layers. To demonstrate the impact of gravity on the pathway, we have performed simulations with and without gravity; their respective force displacement curves along with snapshots of the specimen at given states are shown in S2.a and S2.b. Since region 2 is surrounded by two frustrated soft inclusion layers, it exhibits the highest frustration and is the last region to change polarization during the loading and unloading cycle for both cases (with gravity and no gravity). In the presence of gravity, we obtain similar results to the ones obtained experimentally (Fig.5 in the main text). Due to action of body forces, region 3 is the first to change polarization followed by region 1 and region 2. During unloading, due to the location of the unloading force and due to the contact friction caused by densification within the domain, region 1 changes first polarization followed by region 3, then region 2. On the other hand, in the absence of gravity, during compression, the region that is closer to the unloading force changes first of polarization followed by region 3 and region 2. During unloading, we obtain the identical sequence observed with gravity.

Figure11link

S.3 Mechanical response of the cross-partition

Here we focus on a lattice with embedded cross partitioning. In addition to the preloading present in the equally spaced layer partition, a tilting is applied to the lattice. S3.a shows the force-displacement curve obtained for $\varepsilon_x = 0.12$ where snapping events (1)-(4) and (5)-(7) triggered by compression and decompression correspond to geometric changes displayed in S3.b. Similar to the result obtained experimentally (shown in the main text in Fig. 7), the deformation sequence relies on the preloading asymmetry. The least frustrated region 3 changes polarization first followed by region 1 through the rotation of region 5. Continuous rotation induces the change of polarization of region 2 due to its increased frustration followed by the change of polarization of its centrally symmetric region 4.

Figure12link