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Conceptual Design of Spatial Auxetic Microstructures

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Metamaterials are engineered materials with properties not commonly found in nature. Mechanical metamaterials are a class of metamaterials that have unique mechanical properties such as negative Poisson’s ratio, negative thermal expansion, high shear modulus, high bulk modulus etc. These materials obtain such properties because of their uniquely designed microstructural geometry rather than their chemical composition [1]. Here, we present a conceptual design tool for synthesis of Auxetic or negative Poisson’s ratio microstructures using a mechanics-based framework that involves visualization of load flow through the geometry. The proposed design tool is immersive in nature as it is developed in virtual reality environment.

Auxetic metamaterial design has been an active field of research for the past few years, not only because of their counterintuitive behaviour, but also because of their enhanced mechanical properties such as high shear and indentation resistances, and high fracture toughness. Most of the methods in early literature of auxetic material design can be broadly classified into intuitive methods [2]–[4] and computational methods [5]–[8]. Most of the intuitive design methods are difficult to generalize to a larger set of problems. Numerical design methods such as topology optimization are computationally expensive and provide minimal insights to the design solution.

The authors have previously formulated a novel design framework for synthesizing planar auxetic microstructures by systematically combining several compliant functional building blocks [9]. Each building block known as the Transmitter-Constraint (TC) set performs the two-fold function of transmitting forces from one location to another (Transmitter), and constraining the deformation along a specified direction (Constraint) [10]. The simplest embodiment of a TC set is a compliant dyad obtained by serially concatenating two Euler-Bernoulli beam members. We consider the overall topology as a combination of strategically oriented TC sets. To determine the optimal placement of the TC sets, we are guided by unique mechanics-based insights that permit visualizing flow of forces from input to output. We define the concept of transferred forces that flow axially through the transmitters (implying load transmission) and transversely through the constraints (implying deformation). Through simple guidelines on load flow determined by the compatibility of the load flow directions, we can obtain kinematically feasible topologies as shown in Figure 1 [9]. A detailed review of load flow visualizations and load flow based design can be found at Refs. [10]–[12].
In this study, we have extended the design method to three-dimensional auxetic microstructures. Extending the formulation to spatial dimension is challenging because (i) the simplest TC set may no longer constitute a simple combination of beams, and (ii) the force flow visualization in three-dimensional space can get complicated. We aim to overcome these challenges by providing the designer with an immersive virtual reality based environment. The design process is depicted in the Figure 2, where (a) depicts the design domain. The requirement is that to design an Auxetic microstructure with negative Poisson’s ratio in XZ-plane i.e., $\nu_{xz} \leq 0$. Hence, for an input in positive X-direction, we require a displacement in positive Z-direction. Figure 2 (b) shows an eighth of the overall microstructure in the virtual reality environment. Here, we consider design of orthotropic microstructures and hence, the design is symmetric about three mutually perpendicular planes. This simplifies the design method as we need to design only eighth of the microstructure. Figure 2(c) depicts the complete microstructure of the design obtained in (b). Finally, Figure 2(d) validates the auxetic nature of the designed microstructure. The analysis has been performed in Abaqus/Standard using hybrid cubic beam elements. In conclusion, the proposed design can be used to design three-dimensional auxetic microstructures using an insightful and immersive framework.

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References


