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Cosserat metamaterials are a class of newly designed mechanical metamaterials. Such a material often consists of a chiral lattice when viewed microscopically. Thanks to this special microstructure, it can exhibit either coupled compression–twist [1] or negative Poisson's ratio [2] at the structural level. Despite advances in multiscale constitutive modelling, there is still a lack of a viable method for homogenizing and dehomogenizing such materials. One reason for this, of course, is that such materials have not been widely used in practice. Another more important reason, however, is that even classic Cosserat materials do not have uniquely defined 3D material properties, not to mention correlating these 3D properties to beam and plate properties.

The objective of this work is to develop a unified approach to the constitutive modelling of Cosserat metamaterials, based on the mechanics of structure genome (MSG). MSG is concerned with the constitutive modelling of composites, foams, and metamaterials, based on the concept of structure genome (SG) [3]. Generalized from the concept of RVE, an SG is defined as the smallest mathematical building block of a structure. In this work, the Cosserat elasticity theory is implemented in the framework of MSG, and a geometric exact kinematic formula, which can capture the rotation of chiral lattices, is subsequently derived. This kinematic formula is implemented in a variational statement of the SG, and the expressions for Cosserat 3D structures, beams, plates, and shells are then achieved first by dropping high-order energetic terms and then by minimizing the total potential energy stored within the SG. The present approach is finally implemented in SwiftComp™, a cutting-edge commercial code for multiscale constitutive modelling.

The present approach is validated by simulating: 1) a series of Cosserat beams exhibiting coupled compression–twist [1]; 2) an auxetic 3D block having a chiral lattice [2]. In the first validation example, the predicted relationship between the twist angle per axial strain (also the effective Young's modulus) and the number of unit cells (UCs) is found to agree well with the experimental ones and those predicted by 3D FEA. In the second example, the predicted relationship between the effective Poisson's ratio (also the effective Young's and shear moduli) and the number of UCs is found to agree well with those predicted by 3D FEA. Furthermore, the 3D effective properties of the UC corresponding to each structure are predicted for reference, and the local stress and strain fields in each structure are recovered. In summary, the present approach illustrates a unified approach to constructing the constitutive models for Cosserat metamaterials, as well as their corresponding 3D structures, beams, plates, and shells, over multiple length scales (Figure 1). It is expected to greatly facilitate the design and analysis of novel Cosserat metamaterials.

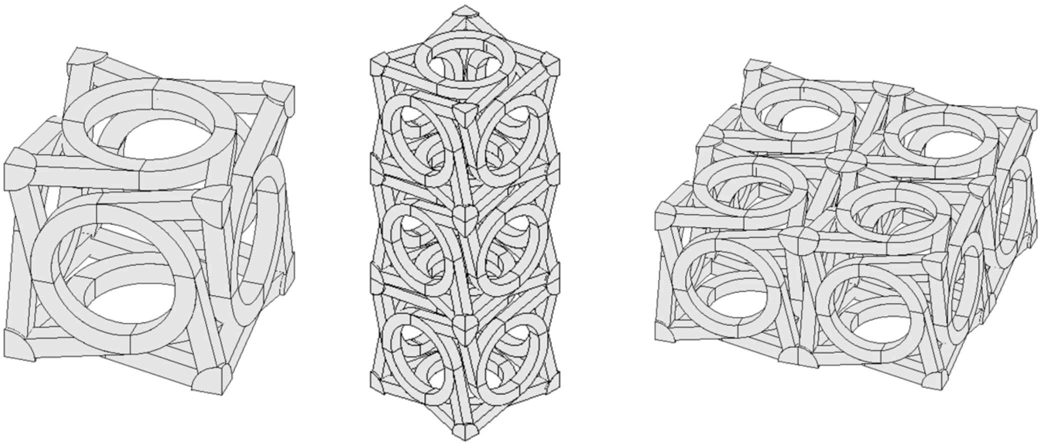

Figure 1. Cossrat material in solid, beam, and plate models

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