

# Virtual-Power-Based Quasicontinuum Methods for Discrete Dissipative Materials

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Each material can be regarded as a discrete structure at the atomistic length scale, but materials based on fibres, yarns and struts are also discrete at the mesoscale (e.g. foams, paper materials, collagen networks, textiles, printed structures). The mesostructures of these materials are often modelled using dissipative springs and/or beams. This renders direct numerical simulations of engineering applications at the macroscale prohibitively costly. Hence, multiscale approaches need to be employed if one wants to incorporate discrete mesostructural models directly. One of these multiscale approaches is the quasicontinuum (QC) method [1]. The QC method has a number of advantages, one of which is its *equation-free* character. This means that no meso-to-macro quantities (i.e. the macroscopic stiffness tensor) and macro-to-meso relations (i.e. periodic boundary conditions) need to be formulated. This makes the implementations comparatively simple and allows for direct extensions to any higher-order interpolation at the macroscale. The QC method was originally formulated for atomistics [1] which are conservative (nonlinear, nonlocal) spring systems. Mesostructural models however, often require dissipative springs or beams. To account for dissipation in the QC method, we have formulated a virtual-power-based QC variant [2]. This new QC variant essentially uses the virtual-power statement of the mesostructural model in combination with a Coleman-Noll procedure. The developments of the virtual-power-based QC approach started with a simple geometrically nonlinear, elastoplastic truss lattice and ever since we have tried to make it more general in order to use it for mesostructures of actual discrete materials. Past and current developments related to the virtual-power-based QC framework focus on/have focused on:

- a mixed QC formulation to allow fibre-to-fibre bond failure [3],
- adapting the material behaviour of springs to model actual textiles and fabrics [4],
- higher-order QC frameworks for beam lattices [5],
- including geometrically nonlinear, elastoplastic rotational springs, and
- a multifield, higher-order QC framework for irregular beam lattices.

In this presentation, the formulation of the virtual-power-based QC framework will be outlined for an elastoplastic truss lattice. Subsequently, one or more of the recent aforementioned developments will be addressed.

## References

- [1] Tadmor et al., *Phil. Mag. A* 1996; 73: 1529-1563.
- [2] Beex et al., *JMPS* 2014; 64: 154-169.
- [3] Beex et al., *CMAME* 2014; 269: 108-122.
- [4] Beex et al., *Mech of Mat.* 2015; 80: 52-66.
- [5] Beex et al., *CMAME* 2014; 279: 348-378.