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Topology Optimization of Discrete Structures and Lattices Considering Manufacturing Cost

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1. Abstract
Topology optimization is a powerful design tool for maximizing the performance of a structure under a set of constraints. Discrete structures (trusses and frames) and lattice-based cellular materials can be efficiently modeled with structural elements (truss or beam elements). In such cases, a starting guess (ground structure) composed of a dense mesh is initially assembled, and elements are subsequently resized and/or removed during the optimization process. Solutions, however, are dependent on the initially selected ground structure: increasing the density of the initial ground structure typically leads to solutions with increased structural efficiency (decreased weight), but also increased topological complexity. As the manufacturing cost of a structure or lattice material is a function of both material cost and assembly cost, minimal material (i.e., minimum mass) solutions that are complex may not be appealing from an engineering viewpoint. This is particularly problematic for situations where much simpler (and hence cheaper) solutions can be found with small performance loss or mass gain relative to the optimal structure.

In this work, we propose a novel methodology to incorporate the manufacturing cost of discrete structures into the performance-based design problem. For simplicity, we assume that the assembly cost component of the total fabrication cost is proportional to the number of elements in the final structure, or equivalently the number of required element connections in the system. To maximize computational efficiency, the proposed method regularizes the discrete function for estimating fabrication cost, thereby enabling the use of large-scale gradient-based optimizers. After exploring the effect of considering manufacturing cost, external loads and boundary conditions on a number of structures and lattice materials, we investigate the definition of "optimal cost-effective design". The methods presented in this work can be largely expanded to cover more elaborate cost models and are applicable to nearly any structural optimization problem.

2. Keywords: Topology Optimization; Manufacturing Cost; Discrete Structures; Lattices; Heaviside Step Function