Hyper-structures for Additive Manufacturing and Generative Design of *ultra*-lightweight, high strength-to-weight ratio, vibration controlling components

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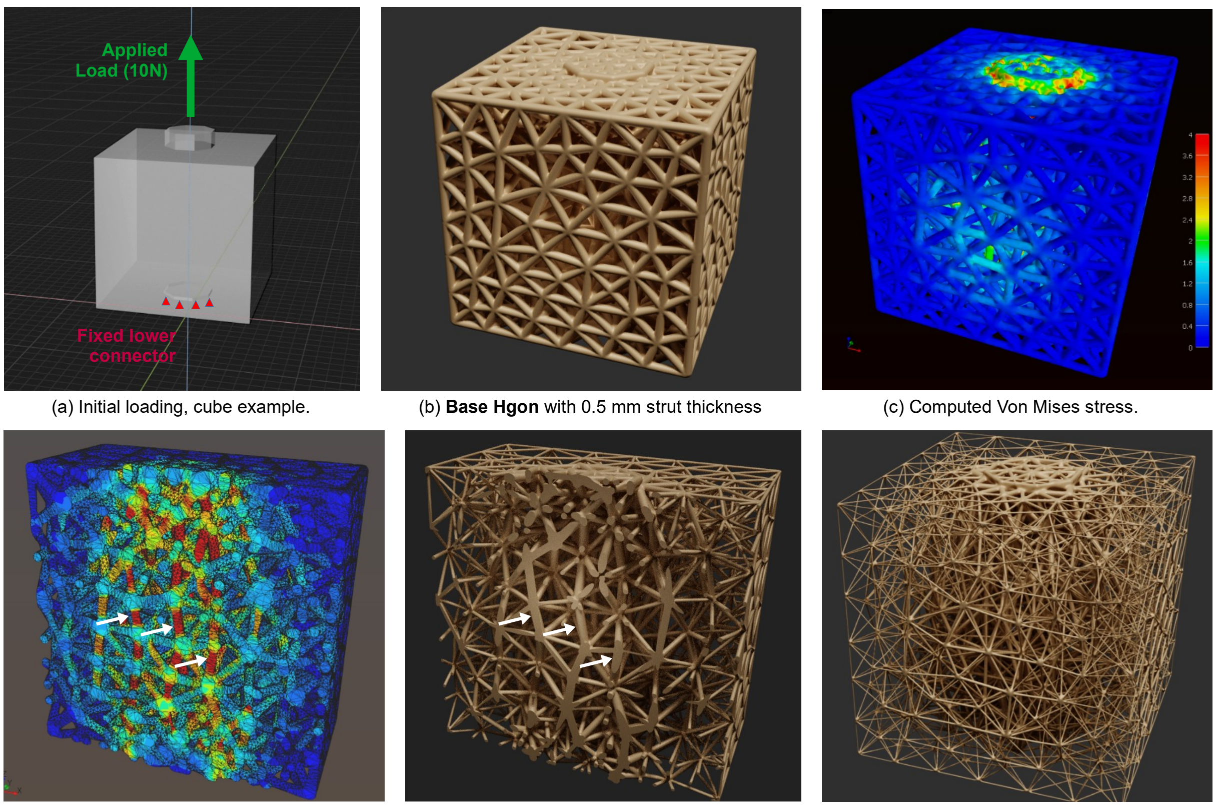
Additive manufacturing (AM, e.g. 3D printing) technologies enable the design and production of novel structures that are impossible to produce using standard manufacturing processes. We have developed a new type of hyper-structure (Hgon) with unprecedented strength-to-weight ratios, unique micro-macro *conforming* topologies, and field-adaptive optimization capabilities. HGon hyper-structures conform to most any complex shape and boundary condition requirements. Hgons also have unique *vibration*, impact, and fatigue resistance properties due to the ability to combine both isotropic and anisotropic multi-scale structures in ways *never before possible*. Stress, strain-energy and related field-adaptive optimization can be done for wide ranging applications; electromagnetic (EM) and fluid-solid (heat transfer) interactions, cushioning, impact, and more. Multiple materials can be used. Novel Generative and Optimization strategies have been implemented *in-house* with fast, GPU and parallel-capable computational approaches in Python and C++.

As an introduction, below is a simplest example of a cube in tension with a generated base isotropic hyper-structure and two successive **stress-adaptive optimizations** L1 and L2:



(a) Initial loading, cube example. (b) **Base Hgon** with 0.5 mm strut thickness (c) Computed Von Mises stress.

(d) Cutaway showing internal stresses. (e) Cutaway, **L1** stress optimized H-structure. (f) **L2** stress optimized Hyper-structure

Figure 1. A basic cube Hgon optimized for tensile load. Both topological density and strut thickness are controlled von Mises stress computed using nonlinear Finite Element Analysis (FEA). Arrows (d, e) indicate 'thickened' struts in high stress regions. The resulting 'hypercube' (f) is 25% *stronger* than the base cube, and *55% lighter*, with just 2 optimization steps. This is a fully manifold, 3D printable structure. *To our knowledge, the first of its kind.*

Hyper-structure generation can be done with much more complex components than this simple cube. Our process works for most any STL or STEP (CAD) solid. To illustrate, Figure 2 (next page) shows a single leaf of a complex electric motor-stator frame component with both curved and very sharp features.

FE methods are used both to generate and analyze hyper-structures. The main 4-step iterative process starts with a CAD or other designed shape. With Hgons, the shape can be simple or very complex (such as Fig. 2), with holes and

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