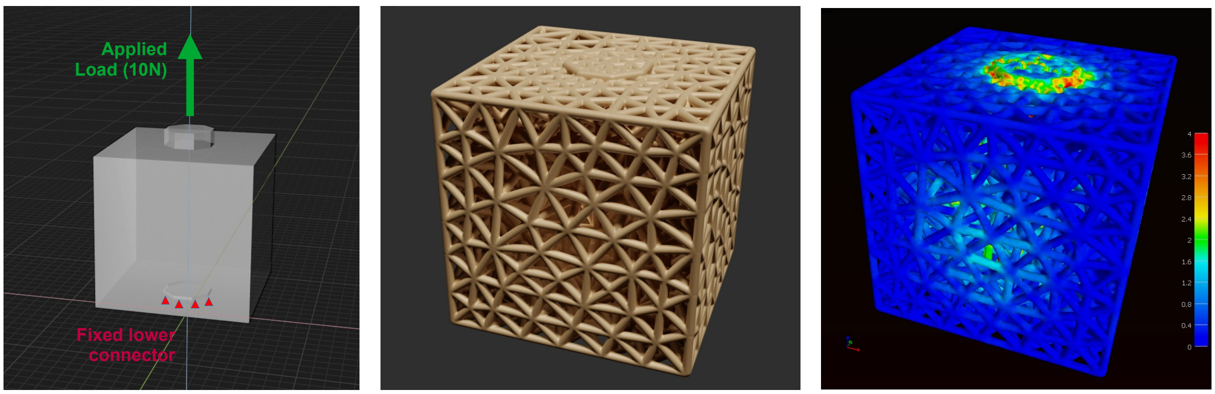
Hyper-structures for Additive Manufacturing and Generative Design of *ultra*-lightweight, high strength-to-weight ratio, vibration controlling components

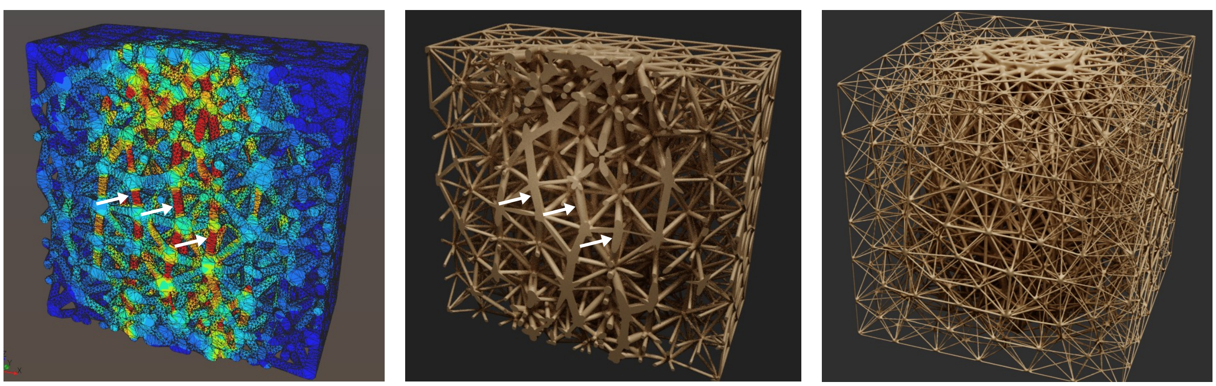
- View the new for 2020 Tech Reel #4 (2 min): https://youtu.be/k-0MyWpFrio

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 to analyze hyper-structures; currently using FEBio for bioengineering applications, ELMER for EM structures and designs, and Tochnog for geophysical and architectural/civil engineering applications. Integration with ABAQUS, ANSYS, and other commercial FE software is under development. Structures can be optimized for ***impact***, vibration, fatigue resistance and many other factors. Current projects and applications include cushioning (client: Philips Resp.), footwear, aerospace, automotive, nuclear, antennae, advanced physics experiments (Z machine), advanced motors, active sensing structures, impact-ballistics, and others. Selected case studies, further introductory info, and a gallery are shown on our website (http://Abemis.com).

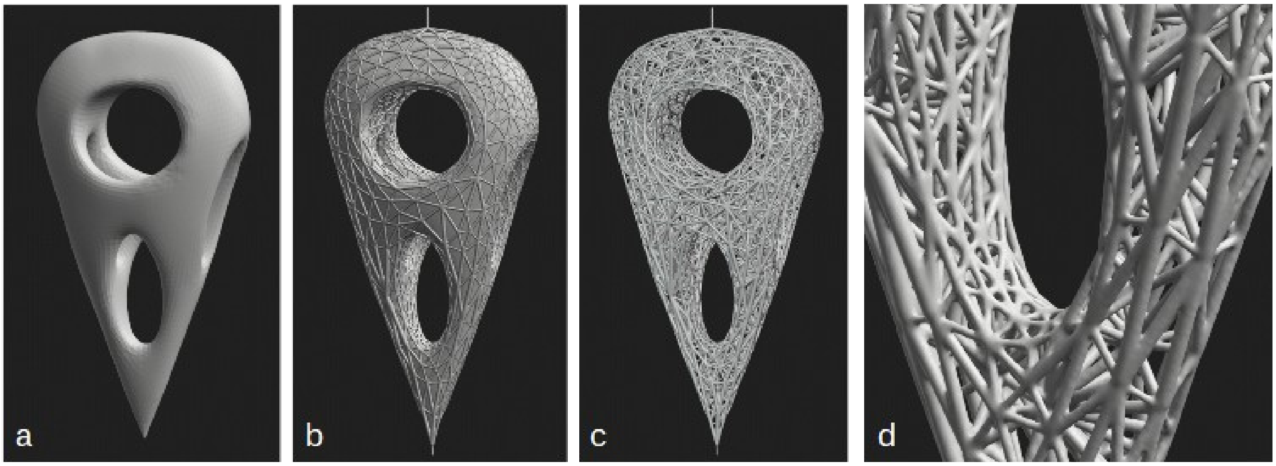


Figure 2. One lobe of an advanced bi-axis motor/generator stator (a) and fully conforming Hgon hyper-structure (b-d). Note the near-perfect conformity (b) to this highly complex shape and adaptive strut sizing (d). This cannot be done with lattices.

It is important to note that Hgon hyper-structures are NOT simple lattices. Hgons expand and computationally extend the concept – i.e. Hgons *can* be lattices, but lattices can *never* be fully isotropic and *conforming* Hgons, particularly for highly complex topologies such as shown in Figures 2 & 3.

Hgons are now optimizable and analyzable using latest GPU-enabled FEA methods (in-house), facilitating a Generative Design workflow. Figure 3 below shows an example tri-connected bracket optimization for an ultralight, **vibration dampening** antenna mount. The process involves computing the overall stress field of the part, and then subsequent iterative stress fields of the parametrically generated Hgon hyper-structure; reparametrize, and repeat.

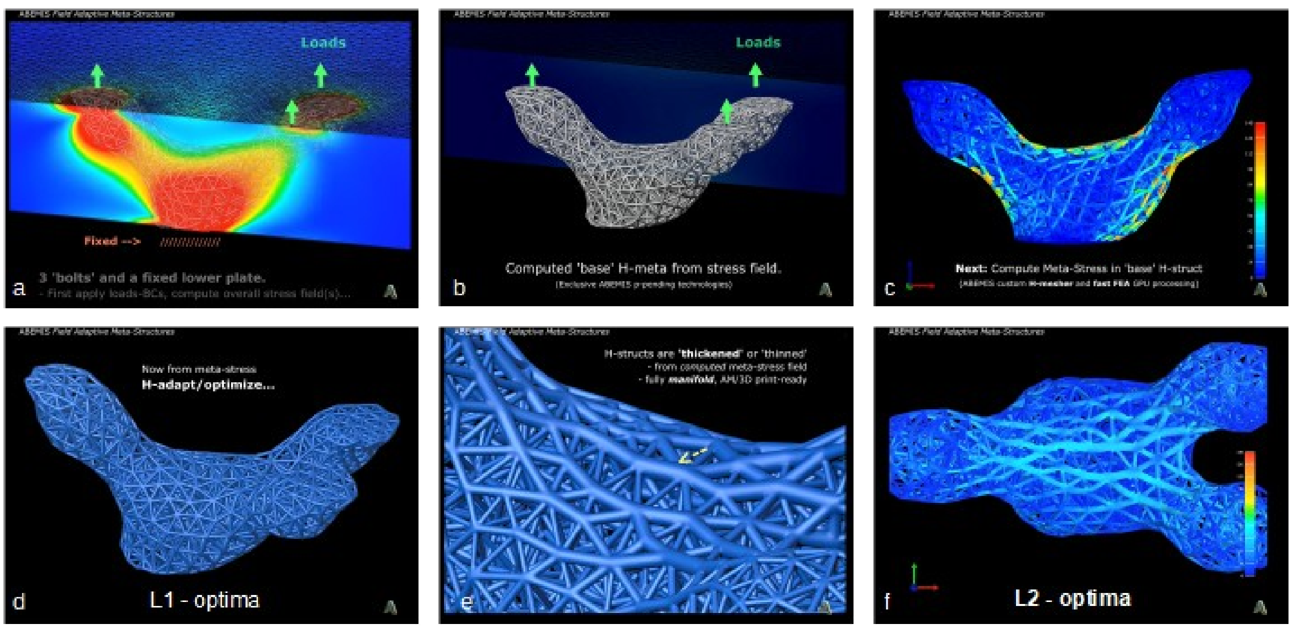


Figure 3. An optimized bracket support (a) generated from defined loads and boundary conditions (von Mises stress), (b) the computed Hgon hyper-structure with (c) 1st level FE stress calculation, and (d,e,f) the 2nd level strut thickness optimization. Struts are thickened or thinned according to computed stresses. The resulting stresses in the structure are reduced by 70%+, while the overall structure is 24% lighter, and still **200% stronger**. This process can be repeated as desired to achieve optimal ultra-*lightweighting*, and other design criteria. To our knowledge *only* ABĒMIS H-structures enable *both* macro and micro-scale optimization.

Many different approaches can be used for macro-micro optimization. Figure 4 below shows a different approach for a vibration isolating bracket support. In this case the outer wedge shape is proscribed (from client's CAD STL file) and an initial FEA is performed to compute stresses in the structure. The base conforming Hgon hyper-structure is computed with mesh *density* (tetrahedra) controlled by the topology and stress field. Then subsequent micro (strut) optimization is done to generate the optimized Hgon – for stress and in this case modal vibration optimizing (damping) ultralight bracket structure. More details of this work can be found online in our 'case studies' section (abemis.com).

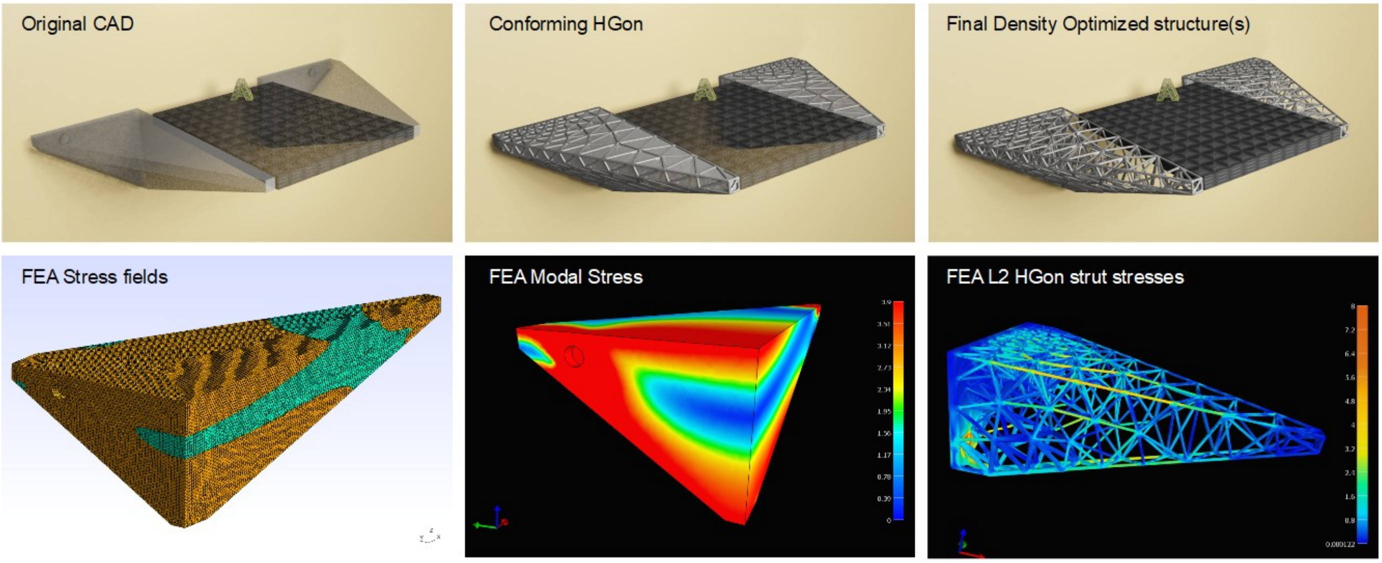
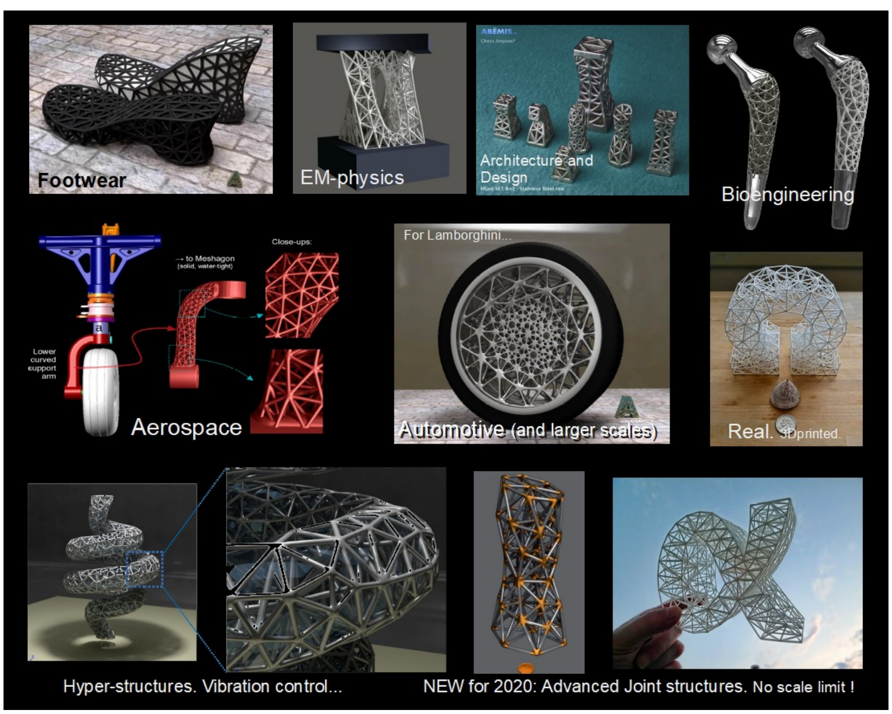


Figure 4. A vibration dampening bracket prototype. Shown is the original CAD, and generated HGon optimized for density, stresses (z-y loads) and dampen vibrations in the 200-2000 Hz range. This uses both a macro (whole component) and micro (L1 strut level) dual optimization approach. Further optimizations with many other criteria can be done. Also note that HGon structures are quite beautiful, sculptural, and architectural (left). They also 'feel' very interesting due to the ultra-lightweight and ultra high stiffness characteristics. People often describe them as... **"Astonishing!"**

HGon hyper-structures offer an entirely new way to design and generate optimized, ultra-light and ultra-strong components. Applications are vast, including Aerospace, Automotive, Bioengineering, Impact/Ballistics, Electro-magnetics (e.g. low and high energy physics), Footwear (sport *and* fashion), Architecture, and Artistic sculptural designs (e.g. atriums, lighting fixtures, large scale frame structures, sculptural, etc.) just to name a few.

The possibilities, and applications, are endless…



To best experience our HGon™ technologies and hyper-structures: **3D viewing and video.**

Many 3D views of HGon generated structures can be found on our Sketchfab website: https://sketchfab.com/tcdoeh/models

– Latest tech demo reel for July 2020: https://youtu.be/k-0MyWpFrio

We have also made a number of video technical introductions and demonstrations which present info and examples.
Please visit these links for more information, technical demonstrations, and example product designs:

1. Basic video technical introduction (2 min, with audio): https://youtu.be/pU_4_fPelJ4
2. Short intro example of L1 and L2 HGon generation (under 1 min): https://youtu.be/unLOuyc9pa8
3. ABĒMIS tech demo reel (2min, no audio, https://youtu.be/a7L0LXZ9bdo) This shows a number of our newest technologies and examples of vibration control, impact/ballistics, **multi-domain** structures, and prototype designs for current clients, and new Finite Element based analysis capabilities (fast GPU).

Case studies are being constantly updated on our website: https://www.abemis.com/case_studies.html

Also, we are now developing new systems for *physical testing* of HGon (or any) structures, with tensile, multi-axis, fatigue testing, more. New hyper-structure testing system (HSTS): PDF (2 page)

Thank you for reading.

Contact us for any further information: info@abemis.com

For a *live* (screen-share) tech demo please contact at: techdemo@abemis.com.

Todd Doehring, Ph.D., CEO: tcd@abemis.com