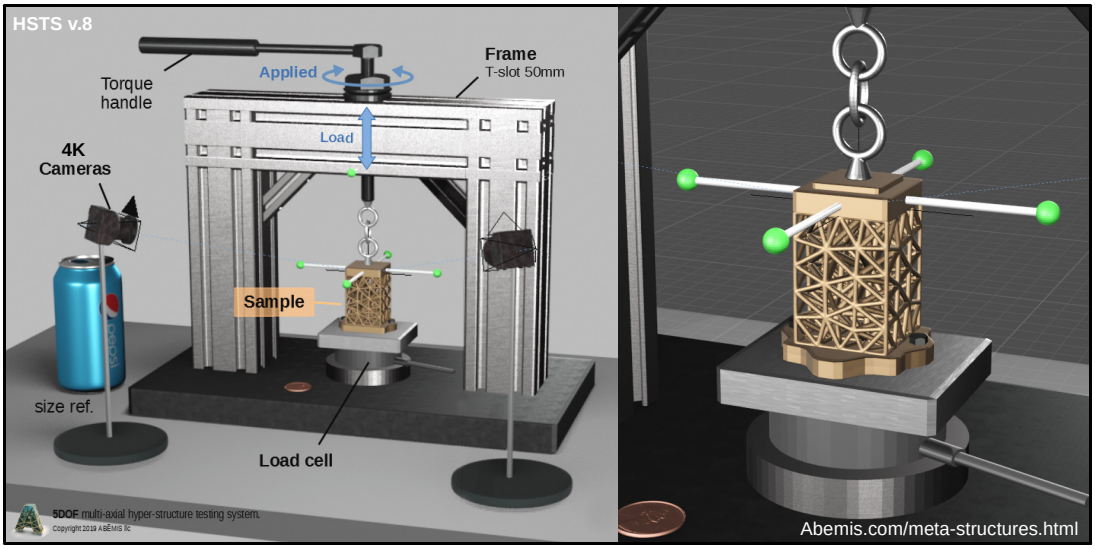
Closing the loop: Multi-axial testing of hyper-structures with *calibrated* GD-FEA models/analyses

Summary: Materials/mechanical testing of hyper-structures, simpler lattices, and related generative design (GD) structures is challenging, mainly because they are not 'solids'. Thus, standard strain measurement techniques can't easily be applied. Also, simple tension tests are not sufficient to describe the load-deformation behavior – multi-axial tests are needed. To our knowledge, there are no existing *simple* multi-axial testing systems with 3D image-mapping/measurement available for this purpose.

– We have developed a novel Hyper-Structure Testing System (HSTS) and service that combines real-world data and concordant FEA, 'closing the loop' for advanced GD-FEA optimization and design. Our novel (p-pending) hyper-structure technologies enable real-world, physically motivated optimization strategies based on our new *physically-based generative design* (PBGD) workflow.

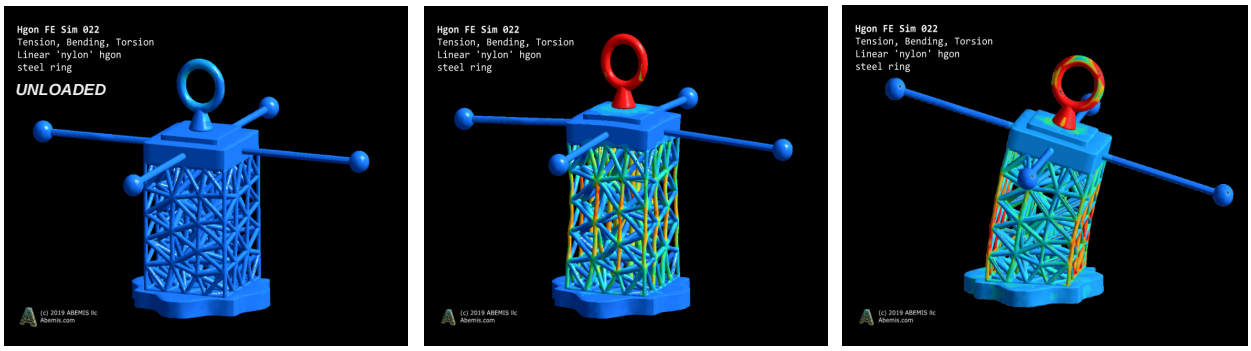
Workflow: First, simple rectangular 'brick' samples are printed using a designated AM materials/system (e.g. nylon, metal) and process methods → Multi-axial (tension-torsion-bending) tests are performed → Exact structure and experimental conditions are modeled/simulated using FEA (ours or your preference) → The *calibrated* FEA is then used to compute predicted (optimized) variations of hyper-structure parameters with increasingly more complex structures → Retest, improve/customize the FEA → Repeat to goal.

Next, the optimized material/structure hyper-calibrated FEA used for **your custom hyper-component** → with *ground truth experiments, enabling emergent-optimized components* with potentially unprecedented capabilities → strength/weight ratios, exotic properties, vibrations, EMF control, Piezoactive, Fluid/Heat transfer, more. *Contact us to discuss. Please visit Abemis.com/meta-structures.html.*



Above left, the new multi-axis, multi-DOF testing system. Bending/shear uses various different clamps-connectors. **Right,** Closeup of a typical AM3D manifold/printable *Hgon* sample. The green targets fixed to the top provide fiducials for high resolution 3D tracking → A 3-camera array captures 3D images of the hyper-structure during loading. This is just one 'simplest' example – *any structure* can now be tested in Multi DOF.

Advantage: Our FE models and systems have been developed with strategies-programming to best 'match' the model and experimental local/global deformations and loads; starting with simple tension-torsion and then moving to more complex loading conditions. Hyper-structure parameters, such as varying strut thickness and strut-joint chamfer (and many more) can be varied and rigorously tested, providing a critical advantage in design-manufacture of *ultra-performing* hyper-components for demanding applications such as Aerospace, Automotive, and Bioengineering. Fatigue testing/analyses can also be done with our new system.



Above, concordant FE model of a mid-density sample showing initial and deformed solutions (von-Mises stress). Note that initial model predictions are reasonable; high stresses appear in appropriate regions. This demonstrates the feasibility of our approach. Calibrated FE solutions can be rigorously statistically compared with equivalent measurements, enabling advanced GD optimization and thus **'closing the loop'.**

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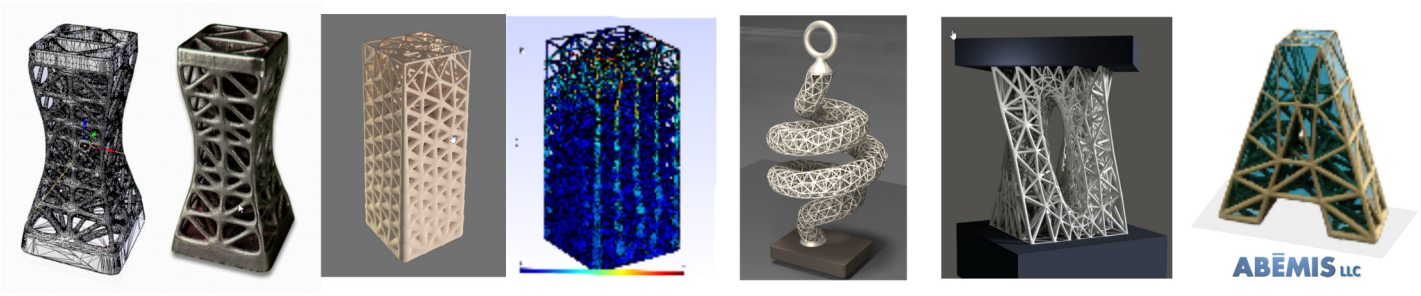
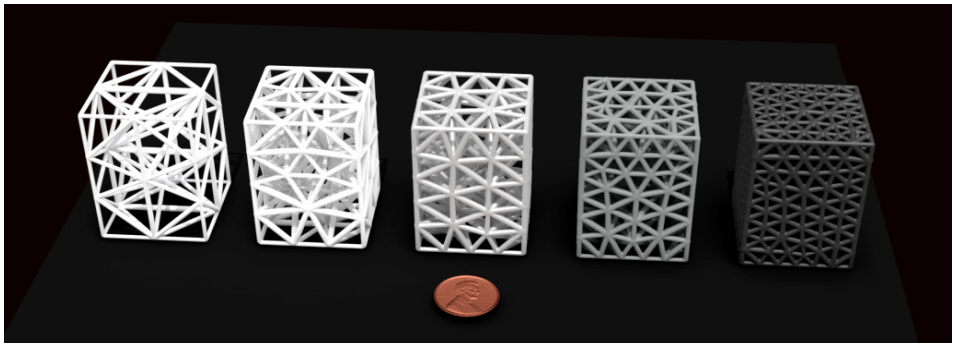
Conclusion: To our knowledge, no other group has this technology to *'close the loop'* for real-world hyper-structures or even other simpler GD structures (lattices, etc). The new combined Multi-DOF testing system, with concordant FEA enables new capabilities for ground-truth meta-structures or any GD structure analysis and design. Our hyper-structures **extend** the lattice concept to new levels. We can perform analyses on advanced/custom topology parts or components, even the most complex structures... There is no limit. We believe this is a 'game-changing' technology advancement, and can provide the extra and unprecedented advantage for both everyday and *ultra-high performance* applications in modern industries (e.g. Aerospace, Automotive, Bioengineering, etc.). Testing system clamps and attachments can be simply modified to customize sample loading (e.g. motorized for automated testing). Predictive models using either our ABĒMIS FE-GPU code or any other desired FEA can be done. Multiple sample arrays with complex hyper-parameters can be generated and assessed to compare and evaluate Hgon or any GD structures for specific needs and performance criteria (e.g. ultra-lightweighting, exotic conditions). **Please contact us for more information/consulting/quotes. VISIT: Abemis.com/meta-testing.html.**



Examples *of more complex testing samples currently under analyses/evaluation*

Hyper-structures can achieve unprecedented performance and vibration control characteristics.
Now, with multi-DOF testing and analysis capabilities. The possibilities are endless.



Series of 5 test samples with varying hyper-structure densities.
Simple shapes allow us to calibrate to modern FE-GPU analyses.
NOTE: These are NOT lattices. They are true conforming meta-structures.

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