Tensegrity Modeling of Biological Systems

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Background and Motivation

- ***Tensegrity = Tension + Integrity***
- Structures composed of discontinuous compressive elements (rods, struts, or bars) in a continuous network of tensile elements (bands or wires).
- Driving force behind mechanical behavior of tensegrity systems is level of ***pretension*** in elements.
- Tensegrity principles can be observed in plants, animals, and even humans.
- Tensegrity systems can exist in a nearly infinite number of shapes and sizes, from microscopic cellular networks to river-spanning bridges.

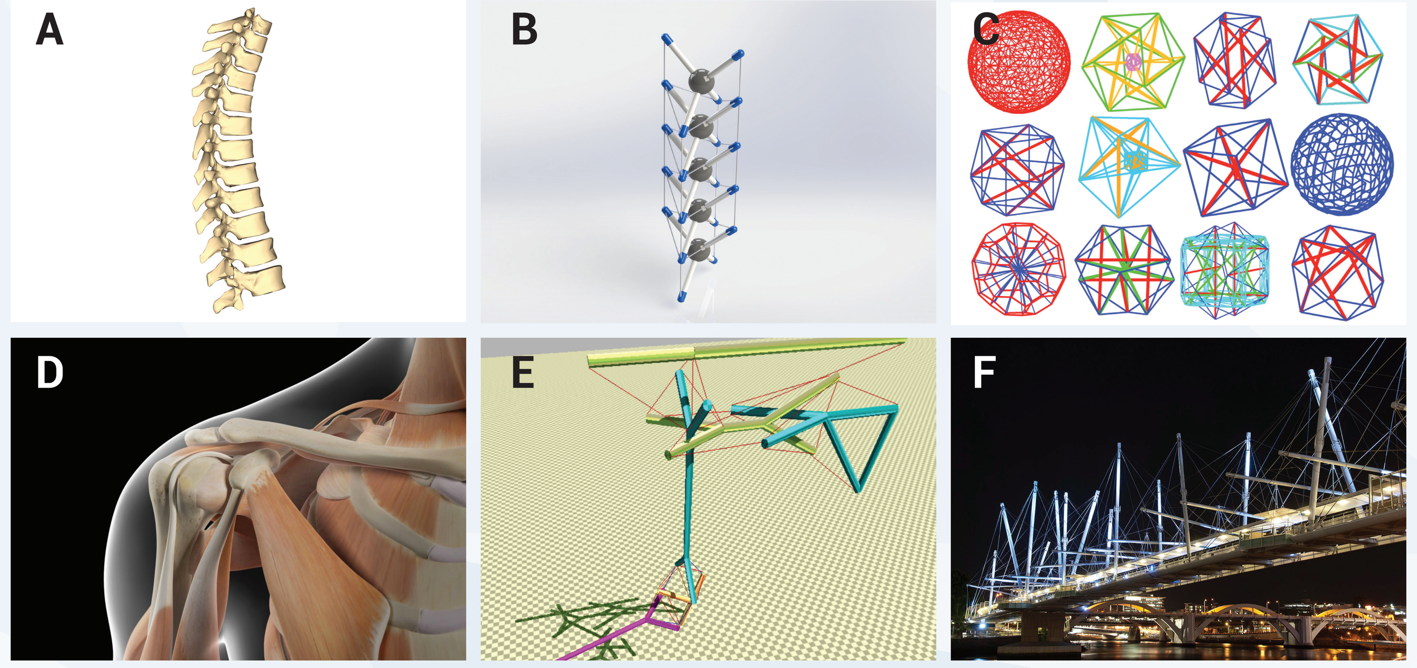

Figure 1: *Thoracic vertebrae (A) and its SolidWorks tensegrity model representation (B), cellular membrane tensegrity models (C), human shoulder (D) and one example of a tensegrity shoulder representation (E), Kurilpa tensegrity-based bridge (F).*

Project Scope

- Evaluate and characterize behavior of tensegrity "t-prism" structure under uniaxial compressive loading.
- Develop new method of simulating and implementing pretension in tensile members.
- Conduct parametric study to quantify the effect of pretension, as well as geometric and material property variations on the deformation mechanics and load-bearing capacity of t-prism structure.

Engineering Applications

- As a result of their ***high strength-to-weight*** ratios, tensegrity structures are perfectly suited for a number of potential applications including deployable bridges, satellite booms, and transportable platforms.

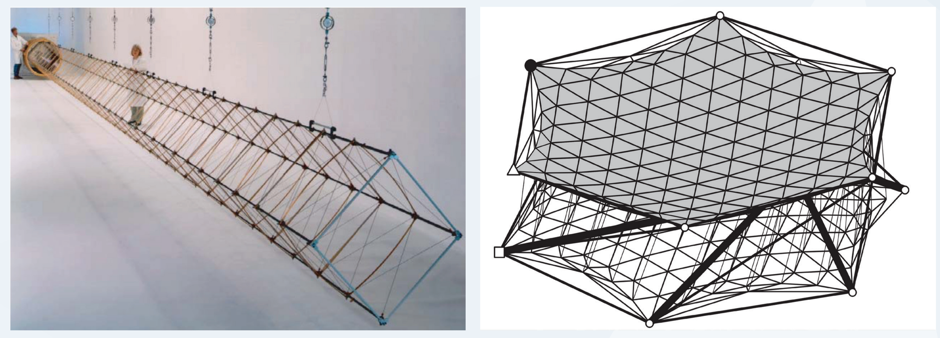

Figure 2: *Tensegrity-inspired extendable satellite boom (left) and design for tensegrity reflector antenna (right).*

3D Printed Model Design

- Expandable bars designed in Solidworks to introduce pretension without having to disassemble structure for each test.
- Utilized Objet260 multimaterial 3D printer.
- Compressive bars used VeroWhite.
- Tensile network used Tango+.
- Initial design used elastic bands, however 3D printing ensured accuracy and repeatability of critical dimensions.

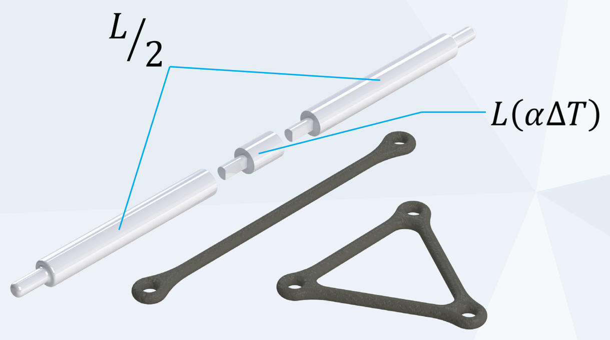

Figure 3: *Expandable bars and tensile network as modeled in Solidworks.*

Finite Element Simulations

- Finite element simulations were conducted using Abaqus FE software to analyze the behavior of the tensegrity prism under uniaxial compression.
- To determine the effect of geometry on the loading and deformation characteristics of the structure, the initial height of the prism was reduced by 50% (H vs. H/2) while leaving other geometry unmodified.

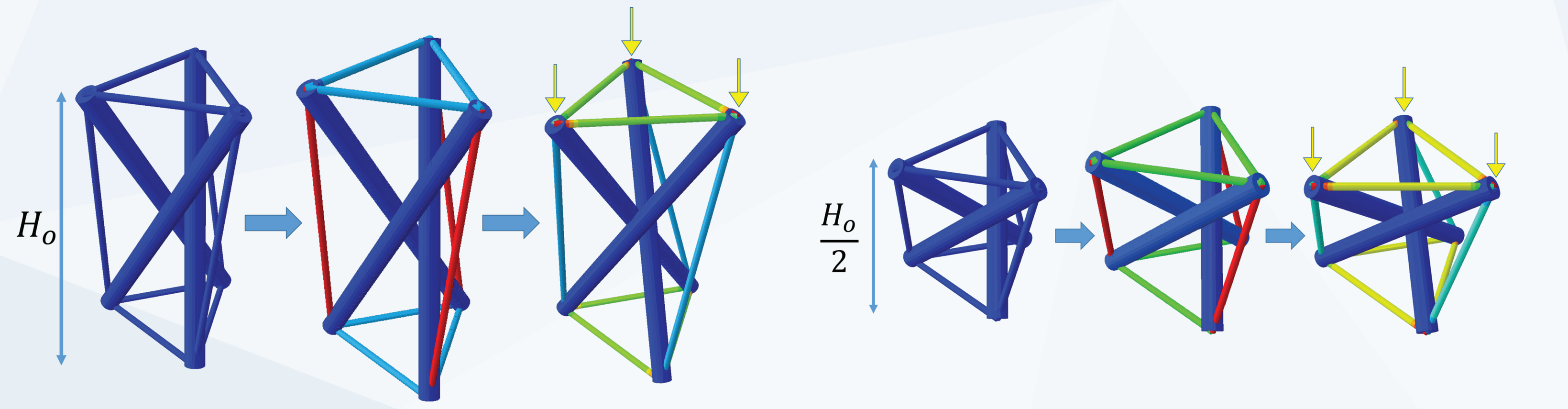

Figure 4: *Undeformed (left), pretensioned (middle), and deformed (right) Abaqus tensegrity prism models for prisms with initial height H and H/2. Variation in color indicates different levels of stress in elements.*

- To pretension these structures to specified level, a simulated thermal stress was applied to the compressive rods according to $\varepsilon = \alpha\Delta T$
- This thermal stress caused the rods to elongate, creating an initial tension in the top, bottom, and side wires equal to that created by the spacers in the 3D printed model.

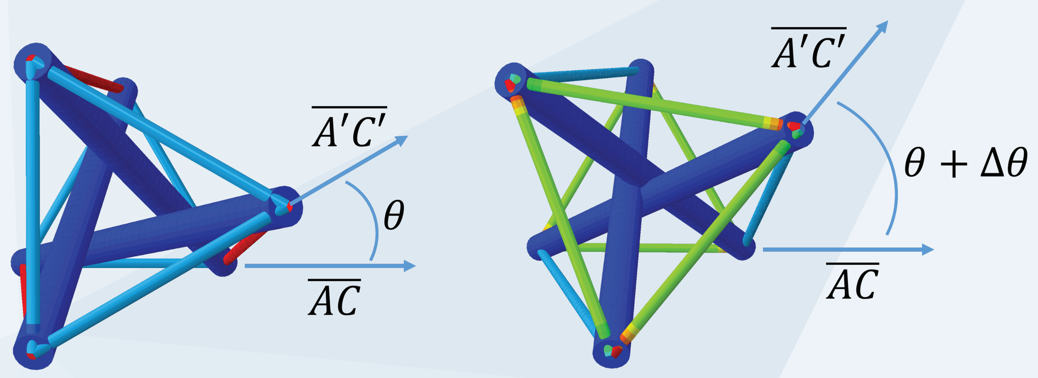

Figure 5: *Relative rotation from undeformed (left) to deformed (right) configuration.*

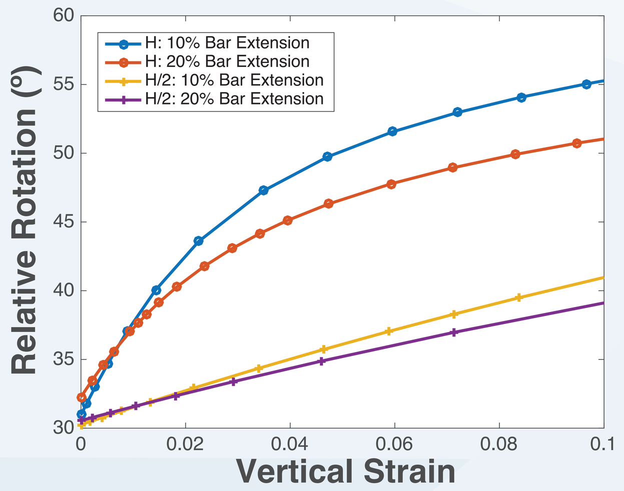

Figure 6: *Abaqus relative rotation simulation results for H and H/2 prisms.*

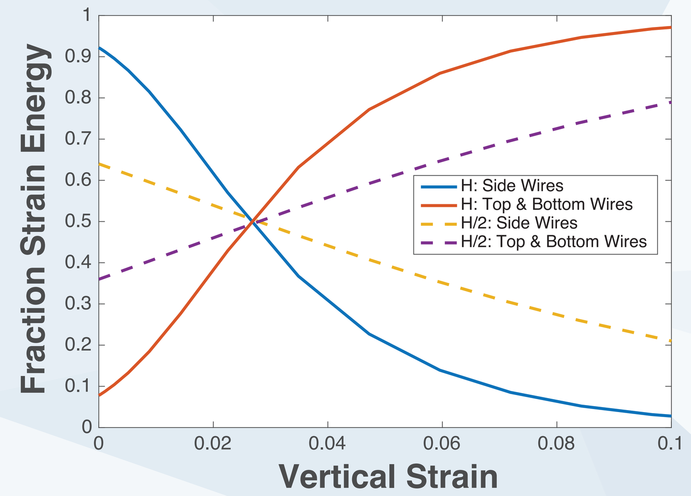

Figure 7: *Abaqus strain energy simulation results for H and H/2 prisms.*

- Relative rotation increases with increasing prism height, decreases with increased pretension.
- Initially majority of strain energy stored in side wires (none in rods).
- During compression, energy transfers to top and bottom wires.
- Total strain energy stored in prism increases nonlinearly.

Experimental Analysis

- Each specimen tested in a Zwick/Roell Z5.0 material testing machine with a 100N load cell.
- Prisms assembled with appropriate bar extension lengths (0%, 10%, 15%, or 20%), and subjected to uniaxial compression to a maximum vertical strain of ε=*0.10*.

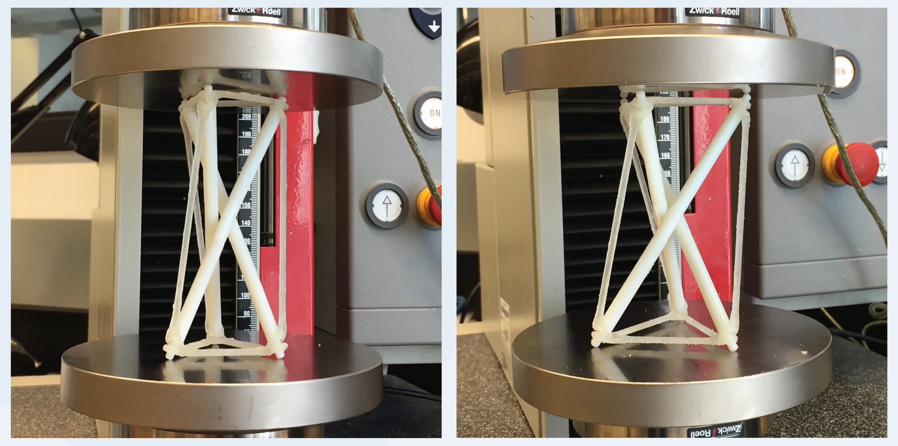

Figure 8: *3D printed tensegrity prism in Zwick/Roell Z5.0 material testing machine. Initial, undeformed prism (left) and deformed prism under 10% vertical strain (right).*

- Load capacity characteristics generally consistent between experimental and simulation results.
- Load capacity decreases with decreasing height-to-width ratio.
- Negligible rotation in experimental results vs. significant rotation in simulation.
- Differences attributable to friction, as well as compressive forces exerted by wires in Abaqus FE simulation.

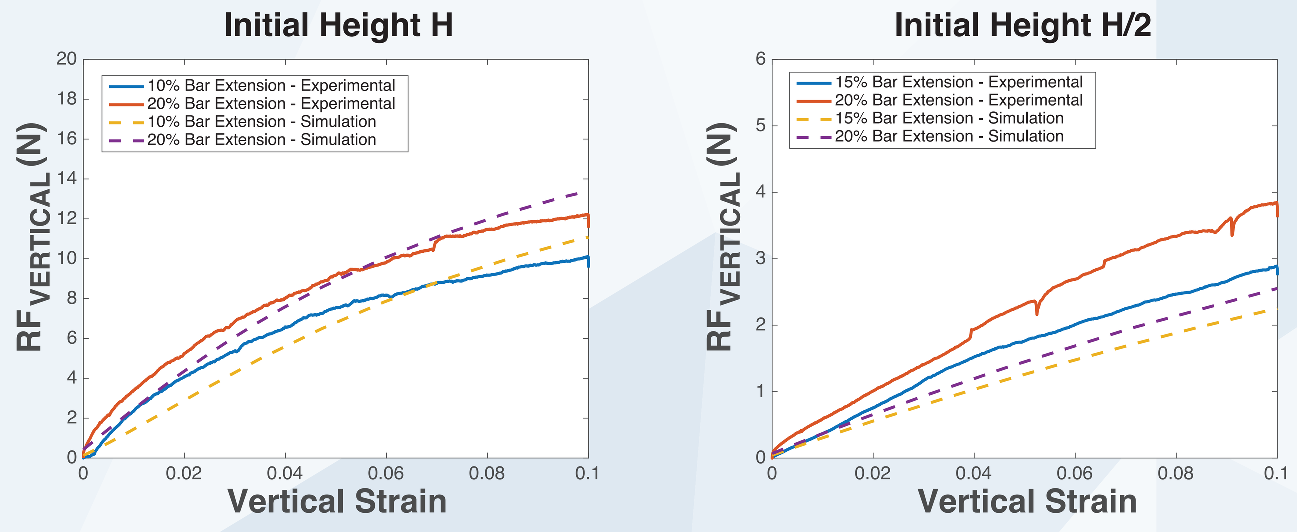

Figure 9: *Effective force in tensegrity prism under uniaxial compression: experimental and simulated results.*

Future Work

- Improve tensile element design to reduce tearout.
- Conduct FE simulations with hyperelastic material properties in tensile elements.
- Quantify effect of friction on load capacity and deformation characteristics of tensegrity prism.
- Conduct analytical and experimental analysis of alternative tensegrity designs including icosahedron and spine model.

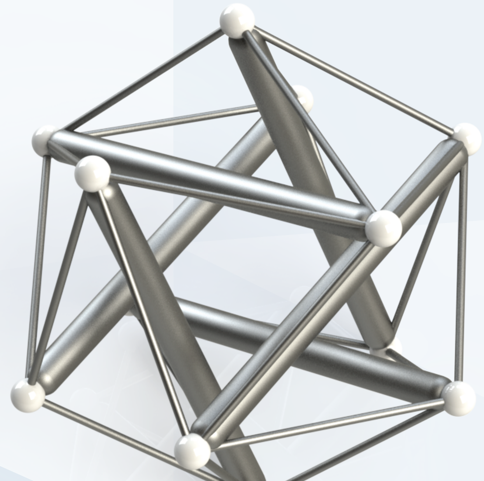

Figure 10: *Solidworks model of tensegrity icosahedron.*

References

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