

# Automated Model Construction & Simulation for Tensegrity Form-Finding

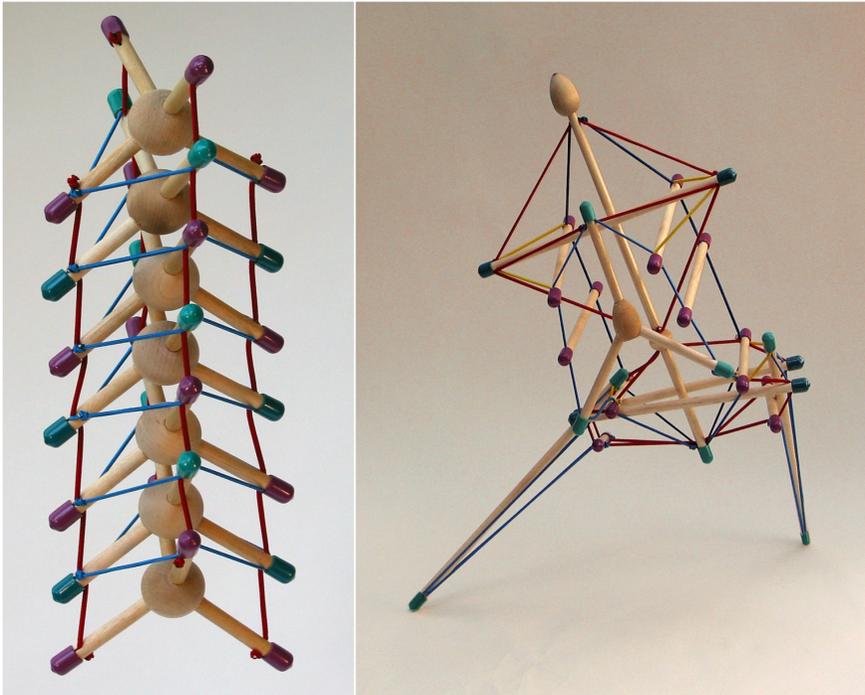
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## Introduction

Tensegrities are structures built from rigid struts and elastic cables.

- Hold their shape by balancing tension and compression.
- Can capture complex motion in a simple & elegant model.
- Can be used to model biological motion.

**Formal definition:** Tensegrity system is a system in a stable self-equilibrated state comprising a discontinuous set of compressed components inside a continuum of tensioned components. (Jáuregui 2004)



Models built by Tom Flemons

## Project Objectives

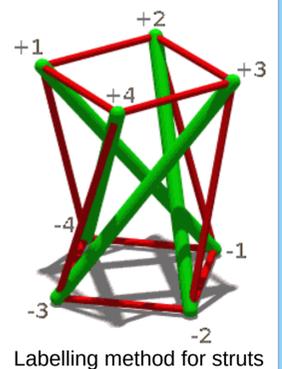
- Develop a method for automated simulation of tensegrity structures.
- Modify PushMePullMe software to support automated simulation.
- Investigate approaches to an evolutionary algorithm for tensegrity form-finding.

## Algorithm Design

Structures are defined in terms of their connectivity as an undirected graph – nodes have integer labels  $-i$  and  $+i$  for each strut in the structure. Edges of the graph describe the connectivity of cables to the ends of struts. PushMePullMe software was modified to support programmatic construction of models.

**Algorithm to evaluate fitness of a structure:**

- Randomly position and orient the struts in space.
- Attach cables to struts in simulation as specified by the graph.
- Enable physics simulation in PushMePullMe and allow the structure to reach equilibrium.
- Evaluate the structural properties of the generated structure using various fitness measures.
- Combine the various fitness measures into an overall fitness value.

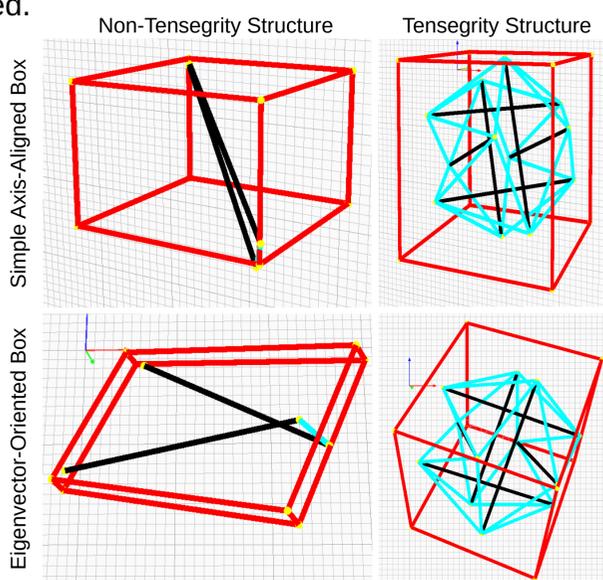


Labelling method for struts

The above algorithm is intended to be used as part of a larger evolutionary algorithm for tensegrity form-finding.

## Fitness Measures

- **Vertex Separation Measure:** Measures how “spread out” ends of struts are from one-another. The further they are spaced, the higher the overall score. Fitness is computed as a function of the mean euclidean distance from each vertex to the centroid of the structure. The mean euclidean distance is then scaled down by the longest strut length in the structure before being passed to a Sigmoid function to normalize the fitness value.
- **Bounding Box Measure:** Most non-tensegrities will collapse into a 2D structure when simulated. Estimating volume of the structure may give a good metric. The simple implementation creates a box aligned with the  $[x,y,z]$  axis. The improved implementation approach arbitrarily orients the bounding box to more tightly fit the data. A good orientation is determined by taking the eigenvectors of the covariance matrix of the vertices and using these eigenvectors as the basis for a new coordinate space in which the box size and position is computed.



## Discussion

- A reliable method for simulation of strut and cable models from only a description of connectivity was developed.
- Modifying the PushMePullMe software was a major challenge to this project, as the source code had dozens of packages and no documentation. A significant portion of the project was spent learning the inner workings of the software and then modifying the software to suit the needs of this project.
- A literature review was conducted and a proposal for implementing an evolutionary algorithm for tensegrity form-finding will be included in the project report.
- 4 additional fitness measures were planned and will be included in the project report:
  - Minimal/Maximal Cabling Fitness Measure
  - Strut Separation Fitness Measure
  - Tension/Compression Equilibrium Fitness Measure
  - Cable Net Enclosing Struts Fitness Measure
- Future work could include:
  - Adding new structure graphs to the library of tensegrity graphs developed for this project.
  - Developing new fitness measures for evaluating candidate structures
  - Implementing a genetic algorithm to generate structure graphs and evaluate their fitness.
  - Improving the method used to tension generated structures.

## References

- Jáuregui, V. G. (2004). Tensegrity structures and their application to architecture: MSc Thesis, Architecture. Queen's University Belfast.
- Paul, C., Lipson, H., & Cuevas, F. J. (2005). Evolutionary form-finding of tensegrity structures. Proceedings of the 2005 Conference on Genetic and Evolutionary Computation - GECCO 05.
- Benjamin Bach, André Spritzer, Evelyne Lutton, Jean-Daniel Fekete. (2012). Interactive Random Graph Generation with Evolutionary Algorithms. W. Didimo and M. Patrignani. Graph Drawing, Berlin, Germany. Springer LNCS, Vol. 7704, pp.541-552.
- Yamamoto, M., Gan, B.S., Fujita, K., Kurokawa, J. (2011) A genetic algorithm based form-finding for tensegrity structure. Procidia Engineering, Vol. 14, pp. 2949-2956.