Tensegrity-Factory Challenge Notes

Introduction

This document contains references and notes for the Tensegrity-Factory Challenge. The current copy of that document is available at http://tensegrity-factory.com/factory.pdf . A current copy of these notes is available at http://tensegrity-factory.com/notes.pdf . More information is available online at http://tensegrity-factory.com .

Background

1. Amy Edmondson documents Snelson's invention of tensegrity models on p. 279 of her book "A Fuller Explanation" http://books.google.com/books?id=G8zttcNdKBAC&pg=PA279
2. Artist Kenneth Snelson's webpage is http://kennethsnelson.net . A wonderful book of the artist's work, "Kenneth Snelson: Forces Made Visible," was published in 2009. See http://www.amazon.com/Kenneth-Snelson-Forces-Made-Visible/dp/1555952437
3. Fuller's "Synergetics" was published in two volumes. It is out of print; used copies are available from Amazon and other booksellers. A complete copy of "Synergetics" is available for viewing online and download as PDF files. Chapters are available for download on the "print selection" tab at http://rwgrayprojects.com/synergetics/toc/toc.html
4. Buckminster Fuller's definition of "tensegrity" is provided in section 700.011 of "Synergetics": "The word tensegrity is an invention: it is a contraction of tensional integrity. [...] Tensegrity provides the ability to yield increasingly without ultimately breaking or coming asunder." See http://rwgrayprojects.com/synergetics/s07/p0000.html for the full definition.
5. Professor Ingber's Scientific American article, "The Architecture of Life", is available for download at http://web1.tch.harvard.edu/research/ingber/PDF/1998/SciAmer-Ingber.pdf . Ingber's research homepage at his lab is http://web1.tch.harvard.edu/research/ingber/ingber.html . If you look through his list of publications, "tensegrity" first appeared in the title in a 1985 paper.
6. Dr. Levin's website is http://biotensegrity.com . His papers "The Tensegrity-Truss as a Model for Spine Mechanics" and "The Scapula is a Sesamoid Bone" are highly recommended. Information in the "commentary" section and the lecture on his DVD address the stress/strain response of tensegrity. Levin's papers demonstrate the fundamental inadequacy of a compression-loaded "levers and hinges" model to explain our posture and movement and why tensegrity is a much better fit.
7. Dr. Levin collaborates with tensegrity model-maker Tom Flemons (http://intensiondesigns.com). Flemons is one of the world's most prolific designers of original tensegrity structures. His models show the functional movement of the human body. Flemons was the inventor of the Skwish toy: http://www.amazon.com/Manhattan-Toy-200980-Skwish-Classic/dp/B000GI0S4E .

The Riddle of Tensegrity

1. The behavior of a high-tension tensegrity icosahedron is described in 724.32 of "Synergetics". A YouTube video showing this behavior and the pertinent sections from "Synergatics" is available at "How a Tensegrity Behaves Under Stress" (http://www.youtube.com/watch?v=K1NsRlhxuwE).
2. Snelson's "Needle Tower" is can be seen in the sculpture garden of the Smithsonian Institution's Hirshhorn Museum Sculpture Garden. An unnamed Snelson tabletop sculpture is on display inside the Hirshhorn. See http://hirshhorn.si.edu/search.asp?search=snelson
3. An alternative text to "Synergetics" is "A Fuller Explanation" by Harvard Professor Amy C. Edmondson. AFE is available as a print or e-book; it is also freely viewable in its entirety on Google Books: http://books.google.com/books?id=G8zttcNdKBAC&printsec=frontcover

4. The second edition of “Anatomy Trains” was published in 2009. A 20-page summary of the first edition is available at http://www.anatomytrains.com/uploads/rich_media/AnatomyTrainsOverview.pdf .
5. Tom Flemons sells a variety of assembled functional anatomical models at his website http://intensiondesigns.com . The Skwish toy that Flemons designed over 20 years ago is available from the infant section of may toy stores. These are low-tension models.
6. Bodyworker and Structural Integration instructor Eli Thompson makes and sells a tensegrity icosahedron construction kit on his website: http://elithompson.com/tensegrity.html . These are low-tension models.
7. Artist Bruce Hamilton is the only merchant selling high-tension tensegrity icosahedron models (http://www.tensiondesigns.com/kits.html). His “vector equilibrium” is a tensegrity icosahedron kit. His models are both functional and quite beautiful.
8. Engineer Mitch Amiano shows his “MAC Method” for constructing a high-tension tensegrity at http://www.unityisplural.com/2008/01/tensegrity-model.html .
9. The “borrowing” of the word “tensegrity” is described on http://castaneda.com : “Tensegrity is the name given to the modern version of the magical passes: positions and movements of body and breath that were dreamt and stalked by men and women seers who lived in Mexico in ancient times, and taught to [list of individuals].” “The word Tensegrity is borrowed from an architect, engineer, scientist and dreamer whom Carlos Castaneda admired: R. Buckminster Fuller”.
10. In 1997, The US Patent and Trademark Office granted a trademark to the publisher of Castaneda’s CDs, DVDs, and VHS tapes: http://tess2.uspto.gov/bin/showfield?f=doc&state=4006:q78oc.2.1 Seeking a trademark is not behavior consistent with an organization that has “borrowed” a word.
11. The definition is further muddled by quotes on the video publisher’s website. On http://www.cleargreen.com/english/main.cfm , the publisher claims: “Tensegrity refers to the interplay of tensing and relaxing the tendons and muscles, and their energetic counterparts, in a way that contributes to the overall integrity of the body as a physical and an energetic unit.” Castaneda’s “tensegrity” seems to qualify as body/mind exercises, but there is no explanation why other body/mind disciplines could not (and do not) achieve exactly the same results.

The Challenge

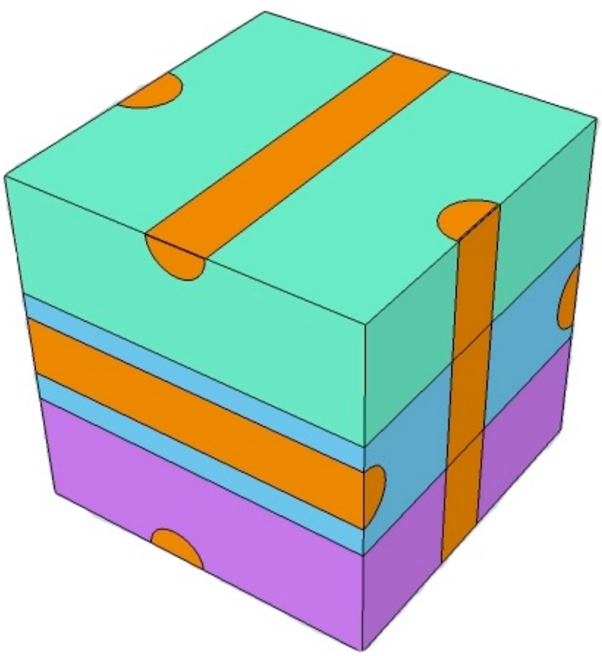


Figure 1

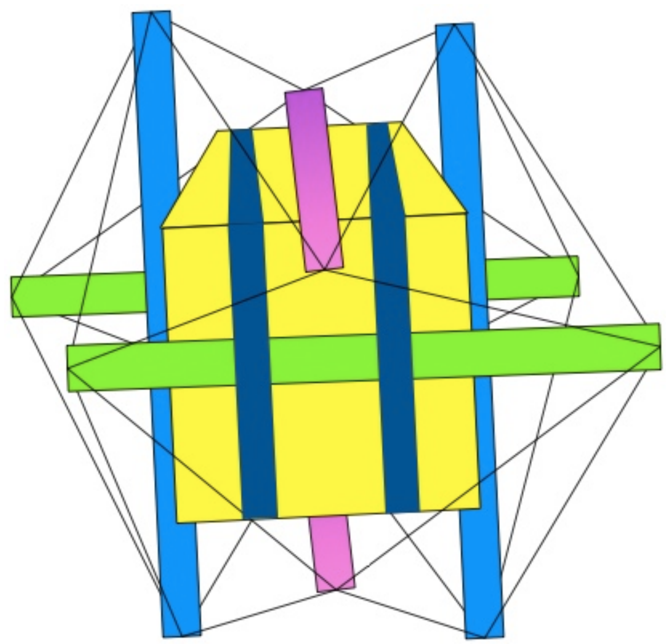


Figure 2

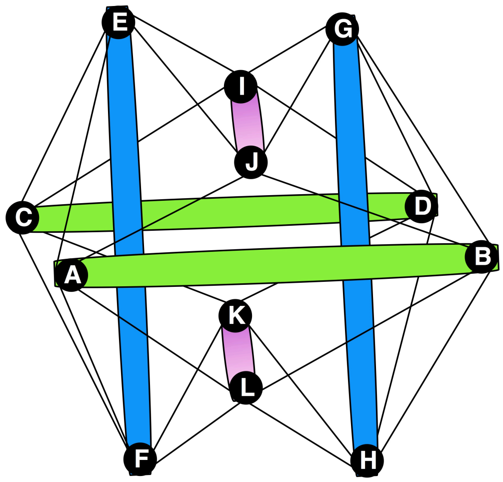


Figure 3

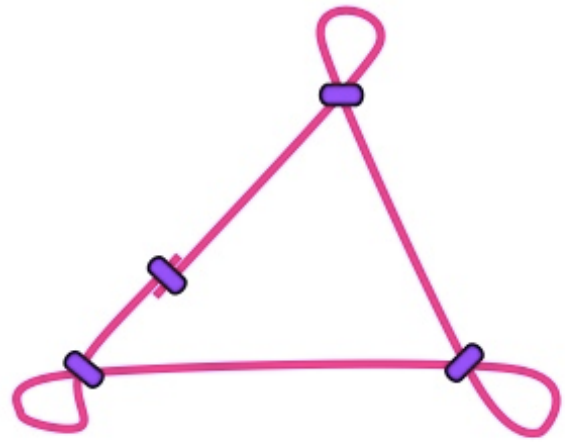


Figure 4

1. Figure 1 shows a solid cube modified to be used as a jig to help build the icosahedron. The icosahedron is built around this jig in the cube-shaped hole in the middle of the structure (see Figures 2 and 3). The cube must be removed after the icosahedron is constructed; one way to do that is shown in Figure 1: cut the cube into 3 slices. During tensegrity assembly, those 3 slices of the cube are held together with a pair of velcro straps. After assembly, the velcro straps are removed and the slices are removed one by one from the center of the structure.
2. Figure 1 shows a semicircular groove cut into the center of each face of the cube. Those grooves can be cut with a circular router bit; the groove should have the same diameter as the round struts. During assembly of the tensegrity, the struts are laid in the grooves.
3. The struts are secured to the jig with a pair of velcro straps. Figure 2 shows a pair of dark blue straps holding the two green struts to the cube. There are a total of six straps; each pair of straps secures two struts to the cube.
4. For material more expensive than wood, the jig could be a hollow. Faces of a hollow cube could be fabricated with a 3D printer (like http://makerbot.com/). As with a solid cube, the hollow jig should have guides for to hold the struts in a fixed position. The jig should break down into removable parts once the tensegrity has been assembled.
5. Once the struts have been secured to the cube, the tension elements are threaded. Figure 3 shows shows a way to thread the 24 tensile elements with a single thread. Here is one pattern that works:
   A - E - C - I - E - J - G - I - D - G - B - J - A - F - C - K - F - L - H - K - D - H - B - L - A
   Note: the endpoints A, B, J, and L are in the foreground; the endpoints C, D, I, and K are in the background.
6. The difficulty of using a single thread design: the string must freely move through a hole/slot on each endpoint while the tensegrity is being threaded. After the tensions are balanced, the string must be robustly secured at each of those end-points. I have located no off-the-shelf hardware that can would do the job.
7. Bruce Hamilton's and Mitch Amiano's "MAC Method" both show the second suggested general approach: a pre-fabricated network of 24 tensile segments that is attached to the struts. This has the advantage that no scaffolding/jig is needed. However, the web would be quite complex for someone new to tensegrity to fabricate. Hamilton's design uses 48 total crimps: 2 crimps per tensile segment.
8. Figure 4 shows a hybrid between these two designs: 8 tension-triangles. The purple bands represent beading crimp tubes and crimping tools (available from sources like http://www.beadalon.com and http://jinkaifishingline.com/). The loops are for hooking over posts on the end-points; the end-point triangles are AEJ, BGJ, CEI, DGI, AFL, BHL, CFK, and DHK (see Figure 3). While the loops would have to be measured and crimped precisely, they would be far easier to create than the 24-thread interconnected tensile web.
9. For this hybrid approach, wooden dowels with small wood screws could be used at the end-points. The three small crimped loops should only be large enough to hook over a wood screw. Crochet hooks could be used to secure a triangle to the structure. The hybrid model parts are inexpensive: 6 dowels, 12 screws, 48 beading crimps, and ~250" of monofilament line.

Future Designs

I believe a single thread design would be best, provided a means can be found to freely thread the string and then robustly secure it at each of the 12 end-points. Off-the-shelf hardware may exist that does that, or a rigid end-cap that could crimp or otherwise clamp the string at each end of the struts could be manufactured.

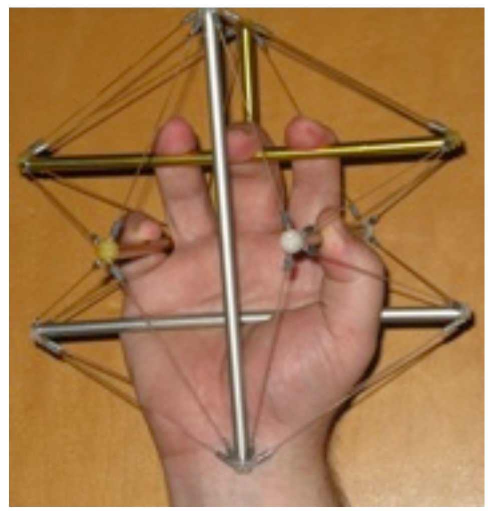
The design and manufacture of tensegrity models has been discussed over the months of July and August (2010) in a mailing list of Buckminster Fuller enthusiasts (archive at http://lists.sculptors.com/pipermail/geodesic/). One intriguing concept discussed there was an alternate way to construct a high-tension model that requires minimal to no scaffolding:

1. Create struts that can be expanded to be ~10% longer.
2. Attach and secure all the strings to the end-points.
3. Expand the struts to tension the lines.

A large expandable-strut tensegrity secured with a single line would be a powerful demonstration. Volunteers could hold the struts in place while the single line was threaded and secured. The struts would then be expanded to fully deploy the tensegrity.

Non-Factory Tensegrity Models

1. Tiny tensegrity artwork would be wonderful! The same threading patterns and jigs for the tensegrity icosahedron could be extended to tensegrity masts. View the other models on Bruce Hamilton's webpage.
2. For Halloween costume ideas, consult Flemons's biological models at http://intensiondesigns.com . For creatures with functional movement, have one tensegrity icosahedron at each major joint. Bones can be shown as struts that extend from one icosahedron to another.
3. Flemons also has a variety of non-biological models on his site: furniture, a playground-sized tensegrity structure, and a tensegrity ring.
4. Images at http://www.oobject.com/category/wonderful-tensegrity-structures/ show several pieces of tensegrity art, including a tensegrity icosahedron ring.



Fabricating a costume: a tensegrity at the hands and every major joint.

Benefits

1. A tensegrity-building exercise could be used as a team exercise in a classroom or at a meeting. Teams of 5-6 could work together to make a model for each team member.
2. In his book "Sync" (http://www.amazon.com/Sync-Order-Emerges-Universe-Nature/dp/0786887214) and his course on Chaos http://www.teach12.com/ttcx/coursedesclong2.aspx?cid=1333), Professor Steven Strogatz encourages everyone to explore nonlinear systems. A critically-tensioned tensegrity model is a small self-contained nonlinear system: you can feel the nonlinear response when you contract the structure.
3. Thomas Myers, author of the book "Anatomy Trains", has a separate essay "Spatial Medicine" on his website (http://www.anatomytrains.com/explore/spatialmedicine/expanded). Myers provides a straightforward and commonsense way to think about our health in terms of the three fractal/pervasive networks in the human body. Meyers's writing there and in "Anatomy Trains" shows what is possible when one explores nature through the lens of a tensegrity model.
4. Cellular tensegrity is well-accepted by academia, but little published research exists on musculoskeletal tensegrity. An explosion in the number of critically-tensioned tensegrity models in the world could ignite a revolution in our understanding—and appreciation—of human structure.