Tension and Compression are balanced in the Buckminsterfullerene structure and the Spaceship Earth

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Rule to Build By:

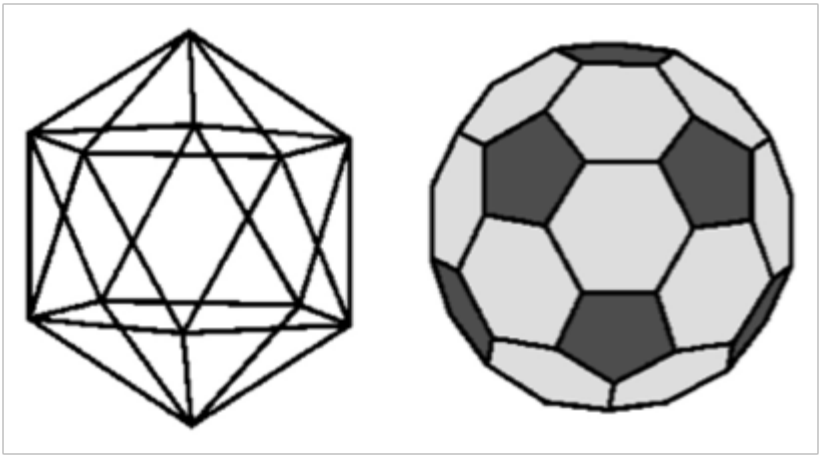
- The architectural principle that is shared between the human-built structure and the nature-built structure is principle #2 “To construct self-support structures, balance forces of tension and compression” (Morris 2010).

What:

- The human-built structure is The Spaceship Earth at Disney’s Epcot (Craven 2010). The nature-built structure is a Buckminsterfullerene, $C_{60}H_{60}$. Both these structures uphold principle #2.

How:

- Buckminsterfullerene is the smallest fullerene structure of the fullerene family with the formula $C_{60}H_{60}$ (Kroto). A fullerene molecule is a very unique structural design because it has very high stability allowing the fullerene to partake in various strenuous reactions and be unchanged (Yarris, 1993). The buckminsterfullerene is naturally found only in small quantities, but synthesizing a buckminsterfullerene has now been perfected to doable synthesis (Hare). The buckminsterfullerene is a pure carbon form consisting of repeating, cyclical covalent bonds (Kroto). Each carbon in the buckminsterfullerene has only three bonds to it, which is problematic since a carbon must have four bonds. The buckminsterfullerene solves this with using the “aromatic rule” of having a double bond (Fryhle, 2006). The buckminsterfullerene consists of repeating pentagons and hexagons to form a near-perfect spherical shape. In order for a fullerene to be a complete sphere is must have no more or no less than 12 pentagons (Euler’s Formula). Other fullerene molecules, such as C70 must also have 12 pentagons but the number of hexagons can vary. In the case of the buckminsterfullerene, there are 20 hexagons (Lenhert). The pentagons in the buckminsterfullerene never touch each other. The shape of a buckminsterfullerene greatly resembles a soccer ball. And if you can imagine a soccer ball, each pentagon (usually colored black) becomes a vertex (Fullerene Science Module).



- Figure 1-1: The figure on the right is a truncated icosahedron that is the basic structure of a buckminsterfullerene. The figure on the left is a soccer ball. Each of the black pentagons represents a vertex on the truncated icosahedron. http://www.chemistry.wustl.edu/~edudev/Fullerene/structure.html

The more basic structure is called a truncated icosahedron and it consists mainly of triangles (Weisstein). The buckminsterfullerene is so stable because its pentagonal shapes are built from triangles. Triangles have a unique property in that they can balance their tension and compression by evenly distributing the weight across their three vertices. When multiple triangles are assembled together, the tension on one triangle is balance by the resisting compression on the vertices of the adjacent triangle (Teacher's Doman: Train Truss Animation). It would take a tremendous force to break a buckminsterfullerene. To give an idea of how stable they are, if you were to slam a buckminsterfullerene against a steel surface at 17,000 miles per hour, it would bounce off unchanged (Yarris, 1993).

As mentioned before the pentagons and hexagons in the structure follow the aromatic's rule. There are alternating double bonds in the structure or resonance structures. The electrons are constantly changing in a buckminsterfullerene, which allows the structure to be very uniform. Double bonds normally shorten the bond, which would ruin the stability of the buckminsterfullerene since the triangular structures would need equal sides but thanks to resonance theory, there is an even distribution of the double bonds. The Spaceship Earth is a geodesic dome and one of the key differences between a geodesic dome and a fullerene is what shapes are used in the structure. In The Spaceship Earth, the structure is built from using repeating triangles instead of pentagons and hexagons (Craven 2010). The structure follows the same design benefit in that the tension and compression exerted on the building is balanced creating an extremely strong structure. The use of actual triangles allows the tension of vertex to balance the compression on the adjacent vertex. This evenly distributes the weight of the building throughout the whole building. The Spaceship Earth can therefore withstand high outer wind forces (Geodesic Domes History). The Spaceship Earth is one of the most unique geodesic domes in the world because it is one of the few that is a full sphere made up of 11,324 individual triangles but still only 12 pentagons (Spaceship Earth)!

Why:

- Fullerenes have an amazing evolutionary design in their use of shapes. Because of their ability to balance the tension and compression exerted on the molecule, all fullerenes have amazing strength and stability (Kroto). So far, Earth has only produced three typed of carbon allotropes, diamond, graphite and fullerenes. The buckminsterfullerene has an evolutionary advantaged to most carbon compounds since it is so stable it is very difficult to destroy. It is theorized that fullerenes could play a heavy role in future evolution since their survival is very likely (Koto). Other evolutionary advantages come with buckminsterfullerene's cage structure. It has been discovered that fullerenes are capable of housing or encapsulating atoms inside their cage (Koto). Despite the buckminsterfullerene's stability, it can still undergo a variety of reactions such as halogenation, electrophilic addition and substitution (Koto). Buckminsterfullerene can also be dissolved in an array of organic solvents including water (Koto). Buckminsterfullerene has many evolutionary advantages that will allow the structure to survive extreme weight/pressure but can still partake in many life-sustaining reactions.

As for The Spaceship Earth structure in Epcot Park, there are many green advantages and safety advantages that come with the design. The Spaceship Earth requires less building material because of the even distribution of weight around the surface area of the building. There is no need for internal support such as beams or columns (Dome Incorporated). All geodesic domes, including The Spaceship Earth offer the solid protection against the most violent weather. Along with the even distribution of weight, domes also have a very low-center of gravity (Geodesic Domes History).

Figures:

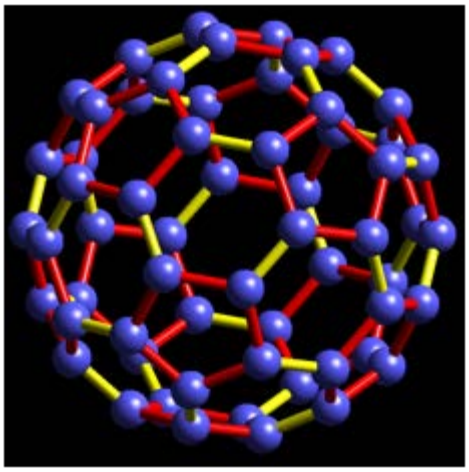


Figure 1-2: Shows a single-bond ball and stick model of Buckminsterfullerene ($C_{60}H_{60}$). Each of the blue balls represents a carbon. It is difficult to count but there are 12 pentagons and 20 hexagons present. Buckminsterfullerene follows principle #2 of the "rules-to-build-by" (Morris, 2010) http://www.godunov.com/Bucky/buckyball-2.gif

Figure 1-3: The Spaceship Earth is a structure at Disney World's Epcot Park. This structure is a geodesic dome that is made up of 11,324 individual triangles and follows principle #2 of the "rules-to-build-by" (Morris, 2010). http://www.csc2.ncsu.edu/conferences/esem/?p=location

References:

"Carbon 60." *Home Page of Solina - R. W. Henson*. Web. 07 Dec. 2010. <http://www.solina.demon.co.uk/c60.htm>.

Craven, Jackie. "Spaceship Earth - Buckminster Fuller and Spaceship Earth Geodesic Domes." *Architecture and House Styles - Architecture and House Styles and Home Design*. Web. 06 Dec. 2010. <http://architecture.about.com/od/geodesicdomes/a/spaceship.htm>.

"ESEM 2009." *Area Attractions and Information*. 2009. Web. 08 Dec. 2010. <http://www.csc2.ncsu.edu/conferences/esem/?p=location>.

"Euler's Formula." *Welcome | Department of Mathematics*. Web. 06 Dec. 2010. <http://www.math.ohio-state.edu/~fiedorow/math655/Euler.html>.

Fryhle, Craig B., T.W. Graham Solomons. *Organic Chemistry*. Hoboken: John Wiley & Sons, Inc, 2006.

"Fullerene Science Module." *Department of Chemistry*. Web. 05 Dec. 2010. <http://www.chemistry.wustl.edu/~edudev/Fullerene/structure.html>.

"Geodesic Domes History." *Dome Inc. Geodesic Dome Home Builders*. Web. 06 Dec. 2010. <http://www.domeincorporated.com/geodesic-domes-history.html>.

Hare, Jonathan P. "The Discovery of C60, Buckminsterfullerene & The Fullerenes." *The Creative Science Centre*. Web. 06 Dec. 2010. <http://www.creative-science.org.uk/c60info.html>.

Kroto, Harold W., and David R.M. Walton. "Fullerene (chemical Compound) -- Britannica Online Encyclopedia." *Encyclopedia - Britannica Online Encyclopedia*. 2010. Web. 06 Dec. 2010. <http://www.britannica.com/EBchecked/topic/221916/fullerene>.

Lenhert, Steve. "Fullerene." *Nanotechnology Encyclopedia*. Web. 05 Dec. 2010. <http://www.nanoword.net/library/def/Fullerene.htm>.

Morris, Robert. "Living Architecture." Wheaton College, 2010. Web. 4 Dec. 2010. <http://acunix.wheatonma.edu/rmorris/la/>.

Pevzner, Boris. "Buckminsterfullerene." *Godunov Enterprises LLC - Innovative Technology Ventures*. 1996. Web. 06 Dec. 2010. <http://www.godunov.com/Bucky/fullerene.html>.

"Spaceship Earth." *Walt Disney World Resort*. Web. 06 Dec. 2010. <http://disneyworld.disney.go.com/parks/epcot/attractions/spaceship-earth/>.

"Teachers' Domain: Train Truss Animation." *Teachers' Domain: Home*. Web. 06 Dec. 2010. <http://www.teachersdomain.org/asset/phy03_vid_bbtrussanim/>.

Weisstein, Eric W. “Truncated Icosahedron.” From *Math World*-A Wolfram Web Resource. 06 Dec. 2010. http://mathworld.wolfram.com/TruncatedIcosahedron.html.

Yarris, Lynn. "Carbon Cages: LBL Scientists Study Fullerenes." *Lawrence Berkeley National Laboratory*. 1993. Web. 04 Dec. 2010. <http://www.lbl.gov/Science-Articles/Archive/fullerenes.html>.