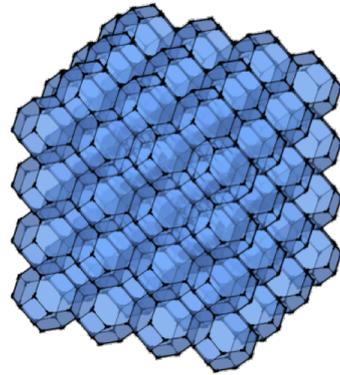


Foam structures for encapsulating regolith in additive manufacturing applications

Dr Gareth Morris, MEng, PhD, CEng (IMechE)

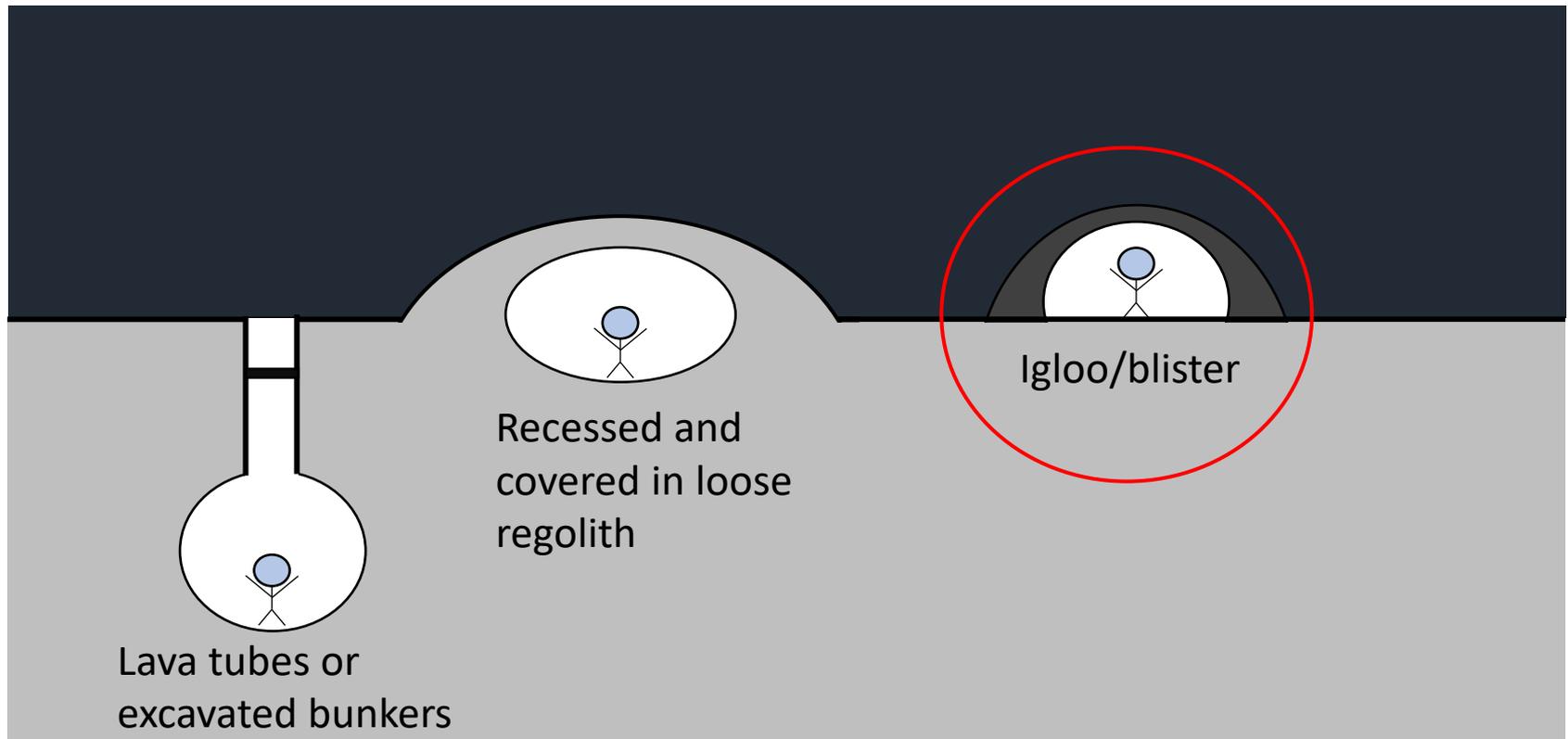


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Shielding a Lunar base

- Lunar environment is harsh
 - Several sources of damage
 - Need to protect crew and equipment
- Radiation
 - Cosmic Rays
 - Solar Flares
- Impacts
 - Micrometeorites
 - Meteorites
- Thermal fluctuation
 - Day night cycle

Shielding options

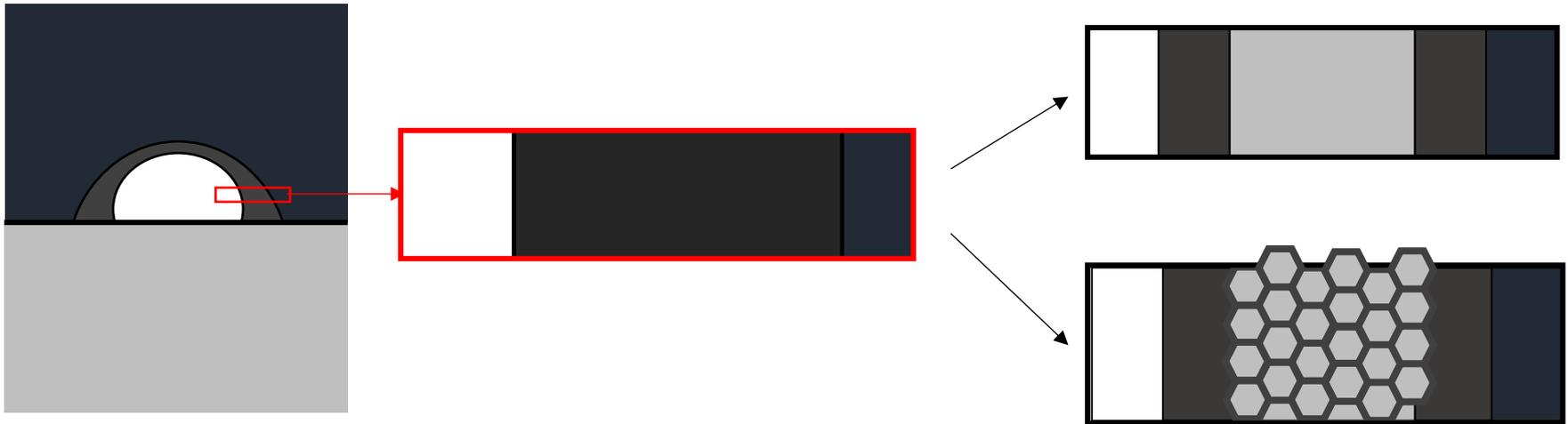


Additive manufacturing methods

- Melt it
 - Sintering
 - Casting
- Bond it
 - Chemical bonders
 - Cementitious extrusion
- Resource is required to fix the regolith in place
 - Energy
 - Adhesive
 - Water

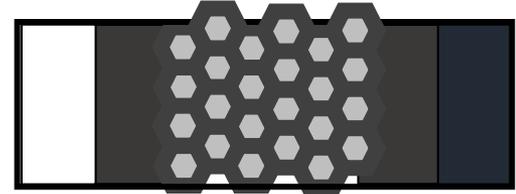
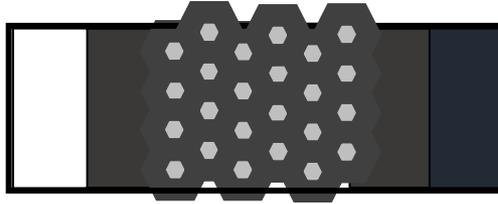
Structure of the shield

- It's there to put mass in the way

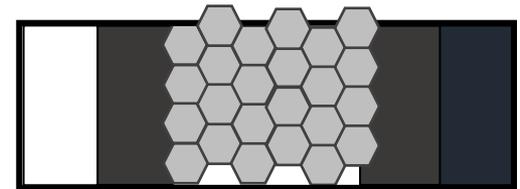
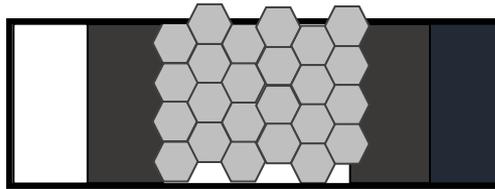
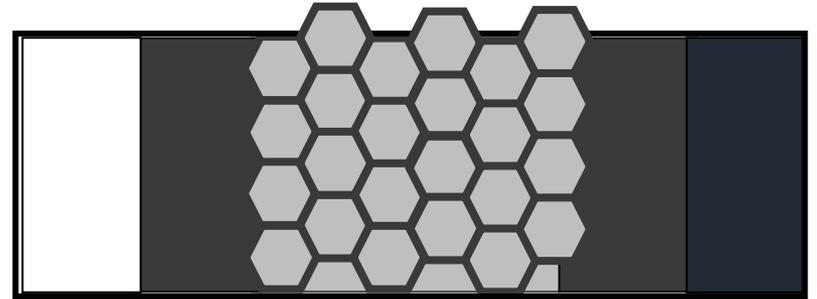
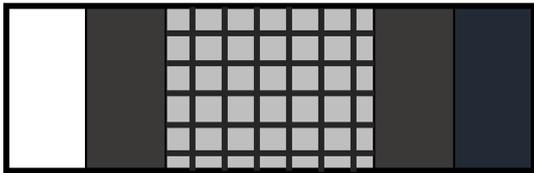


- The shield only needs to constrain the regolith
- A cellular structure requires less bonded material but allows the same mass of shield
- G. Cesarretti *et al.* **Acta Astronautica 93 (2014) 430-450**

Cellular networks

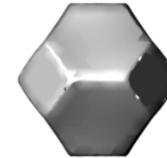


Cell wall thickness affects how much material needs to be bonded

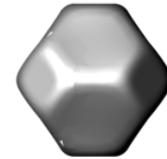
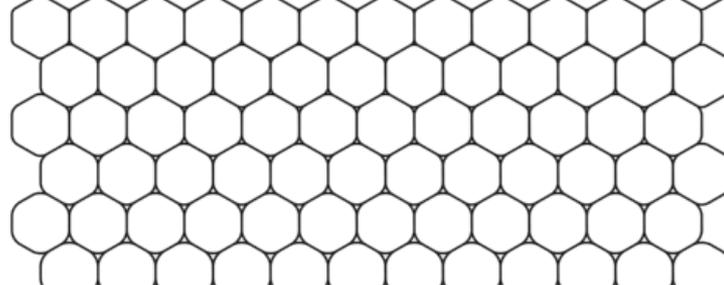


Foam structure - cells

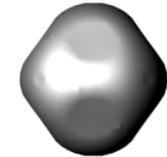
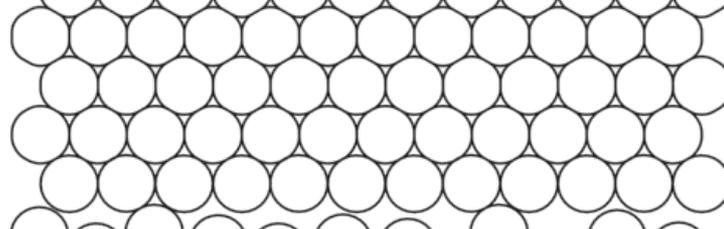
Dry Foam



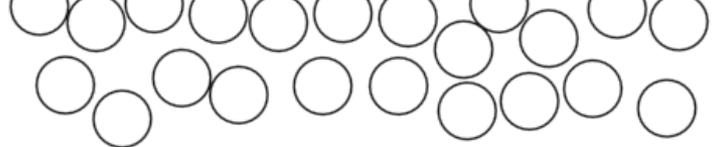
Polyhedral cells



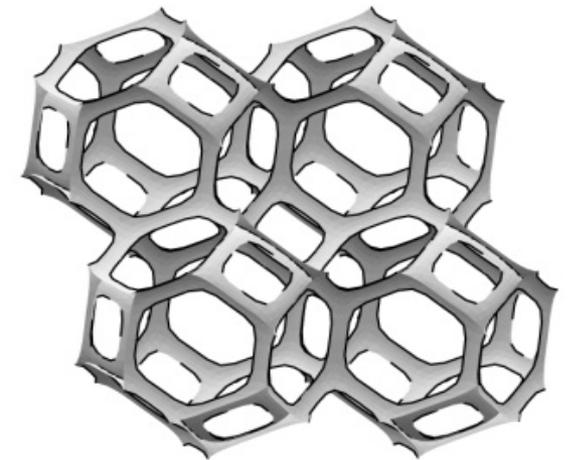
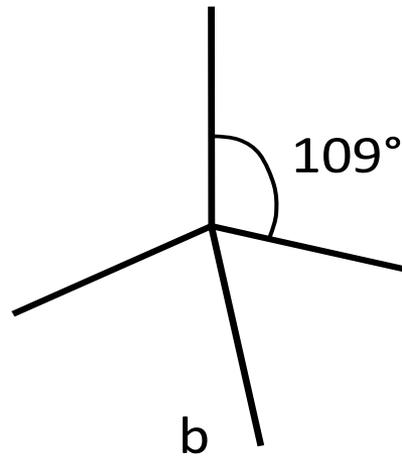
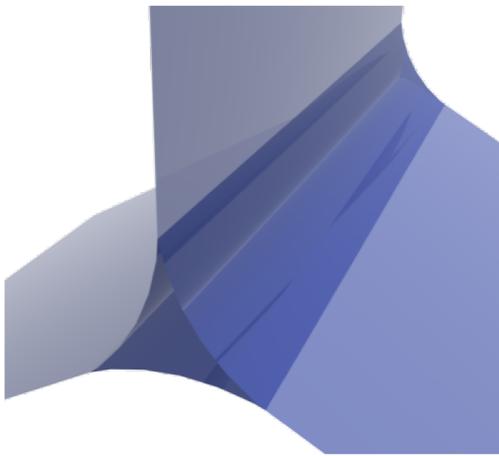
Wet Foam



Bubbly liquid

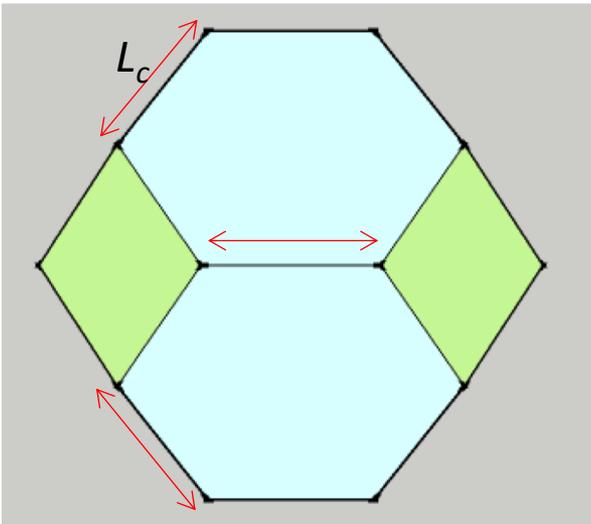
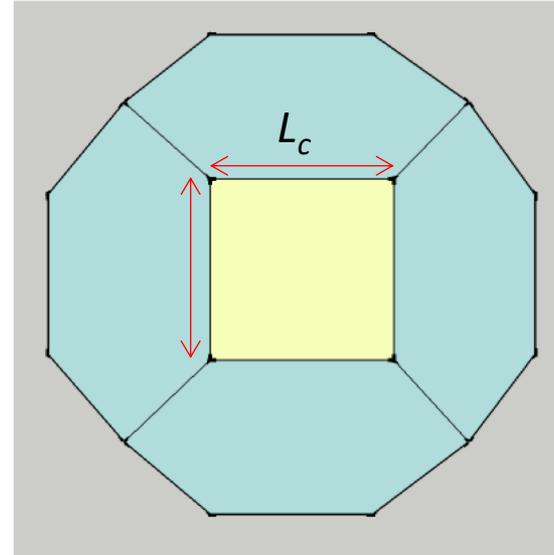
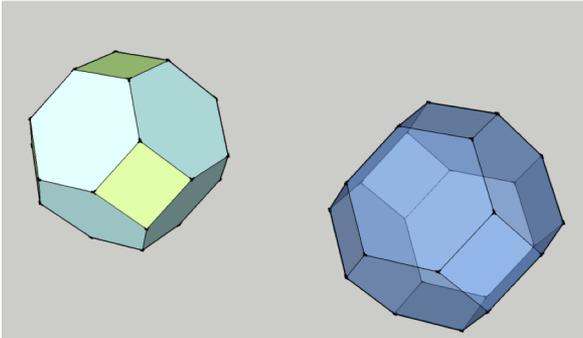
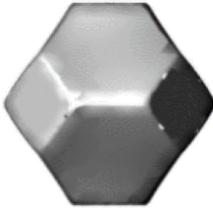


Foam structure – Plateau borders

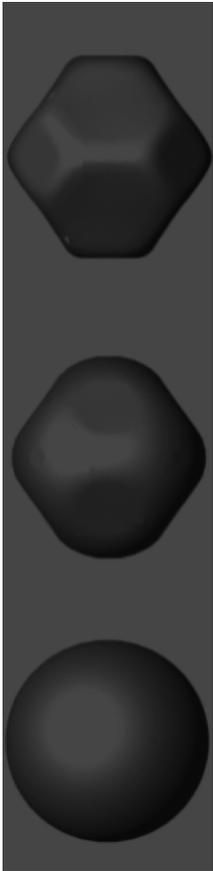


A network of Plateau borders in a regular foam generated using *Surface Evolver* (Brakke 1992)

Foam structure – Kelvin Cell

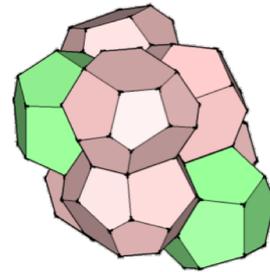
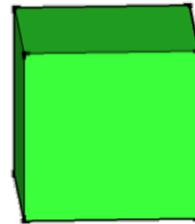
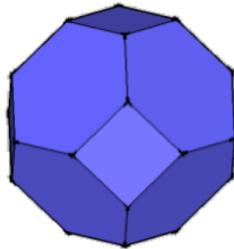
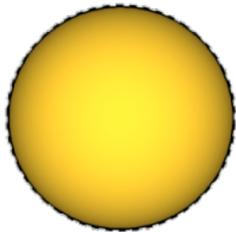


- L_c is the same for all edges
- Six squares
- Eight hexagons



Unit cells for construction

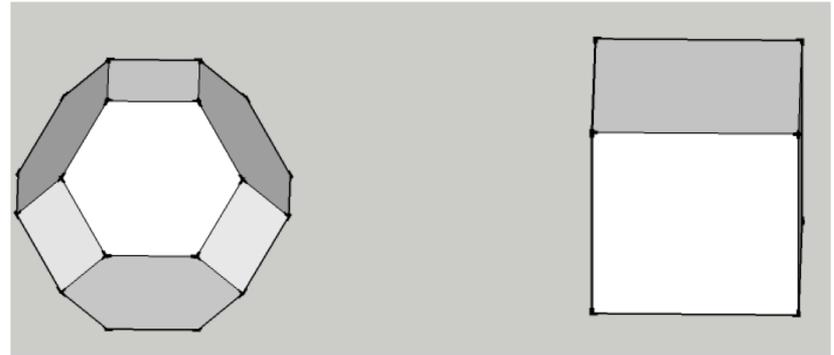
- Kelvin cell has 9.7% greater surface area than a sphere for the same volume.
- The surface area of the Kelvin cell is ~12% less than the cube for the same volume.
- Weire-Phelan structure has 0.3% less surface area than Kelvin



Cell comparison

- Kelvin cell

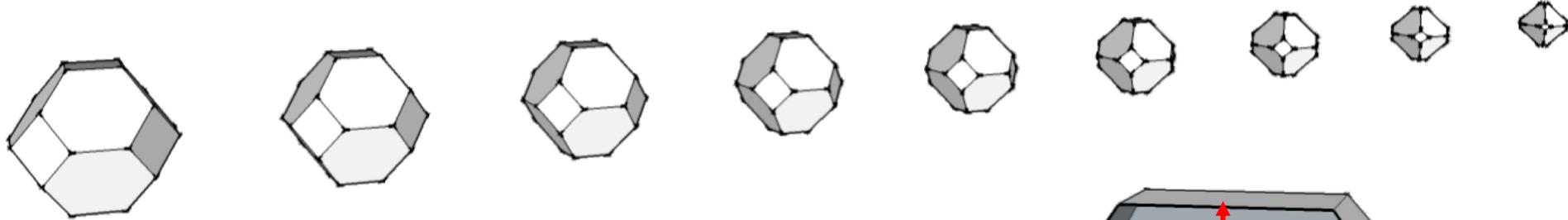
- L_c is 100 cm
- Cell width is 300 cm
- Unit cell is 0.0113 m^3



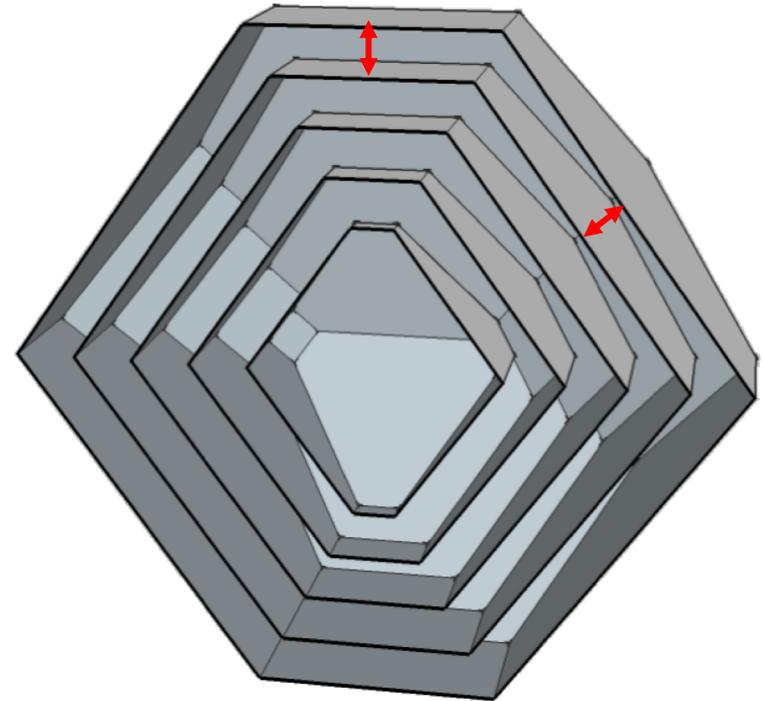
- Cube

- Edge is 224.5 cm
- Unit cell volume is 0.0113 m^3

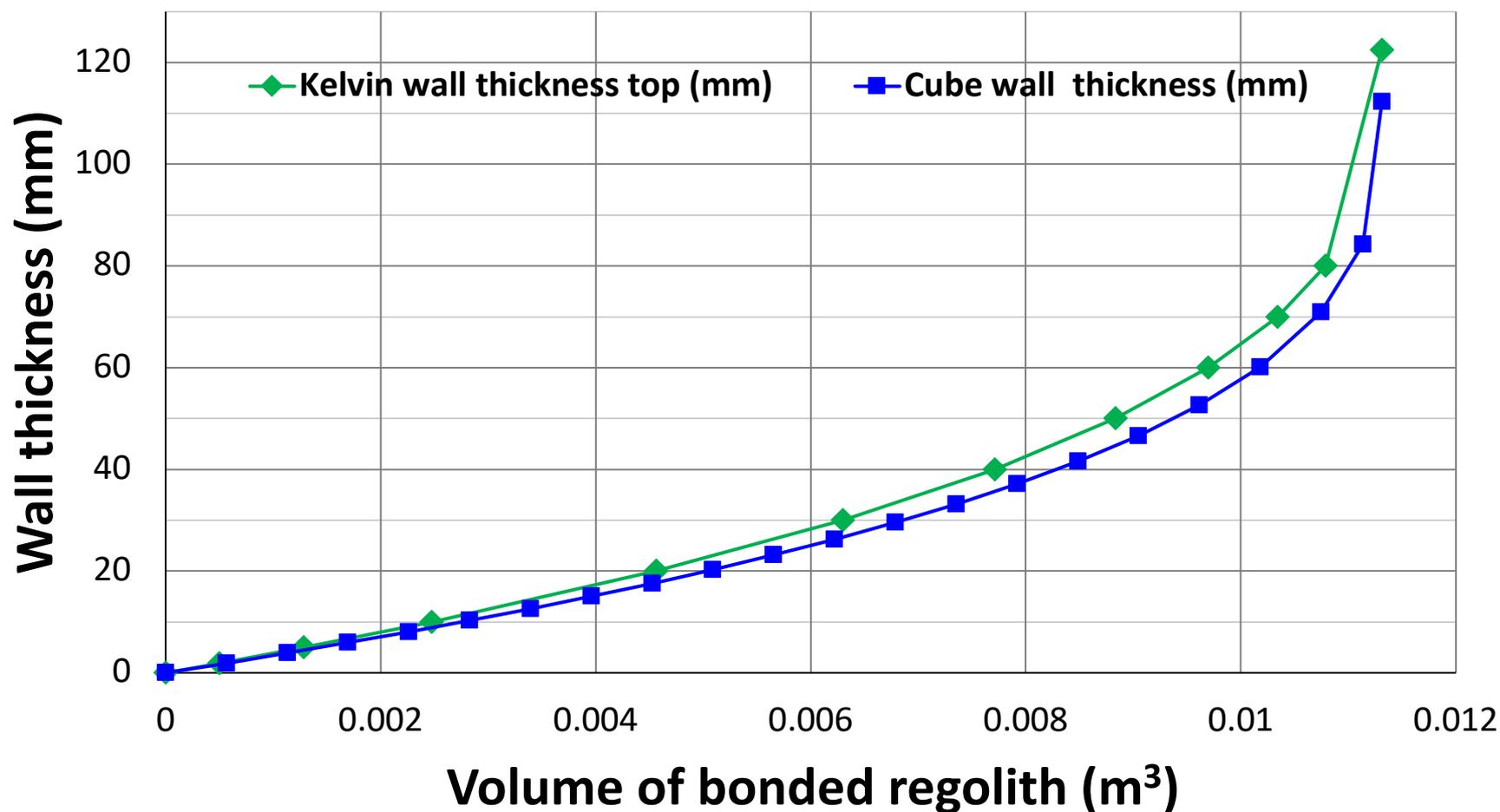
Calculating shell thickness



- Increase wall thickness uniformly
- Move facets, do not shrink cell
- Interior surface changes shape

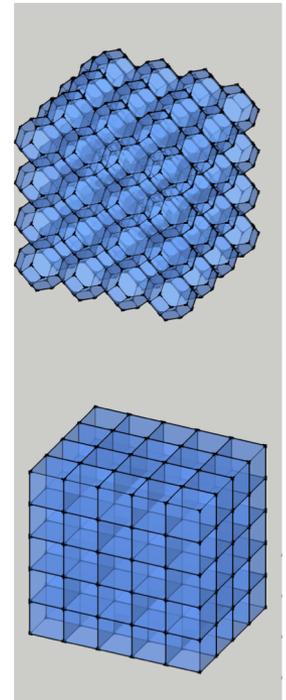
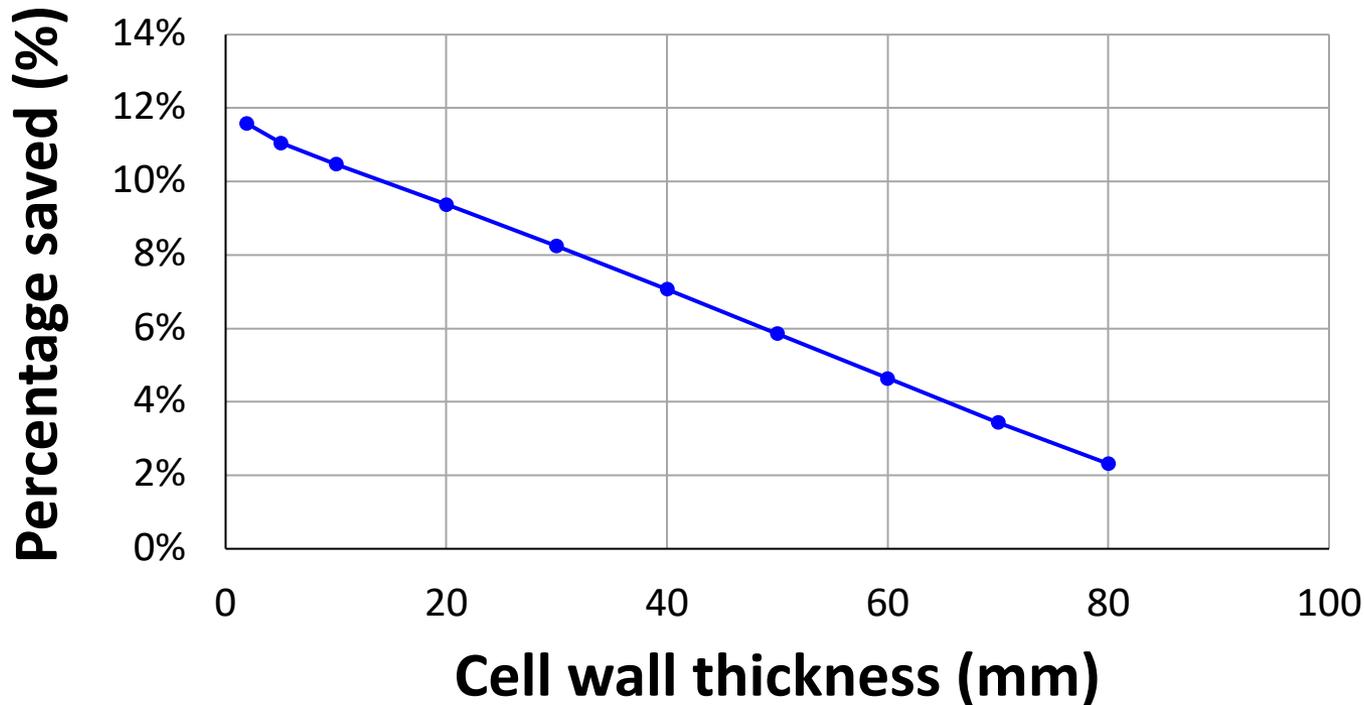


Wall thickness vs volume for cell



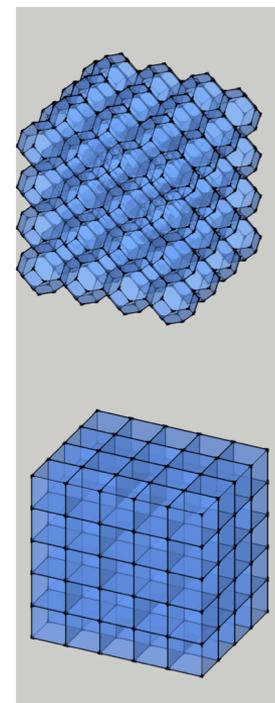
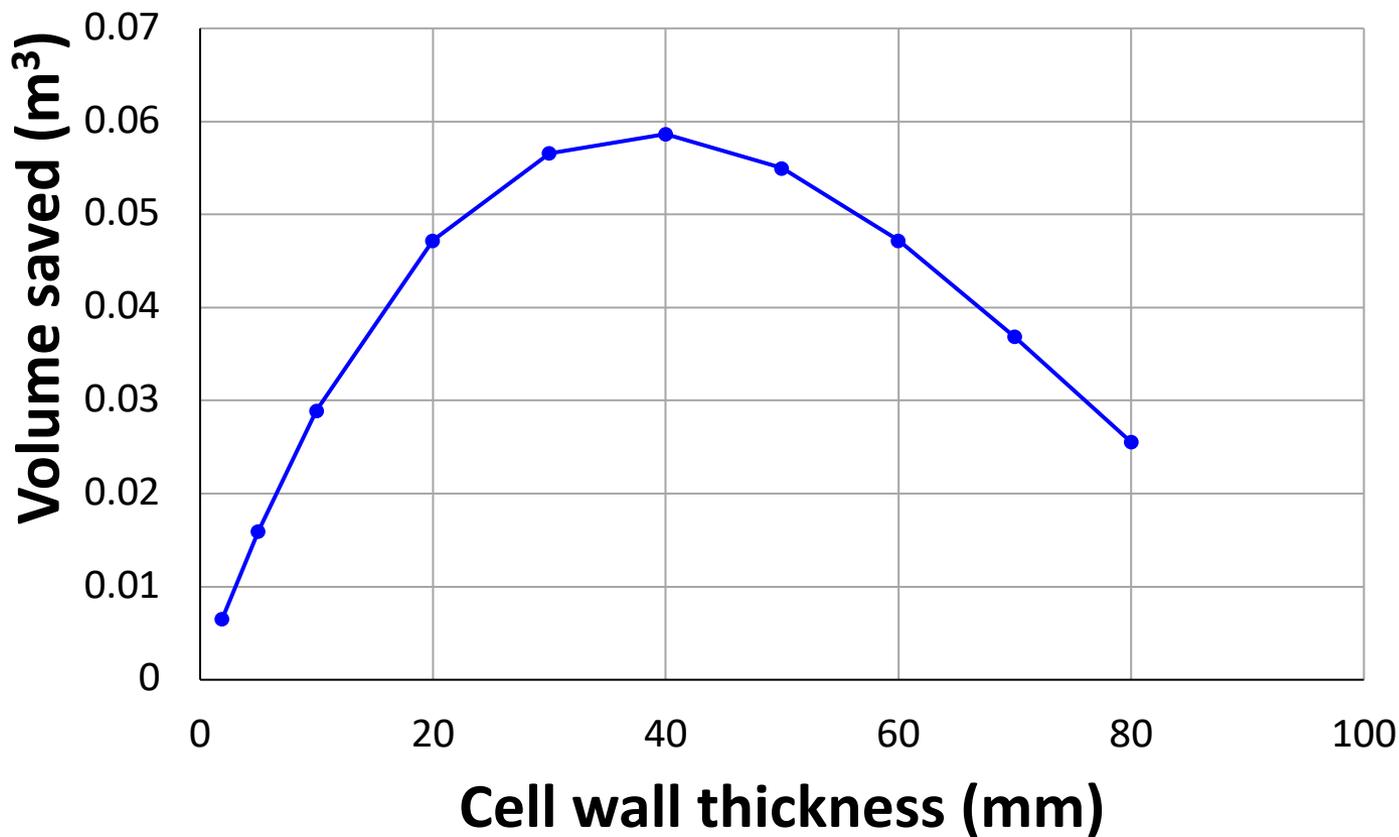
Volume saving for 100 cells

- 100 cells give a 1.13 m³ block (0.0113 m² cells)
- As the walls get thinner, savings tend towards the theoretical limit of 12%



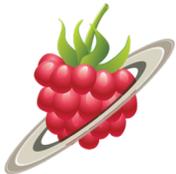
Volume saving for 100 cells

- As bonded volume decreases so too do savings in the amount of regolith to bond

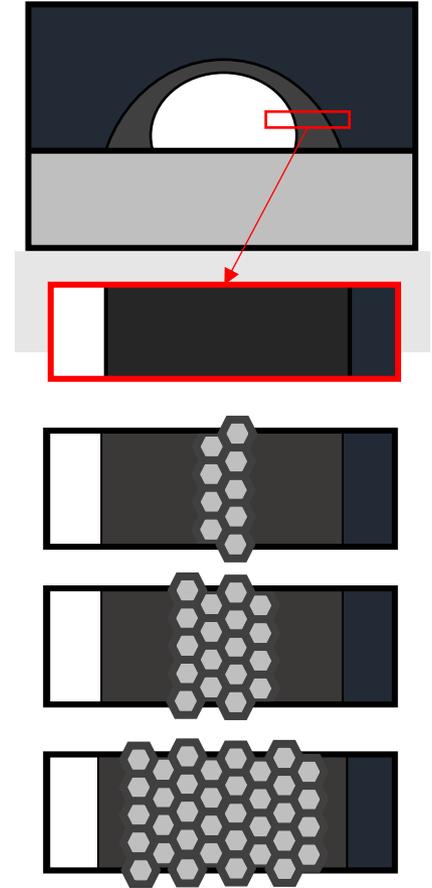


Shield thickness effects

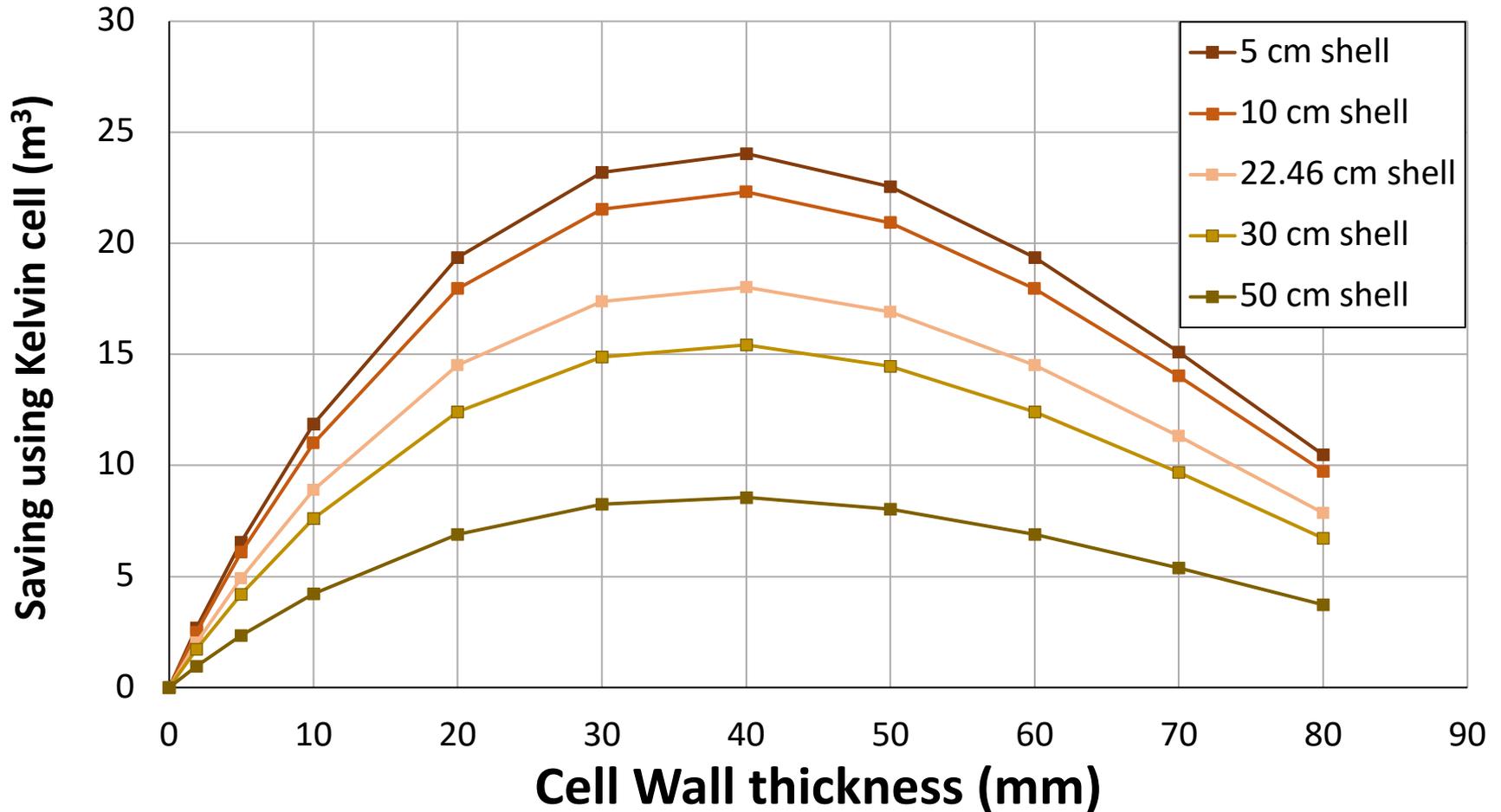
- How does shell thickness affect savings in cell structure?
- Take a dome case (JSR group report)
 - 13 m hemisphere ($\sim 575\text{m}^3$ interior)
 - 1.5 m shield thickness ($\sim 500\text{ m}^3$)
 - Vary shell thickness from 5 -50 cm



Daniel Sinkel, Elizabeth Scott, Logan Goodrich, Gareth Morris, *Jello Space Raspberries* (group 2), **Space Resources Fundamentals course, Colorado School of Mines, 2017**



Changing shell thickness

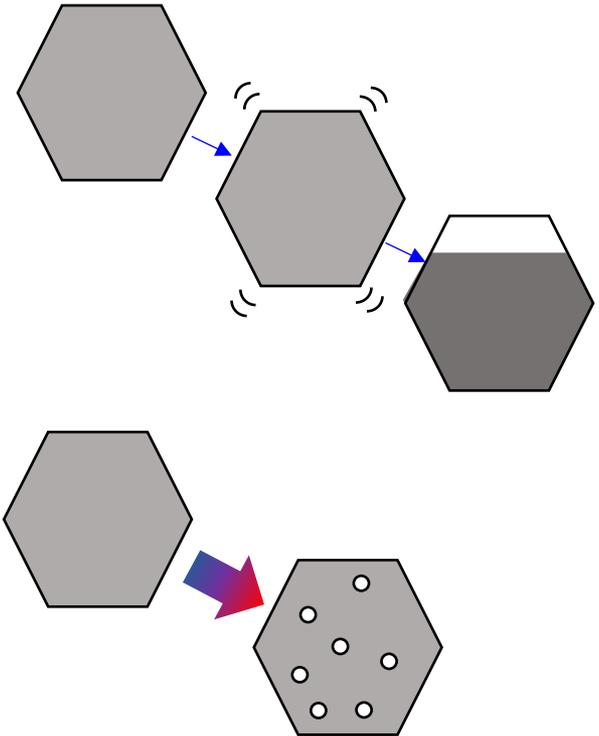


Summary

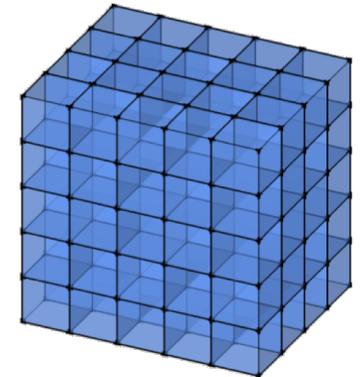
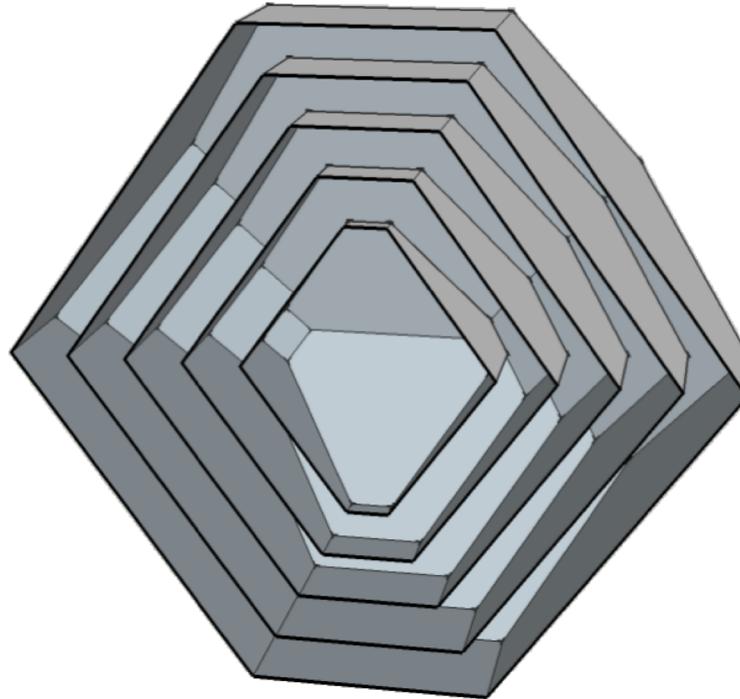
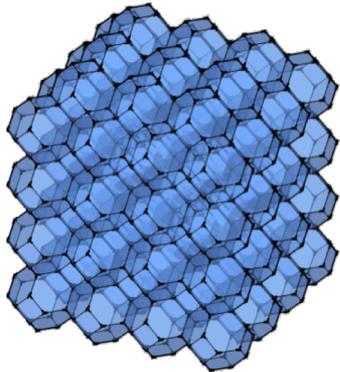
- Optimising printed structure could reduce amount of bonding required
- Reduce power or mass requirements for construction
- There is a lot of optimisation to investigate
 - How does structure affect durability?
 - How does cell size affect optimum wall thickness?

Risks

- Granular settling
 - Small vibrations cause settling
 - Open pathways for radiation form
- Off gassing
 - Regolith is constrained
 - Thermal fluctuations could lead to build up of gas

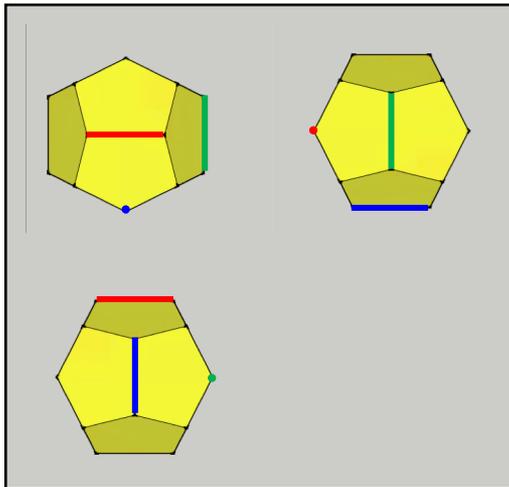
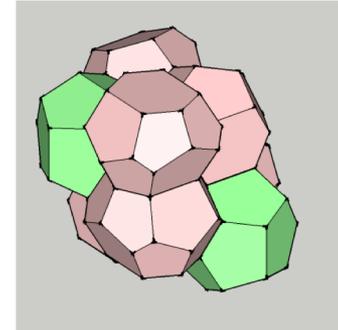
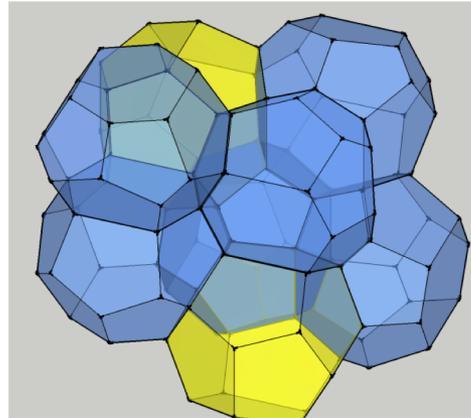
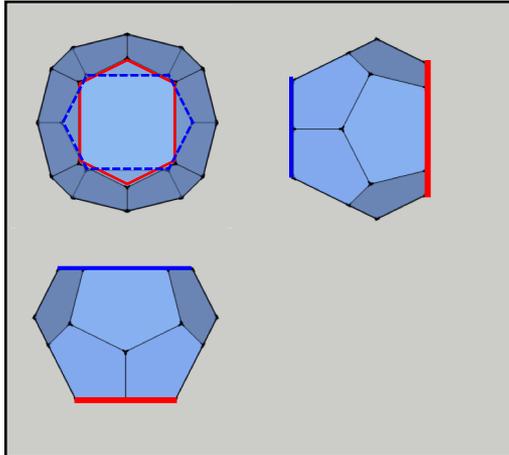


Questions?



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Weire Phelan structure



- 0.3% less area than the Kelvin structure
- Insignificant gains

