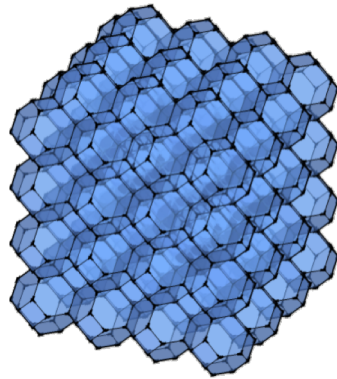


# Foam structures for encapsulating regolith in additive manufacturing applications

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

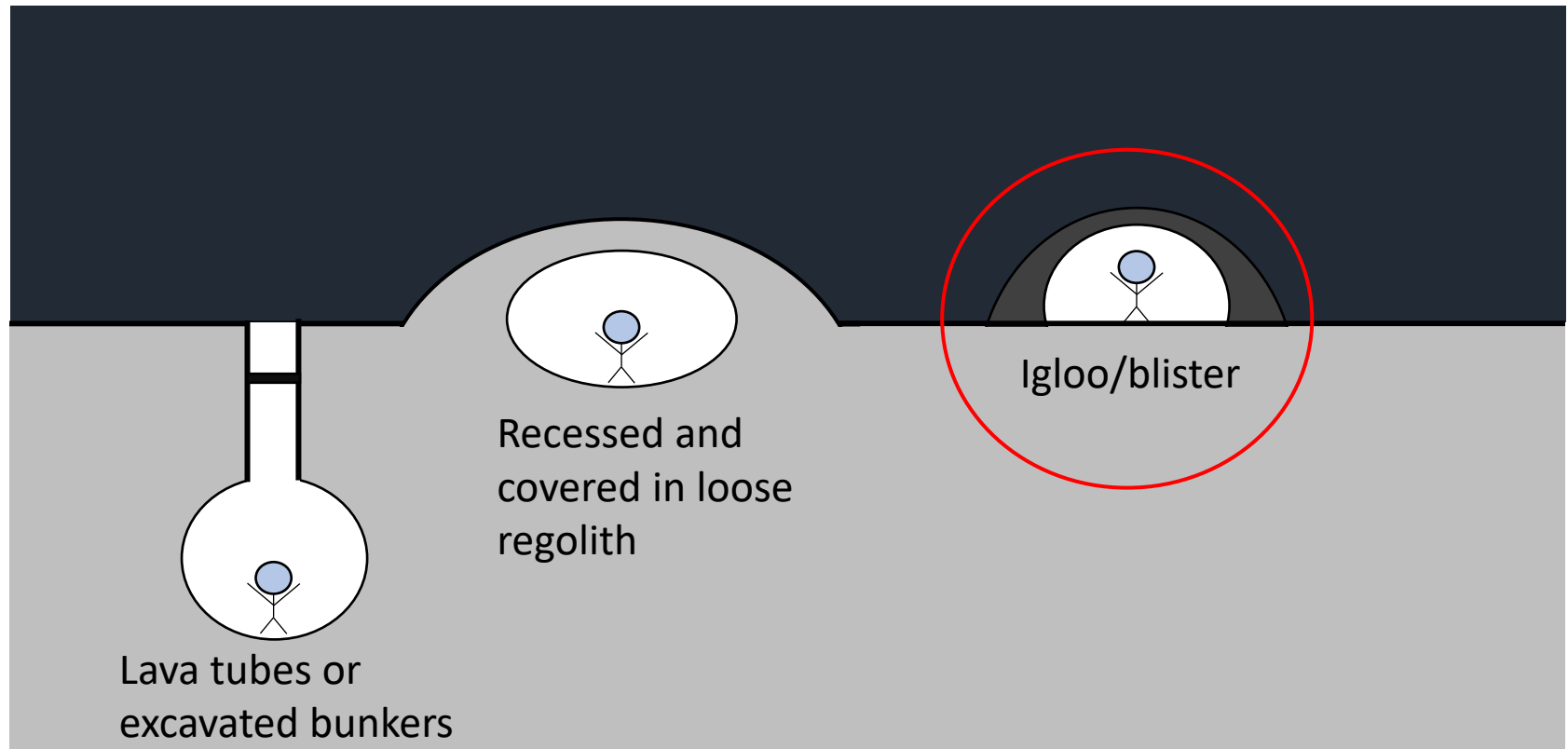


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# Shielding a Lunar base

- 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



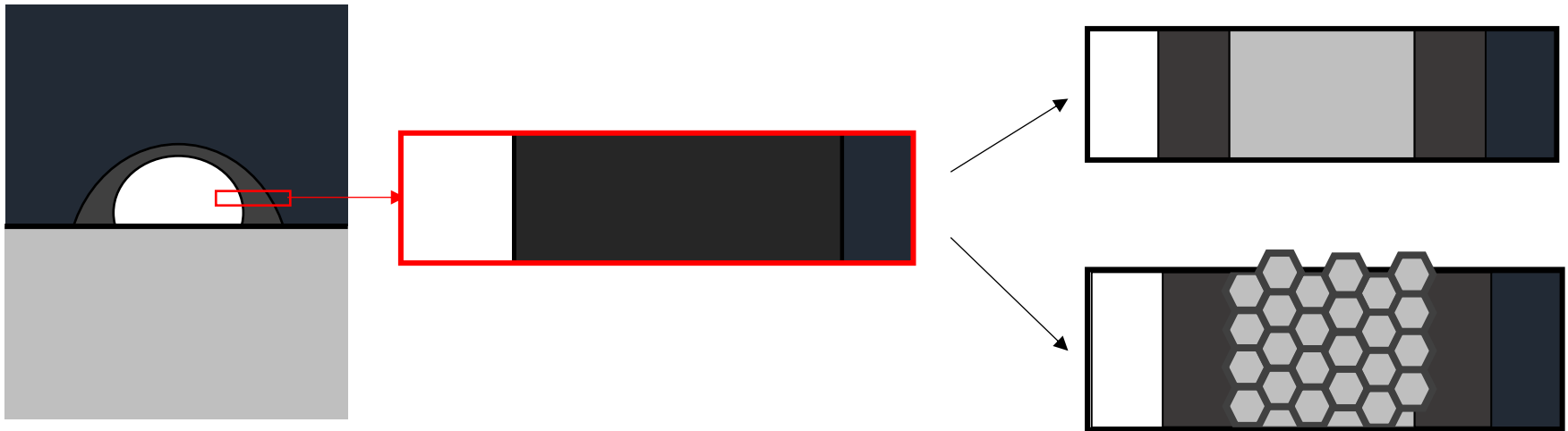
# Additive manufacturing methods

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



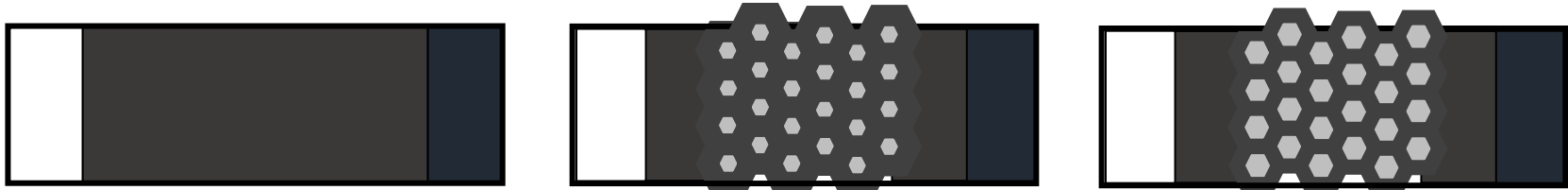
# Structure of the shield

- It's there to put mass in the way

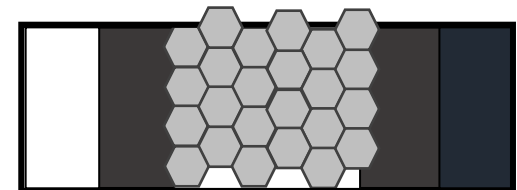
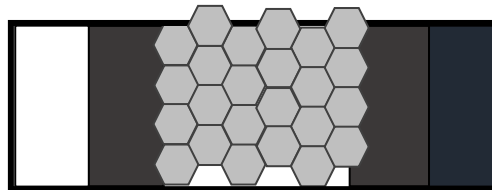
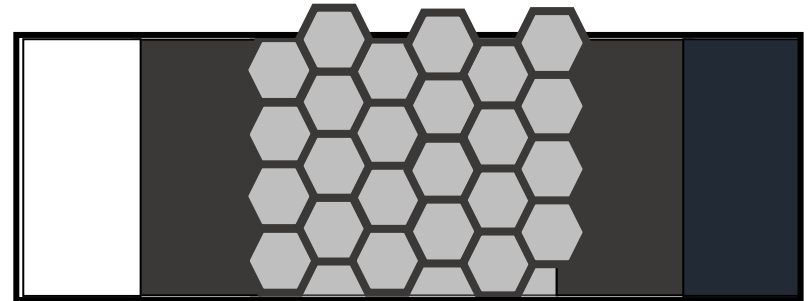
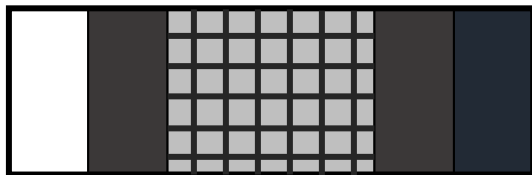


- The shield only needs to constrain the regolith
- A cellular structure requires less bonded material but allows the same mass of shield
- G. Cesarretti *et al.* **Acta Astronautica** 93 (2014) 430-450

# Cellular networks



Cell wall thickness affects how much material needs to be bonded



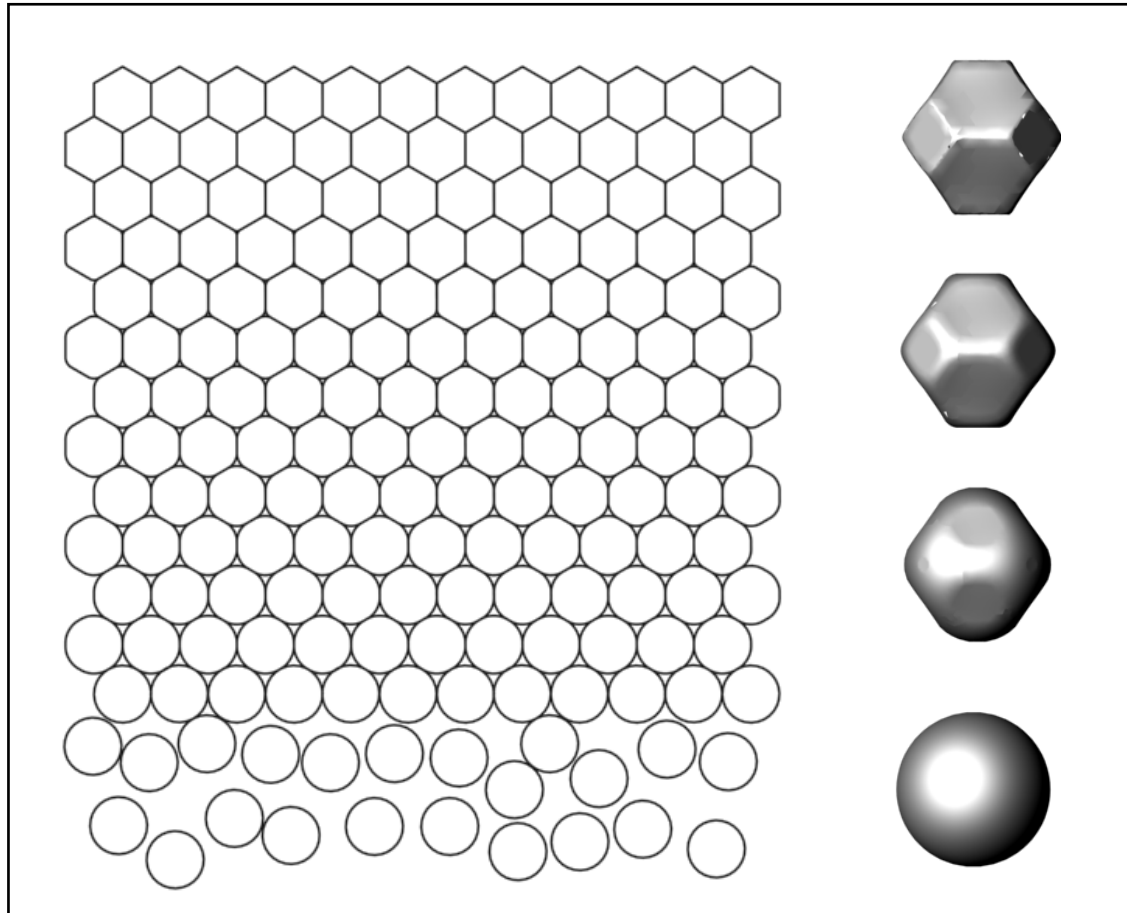
# Foam structure - cells

Dry Foam

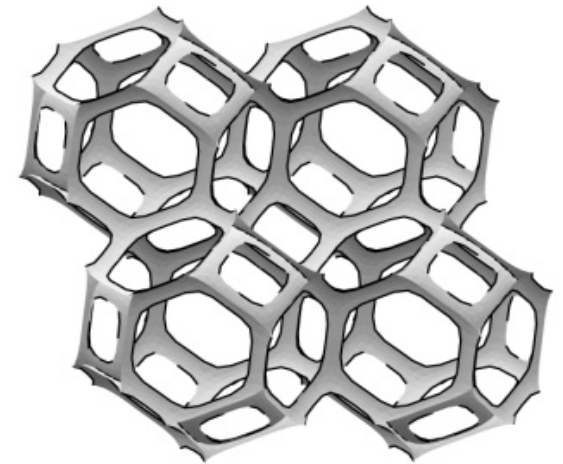
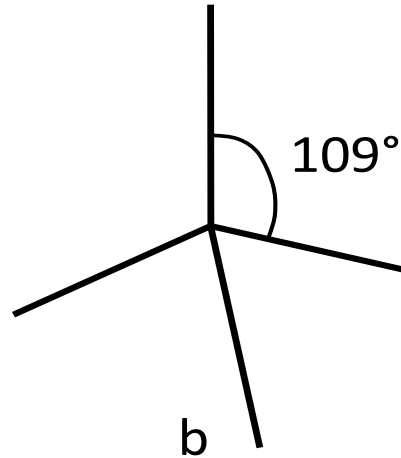
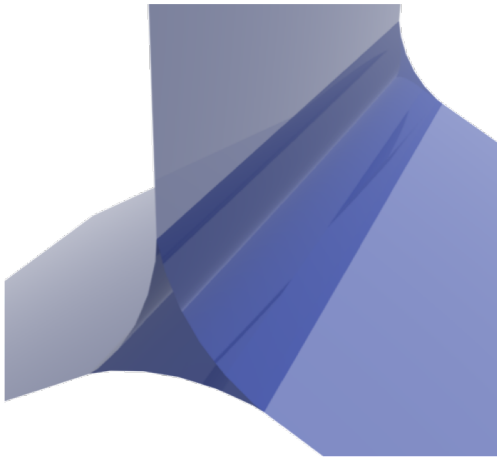
Polyhedral cells

Wet Foam

Bubbly liquid

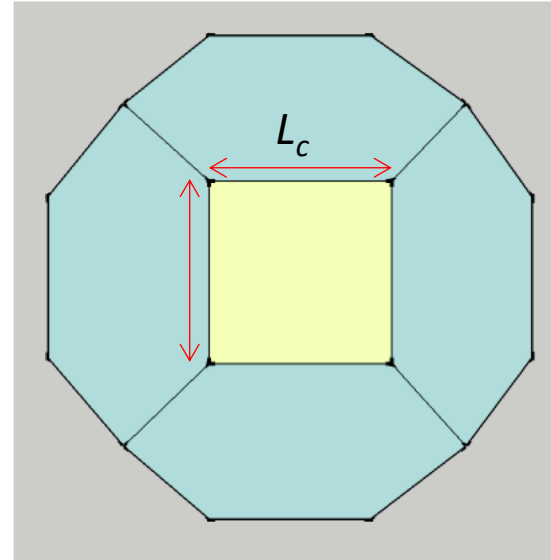
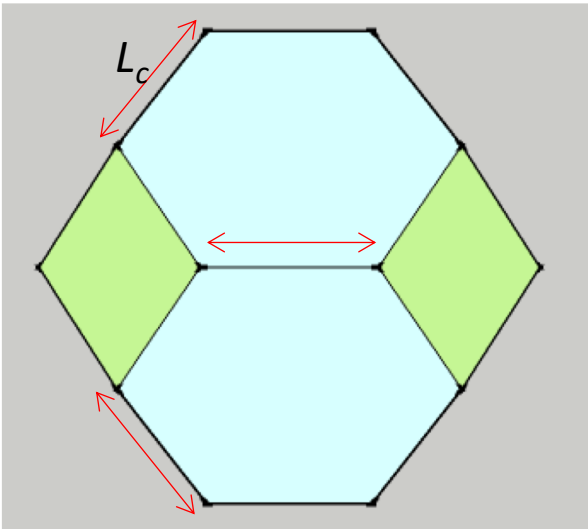
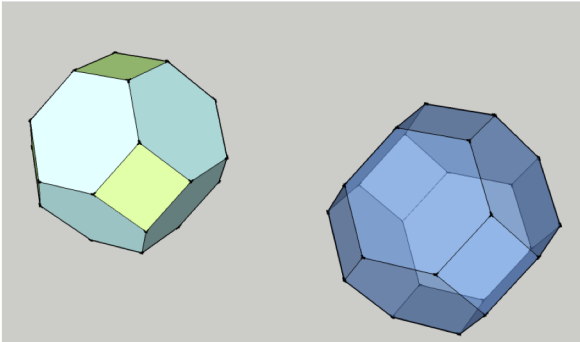
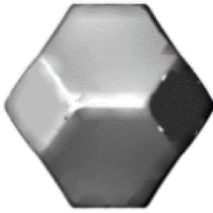


# Foam structure – Plateau borders



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

# Foam structure – Kelvin Cell

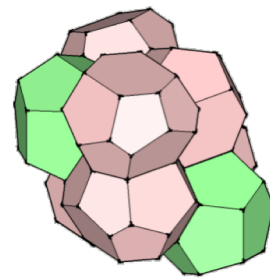
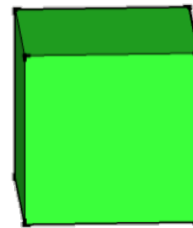
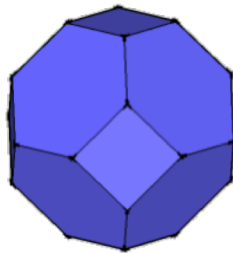
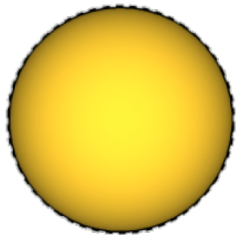


- $L_c$  is the same for all edges
- Six squares
- Eight hexagons



# Unit cells for construction

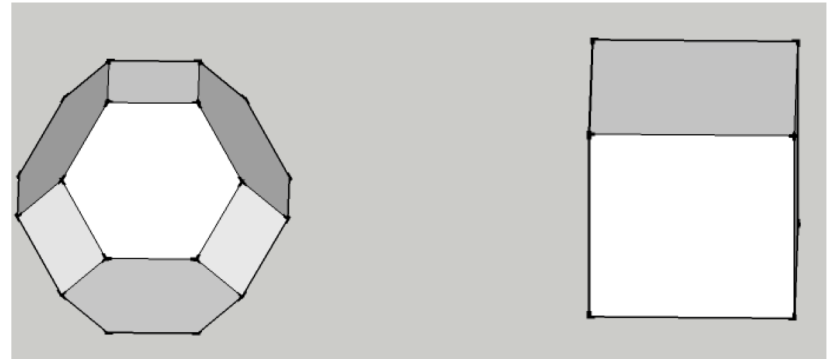
- Kelvin cell has 9.7% greater surface area than a sphere for the same volume.
- The surface area of the Kelvin cell is ~12% less than the cube for the same volume.
- Weire-Phelan structure has 0.3% less surface area than Kelvin



# Cell comparison

- Kelvin cell

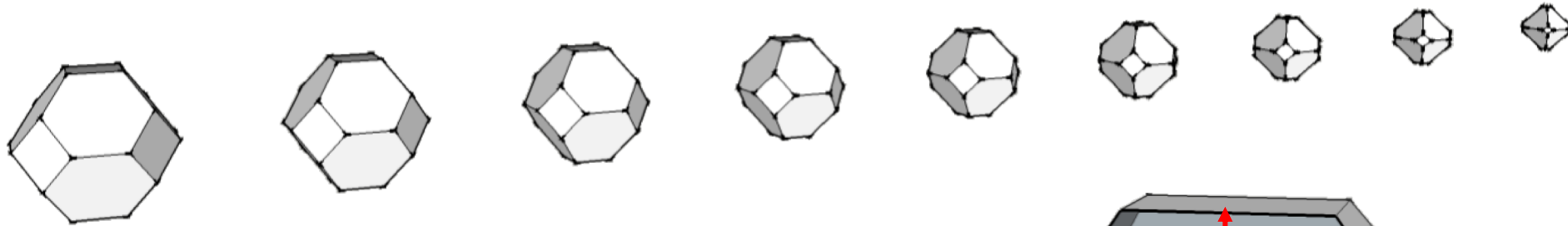
- $L_c$  is 100 cm
- Cell width is 300 cm
- Unit cell is  $0.0113 \text{ m}^3$



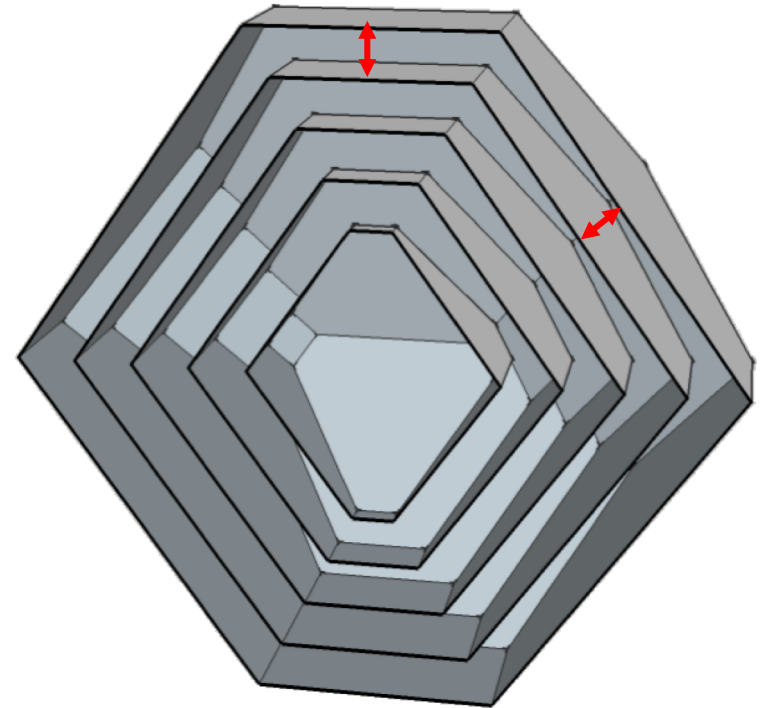
- Cube

- Edge is 224.5 cm
- Unit cell volume is  $0.0113 \text{ m}^3$

# Calculating shell thickness

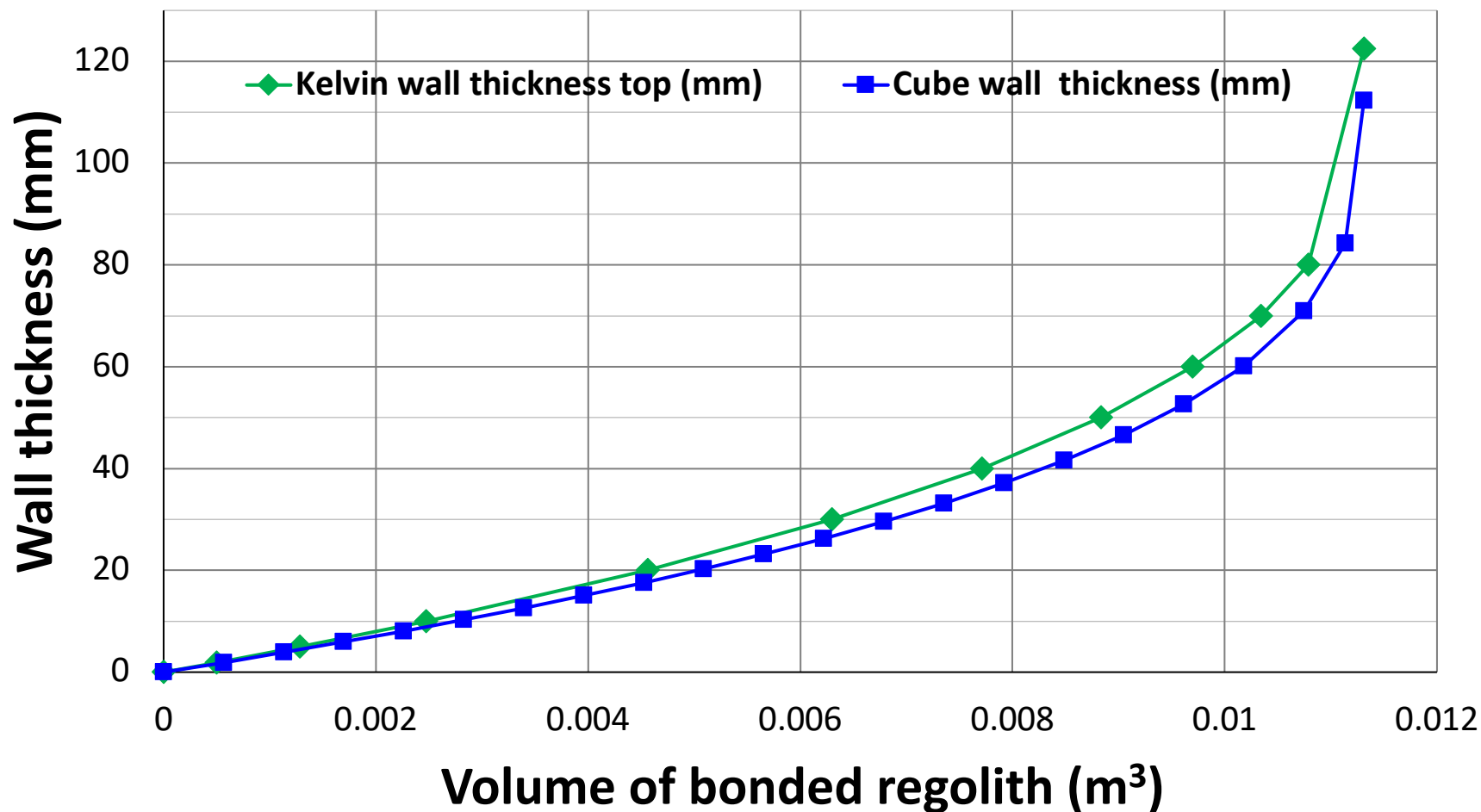


- Increase wall thickness uniformly
- Move facets, do not shrink cell
- Interior surface changes shape



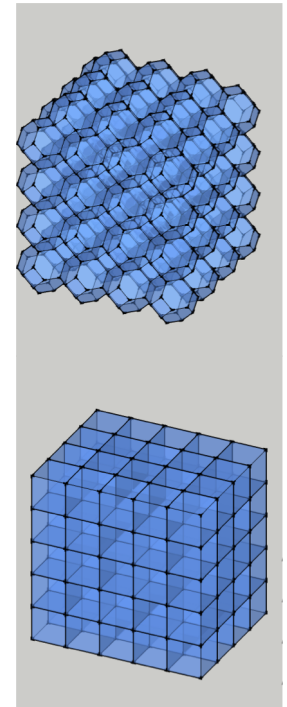
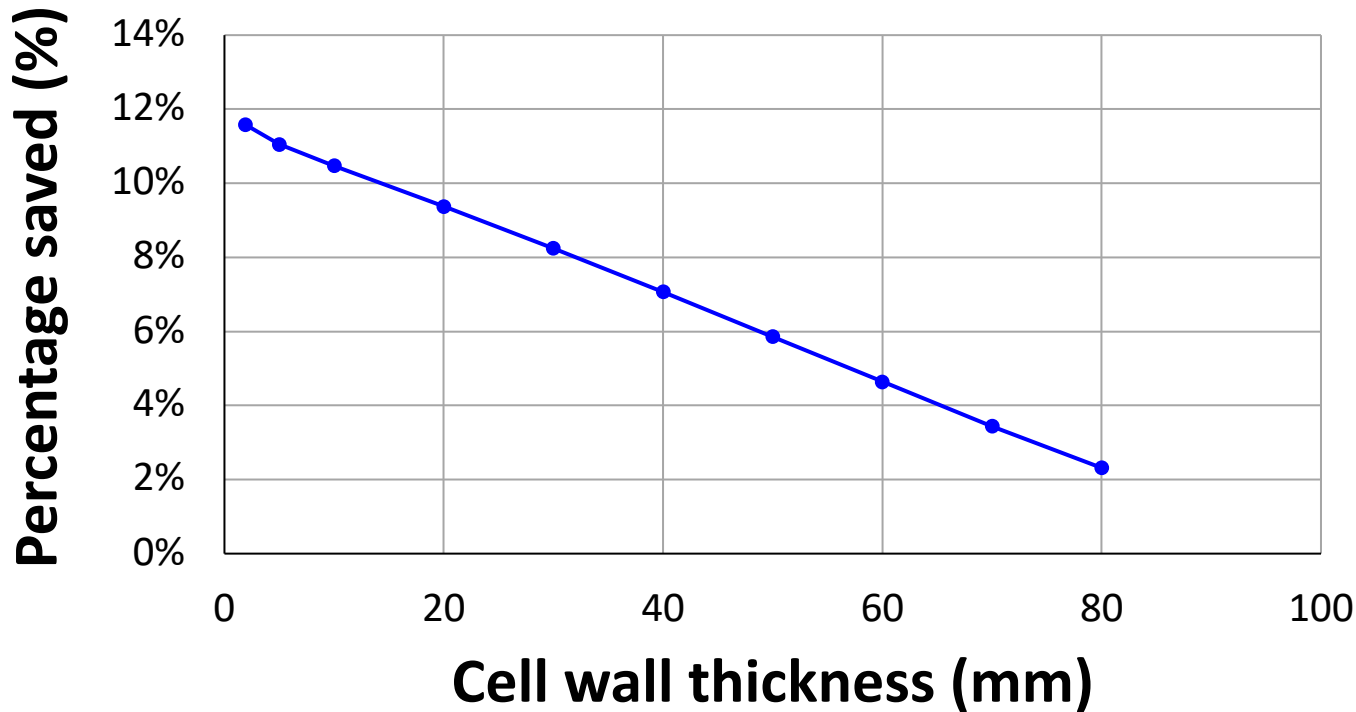


# Wall thickness vs volume for cell



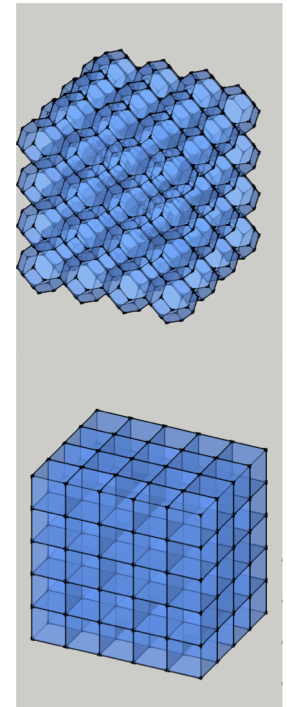
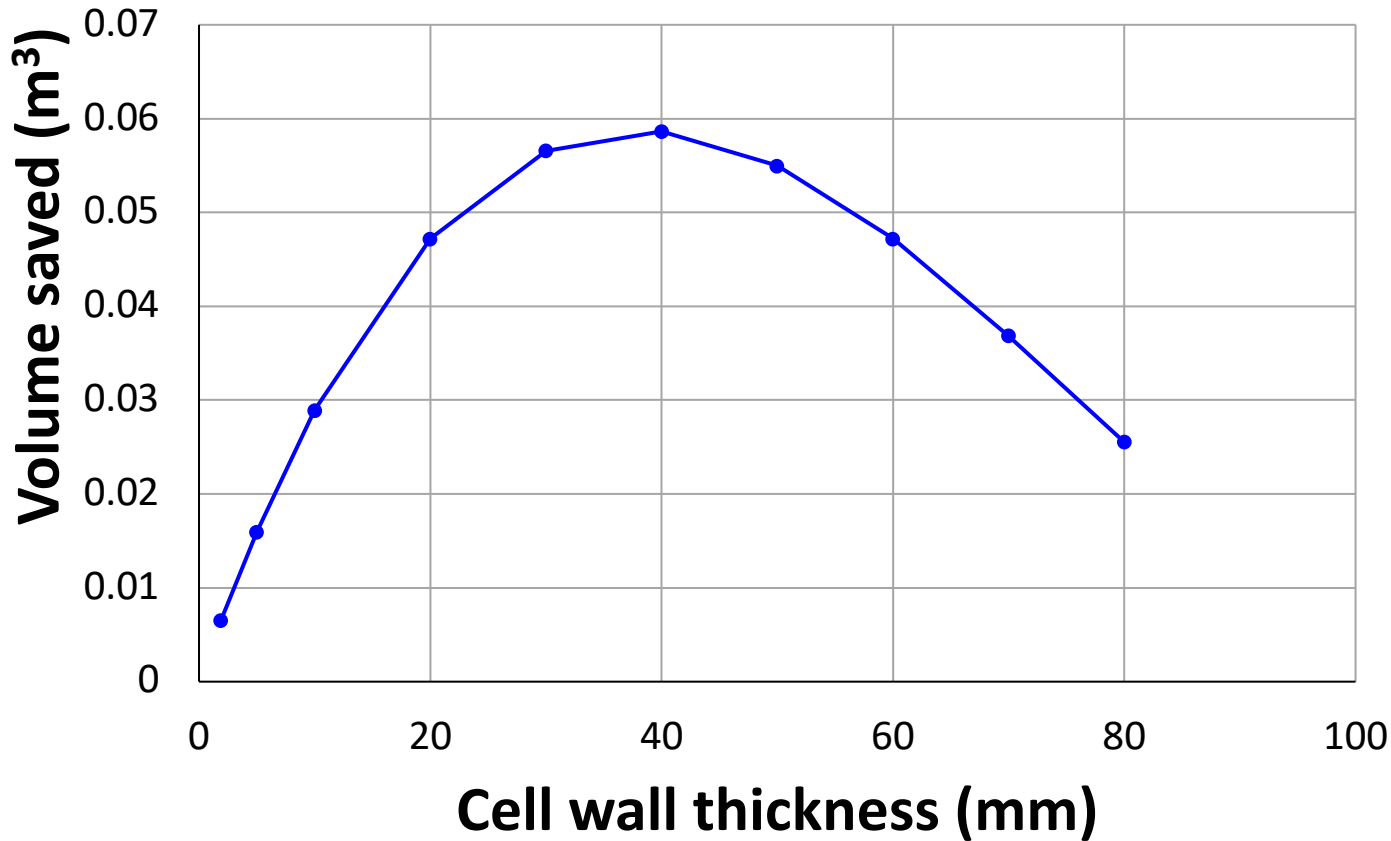
# Volume saving for 100 cells

- 100 cells give a 1.13 m<sup>3</sup> block (0.0113 m<sup>2</sup> cells)
- As the walls get thinner, savings tend towards the theoretical limit of 12%



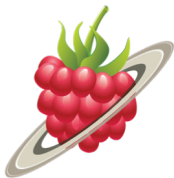
# Volume saving for 100 cells

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

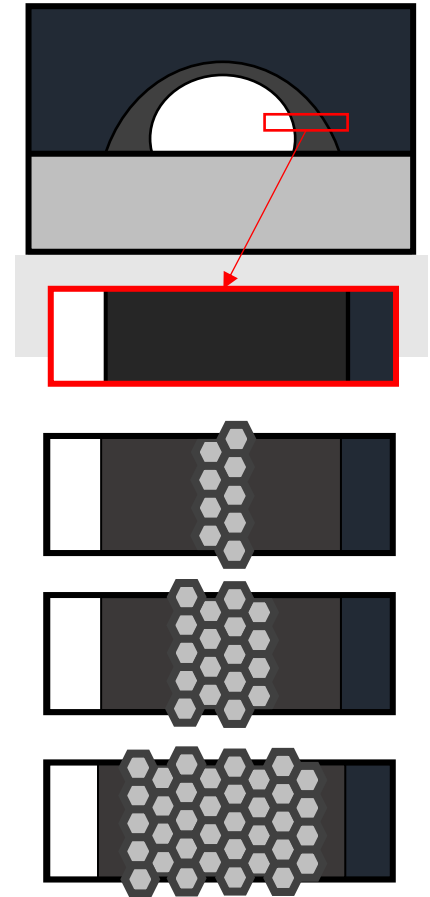


# Shield thickness effects

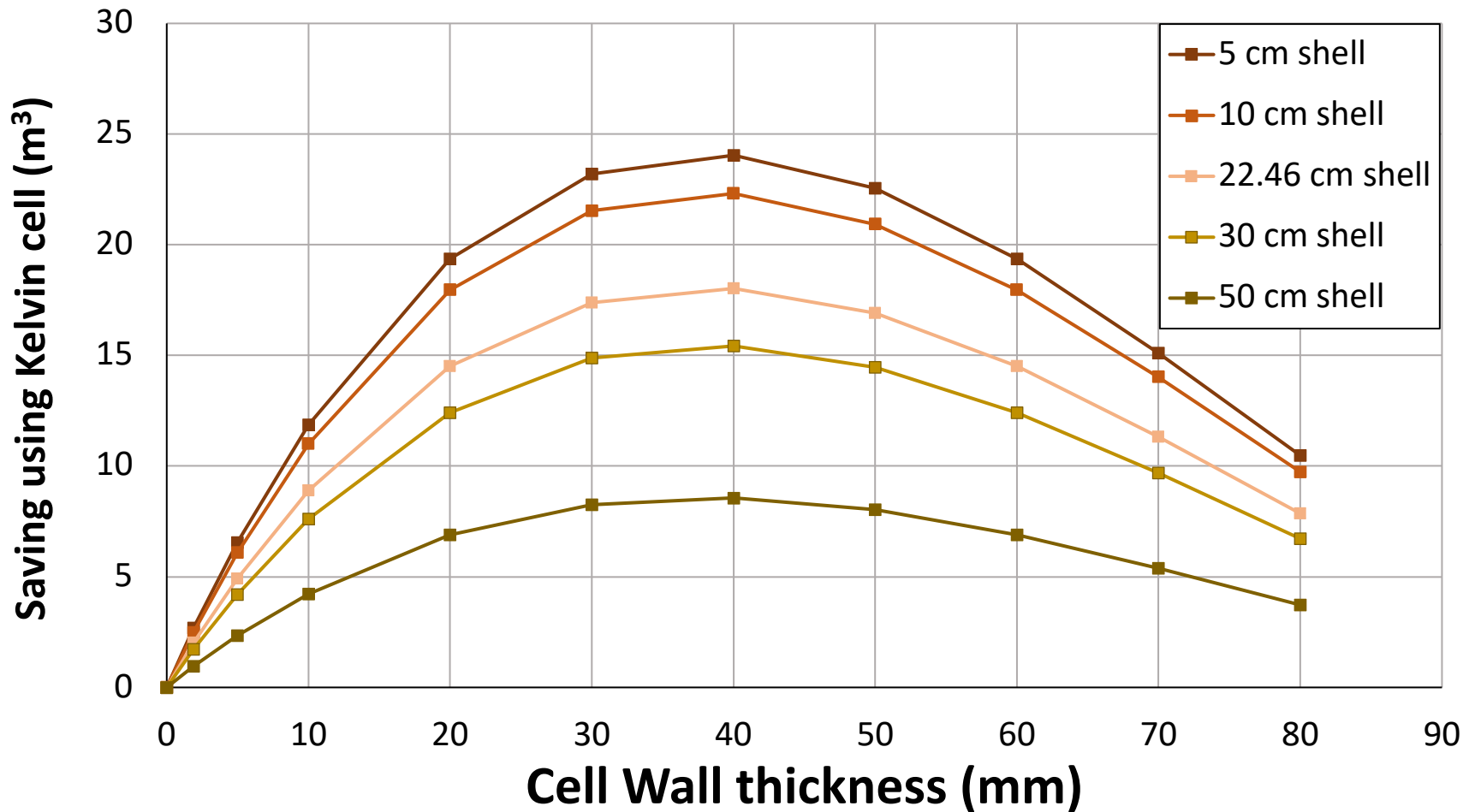
- How does shell thickness affect savings in cell structure?
- Take a dome case (JSR group report)
  - 13 m hemisphere ( $\sim 575\text{m}^3$  interior)
  - 1.5 m shield thickness ( $\sim 500\text{ m}^3$ )
  - Vary shell thickness from 5 -50 cm



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

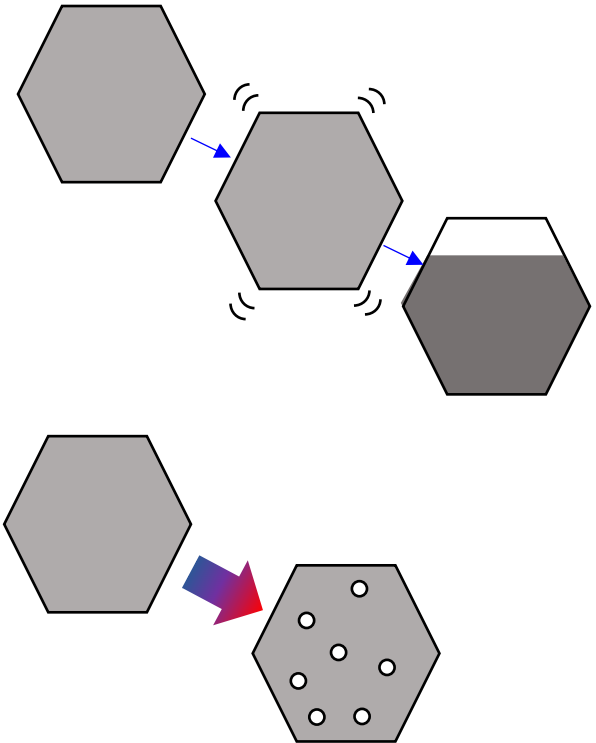


# Summary

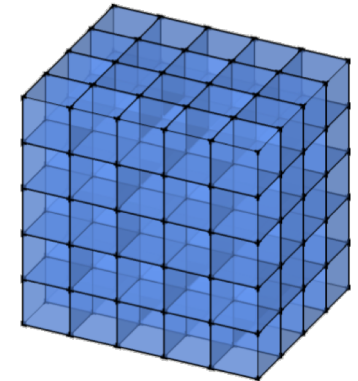
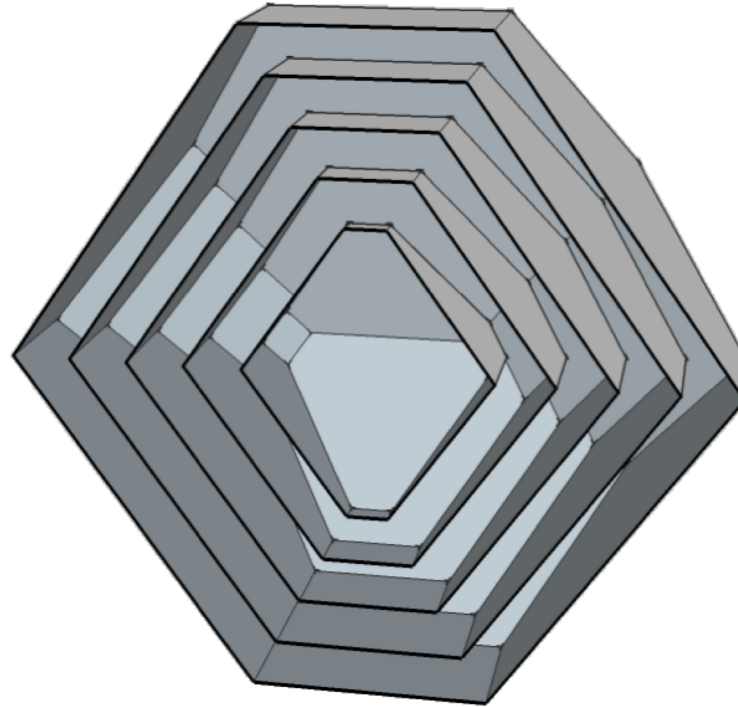
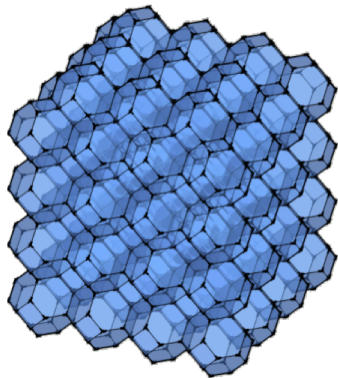
- Optimising printed structure could reduce amount of bonding required
- Reduce power or mass requirements for construction
- There is a lot of optimisation to investigate
  - How does structure affect durability?
  - How does cell size affect optimum wall thickness?

# 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



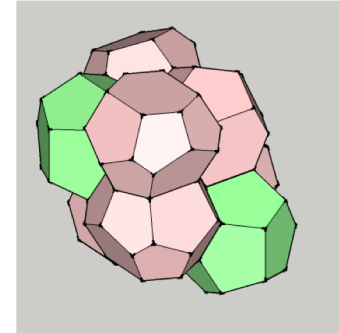
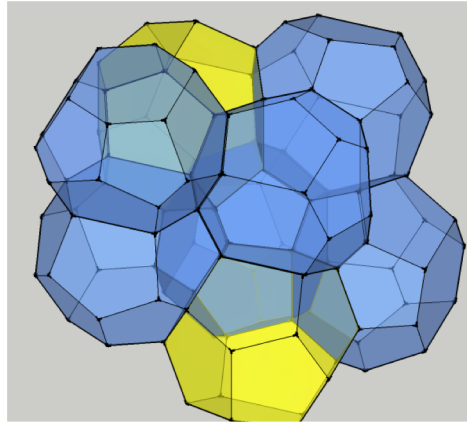
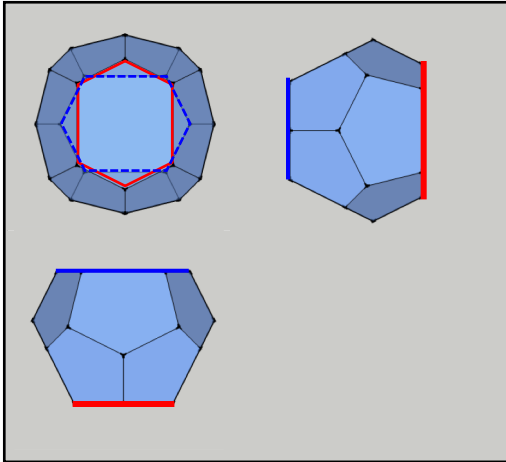
# Questions?



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# Weire Phelan structure



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

