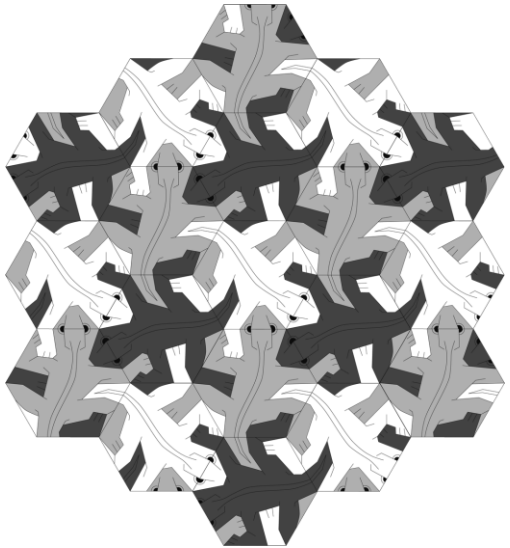
A Glimpse of Topological Interlocking Configurations



Reptiles (M.C. Escher)
http://wp.calmagrafica.es/wp-content/uploads/2010/05/mosaico-lagartos.gif

Hello!

I am Andres Bejarano

Interested in Computer Graphics, Geometry and Algorithms and Theory

Currently working on interlocking configurations advised by professor **Christoph Hoffmann**

Content

- Previous Work
- Topological Interlocking
- Current Approach
- Ideas and Future Work

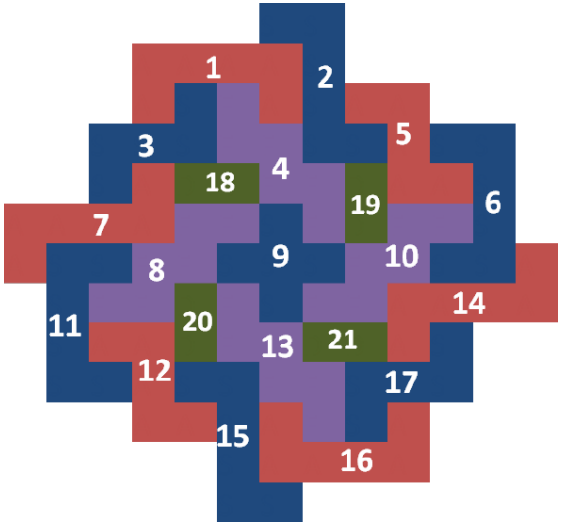
1.

Previous Work

A semester ago in a glunch, not too far away

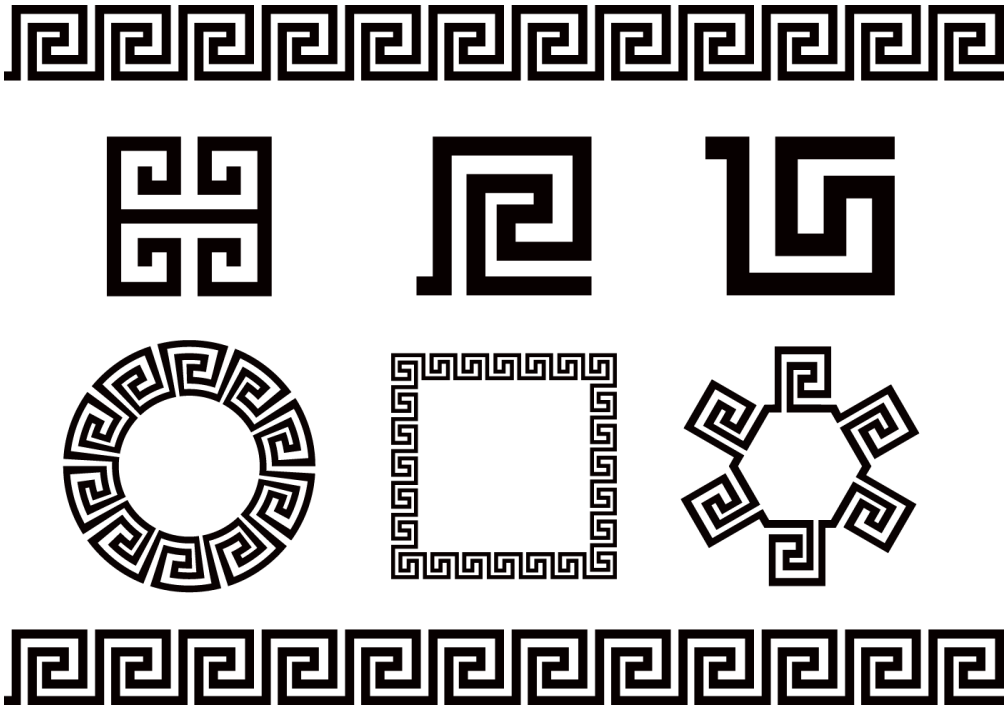
Interlocking configurations with polyominoes

- A **PSPACE-hard** problem (intractable).
- Only possible if we use **hexominoes** or higher degree polyominoes.
- **Non-monotone** pieces are required.



Sidharth Dhawan, Zachary Abel. Complexity of Interlocking Polyominoes. 17 December 2011. arXiv:1112.4087. http://arxiv.org/abs/1112.4087

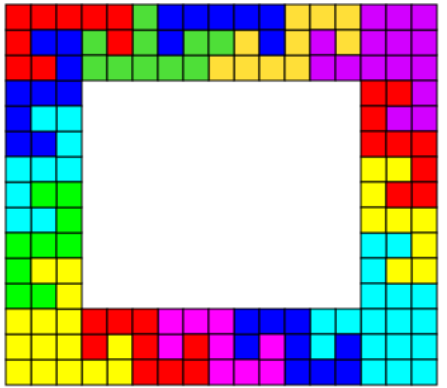
Greeks were right!



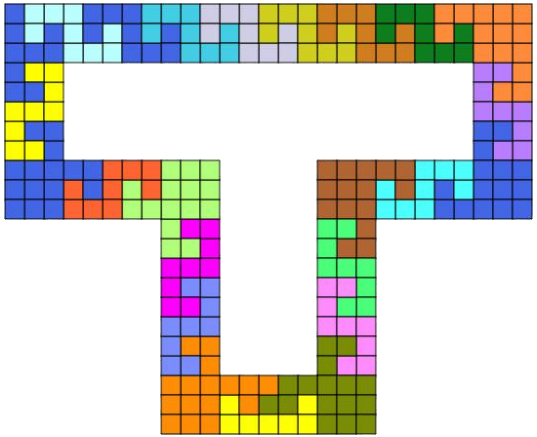
Greek Key Pattern
http://int-galleries.com/vector/greek-key-pattern-vector.php

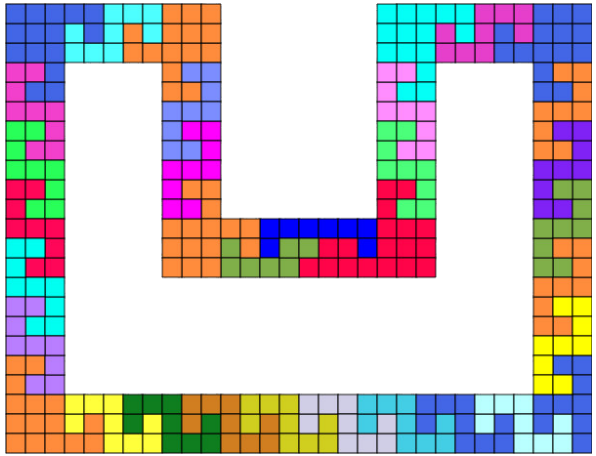
Assemblable interlocking polyominoes

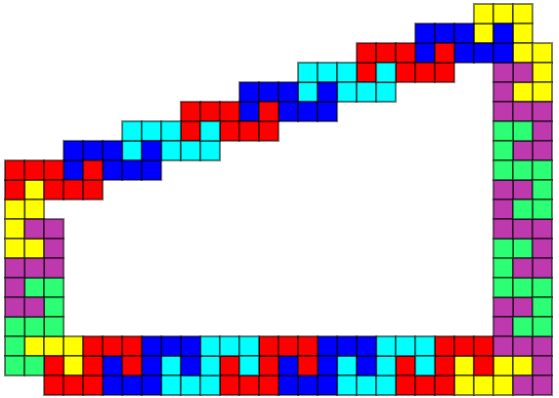
- Based on **S-shaped** pieces or Greek Fret.
- Interlocking only in the **boundary**.
- Assemblable by modifying **three consecutive** S-shaped pieces.



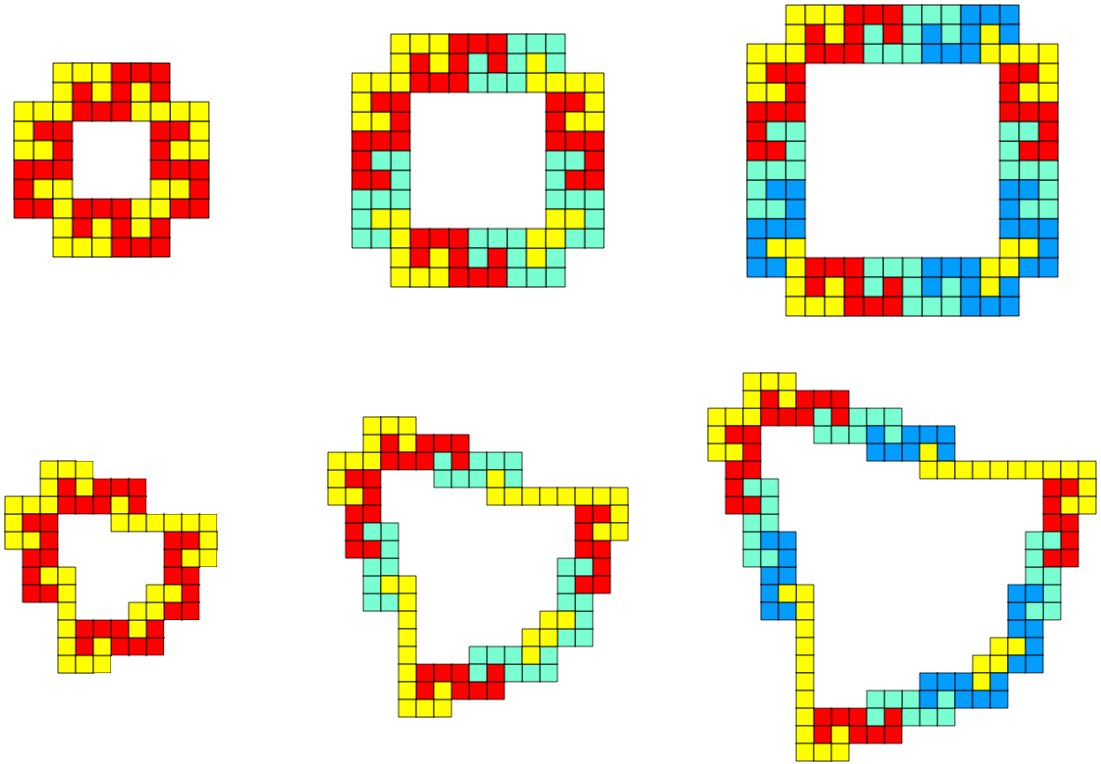
Some examples!



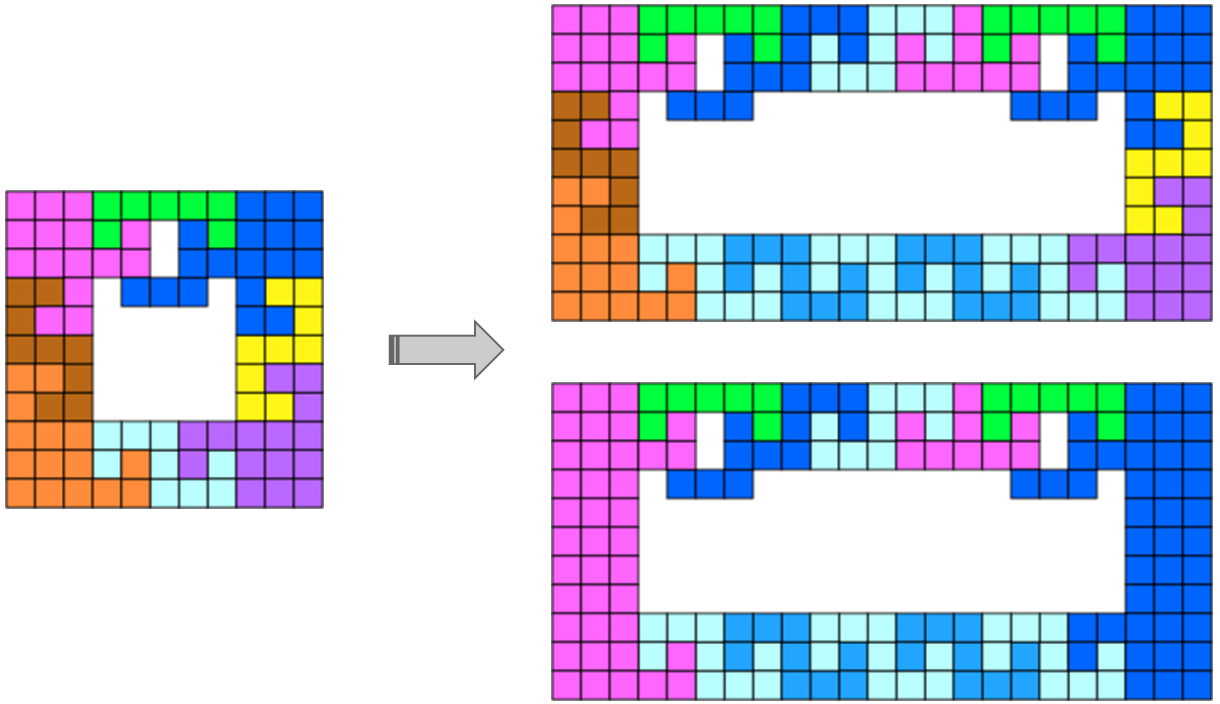




Some examples!



Some examples!



But...

Is it truly interlocking?

If the configuration is assemblable then we loss interlocking (at least in the key piece in the opposite assembly direction).

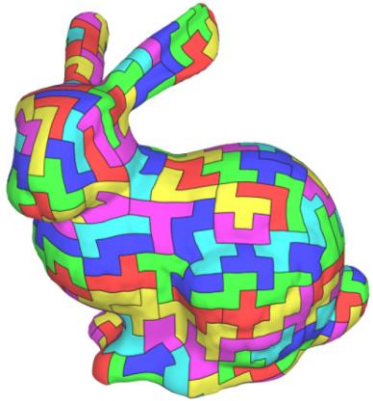
Can we expand to 3D?

Yes, the same principles can be applied to polycubes.

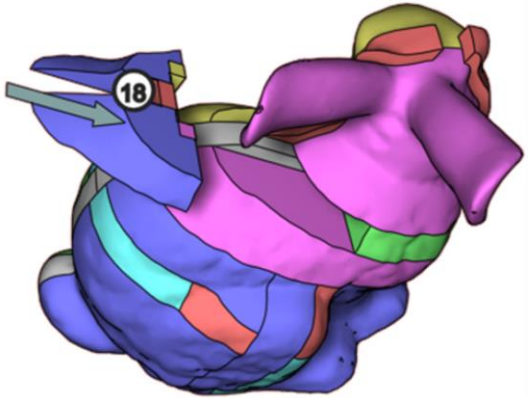
Has someone worked on this before?

Yes, and it has been an active field for some enthusiasts and researchers as well.

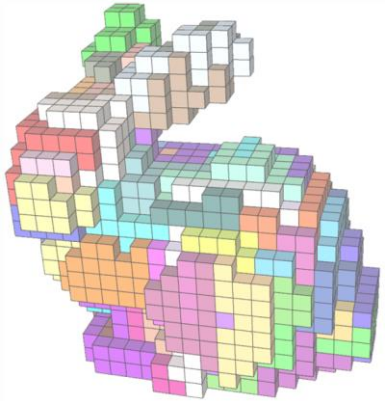
Interlocked bunny in history



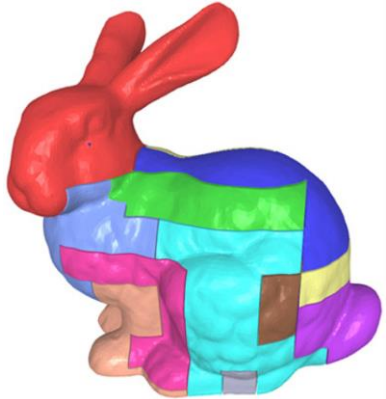
3D Polyomino Puzzle [Lo 2009]



Making Burr Puzzles From 3D Model [Xin 2011]



Recursive Interlocking Puzzles [Song 2012]



Printing 3D Objects With Interlocking Parts [Song 2015]

2.

Topological Interlocking

Interlocking as you might have never imagined

Trivia

Can we build an interlocking structure using people, all of them with the same pose?
(using hands is not allowed)

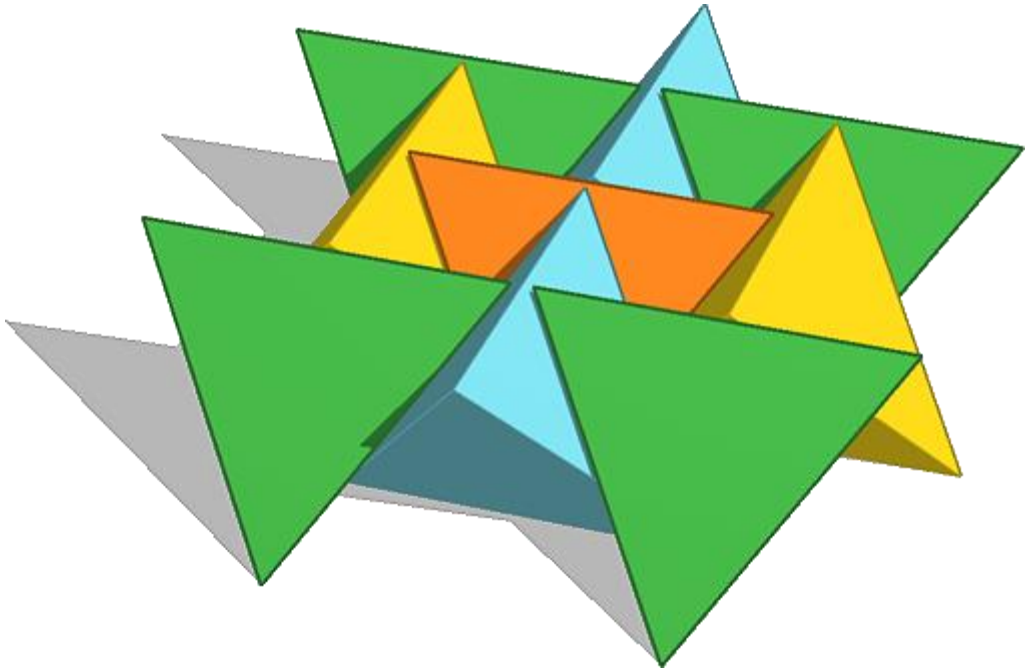
A Lap Circle!

http://www.aplayfulpath.com/wp-content/uploads/2014/03/play_laps.jpg

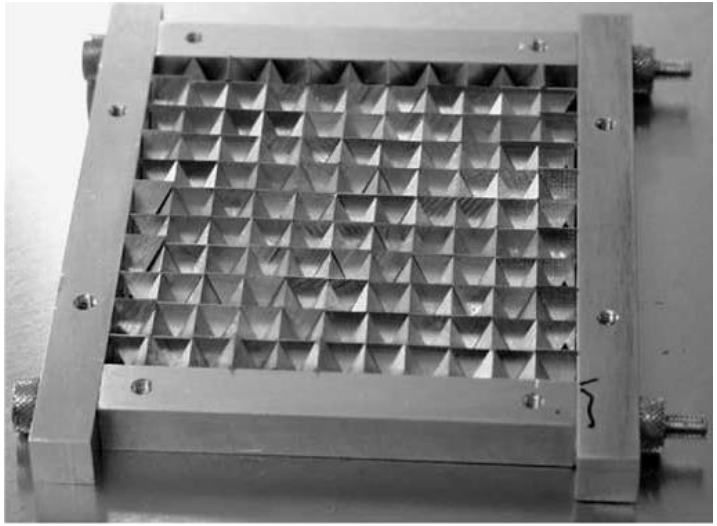
Topological Interlocking is a structural organization for which the building blocks are locked in their positions by purely geometrical constraints.

[Dyskin 2003]

How does it work?



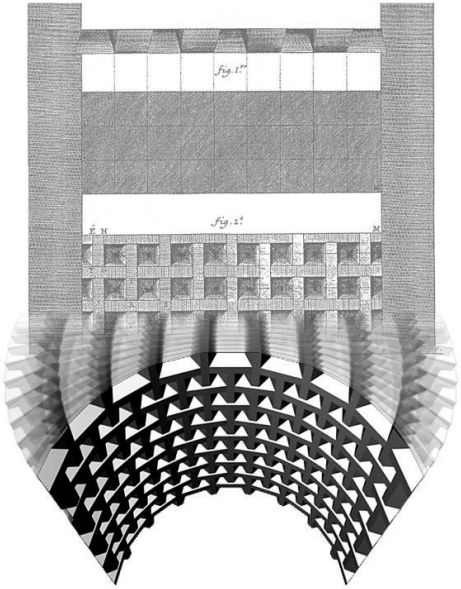
We need support



Assembly in rigid frame and concentrated force loading [Dyskin 2003]

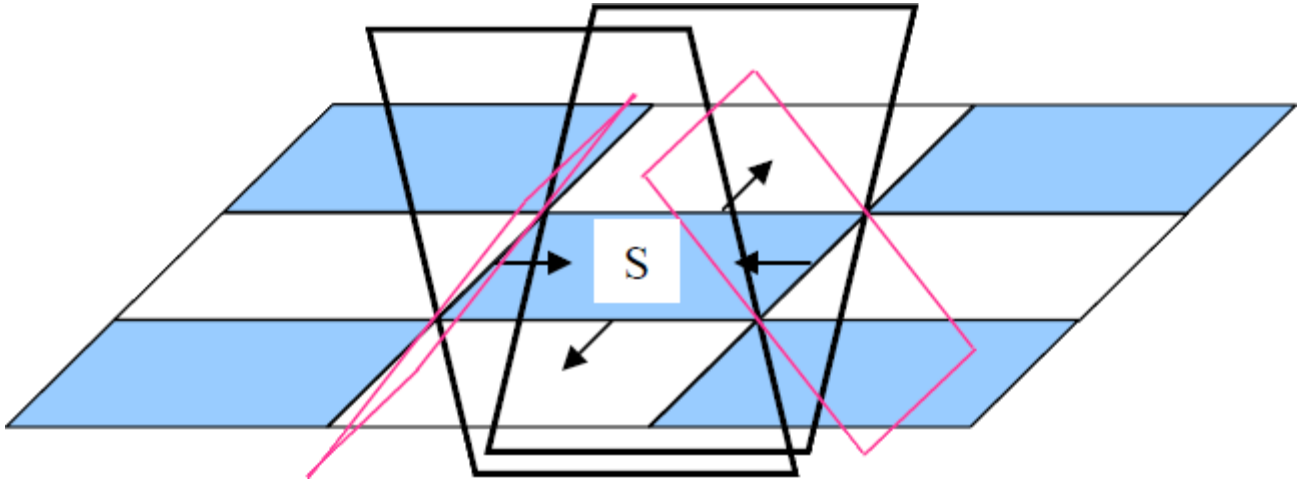
Topological interlocking history

- Principle known since 1699 by **Joseph Abeille**
- Brought back to life by **Michael Glickman** in 1984
- Concept enhanced by **Arcady Dyskin** since 2001



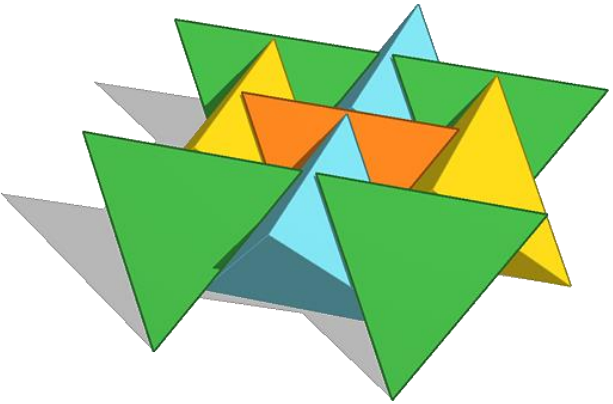
Abeille ashlar barrel vault transformation [Fallacara 2006]

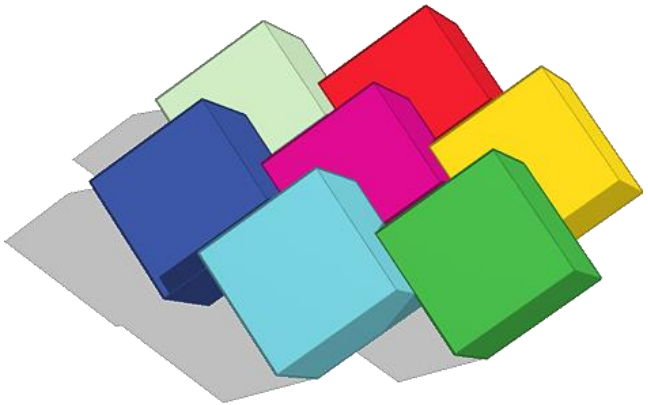
Let’s build one!



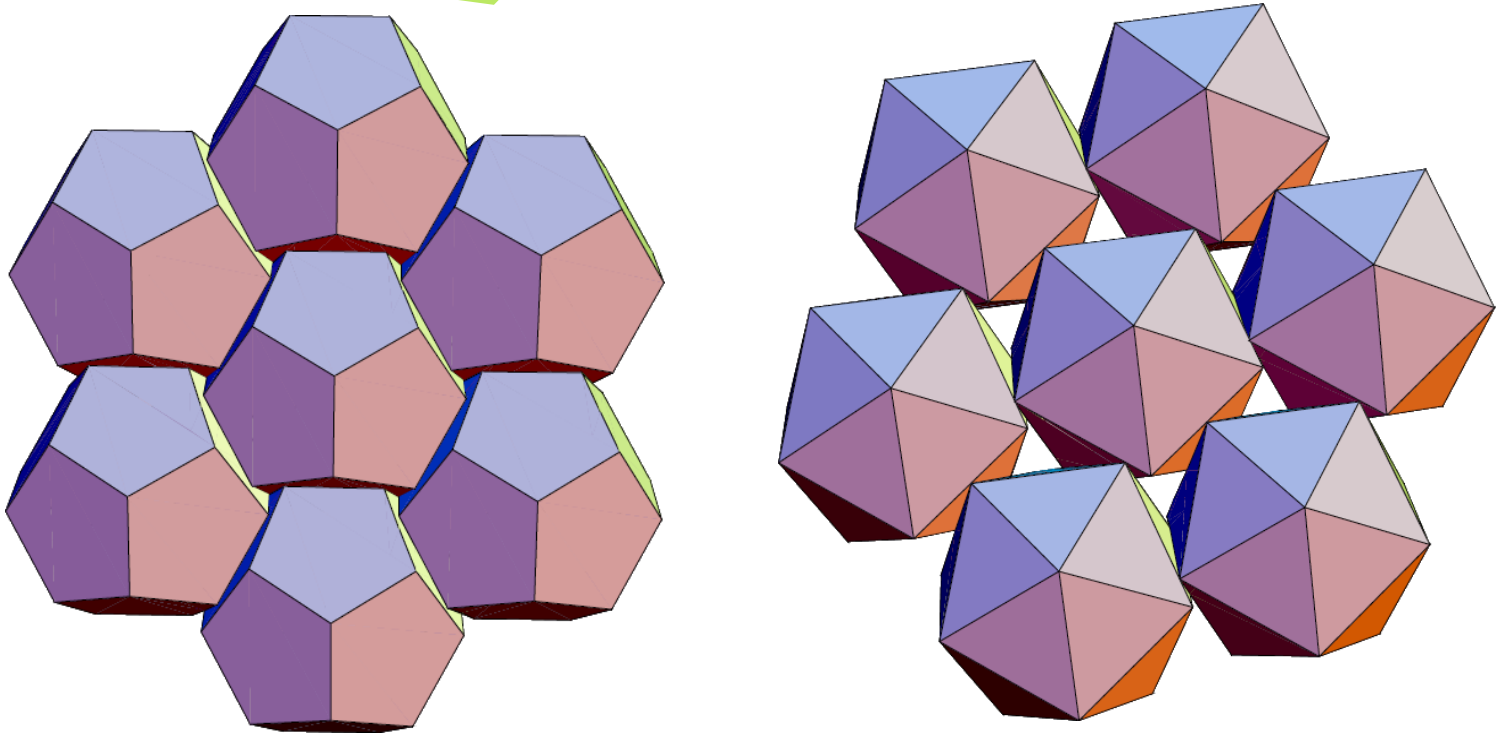
Loopsided Planes of the Square [Kanel-Belov 2008]

Platonic solids work!



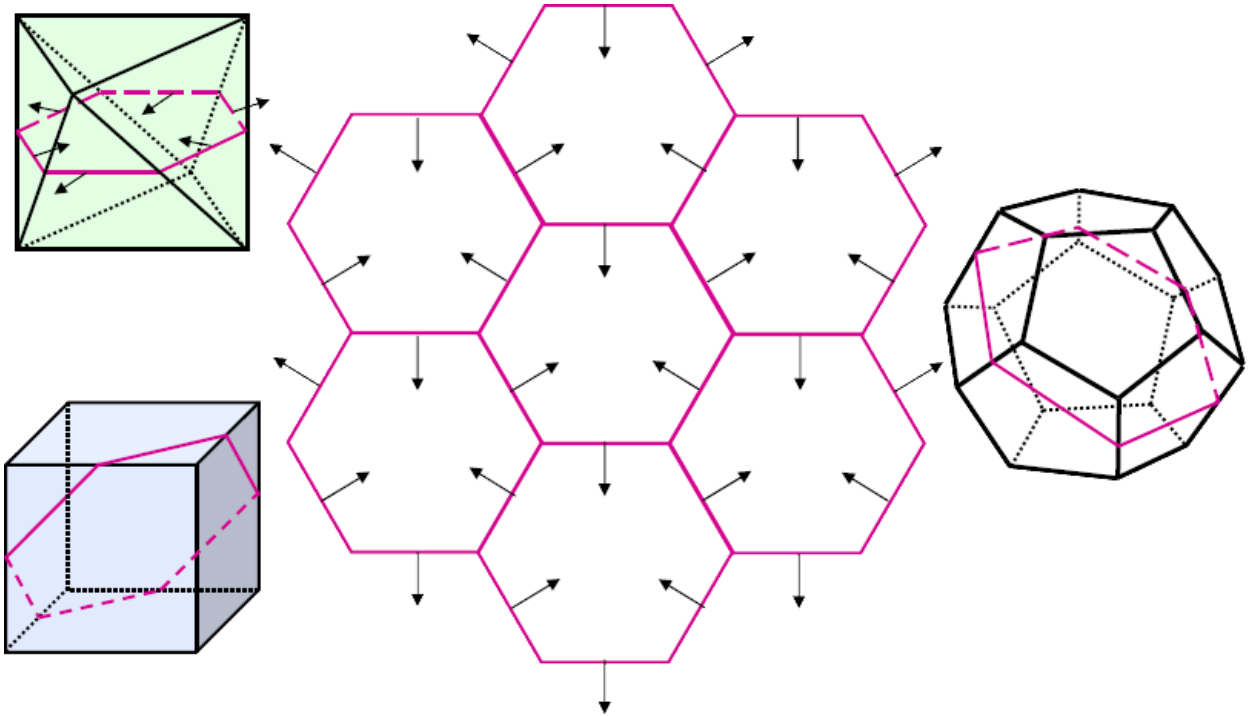


Even the bigger ones!



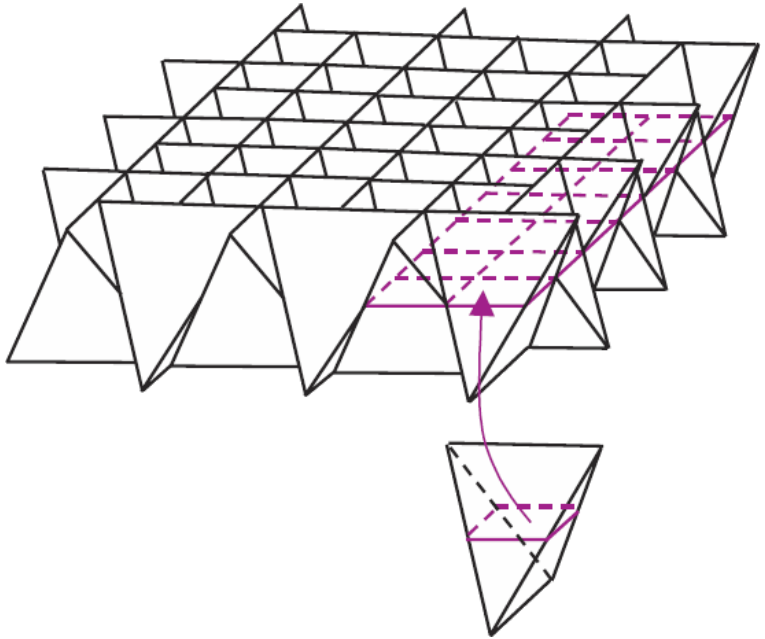
Interlocking Dodecahedra and Icosahedra [Kanel-Belov 2008]

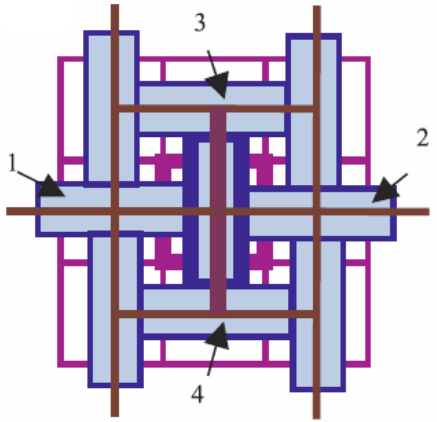
Here's how



Hexagonal Tiling of the Plane [Kanel-Belov 2008]

Why it works?



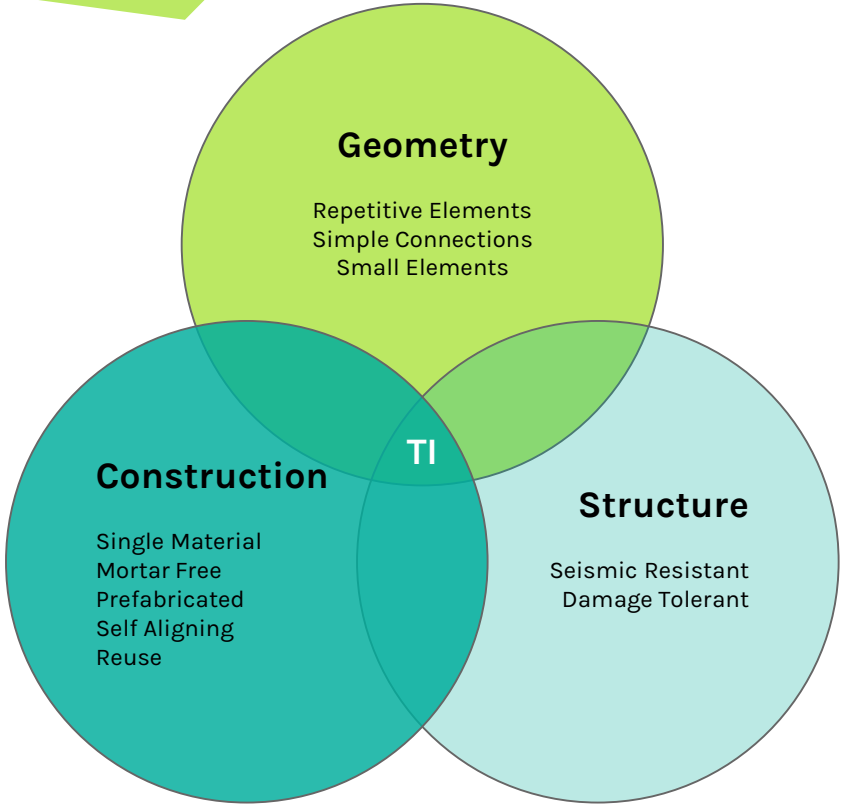


Planar Sections and Evolution [Dyskin 2003]

Advantages

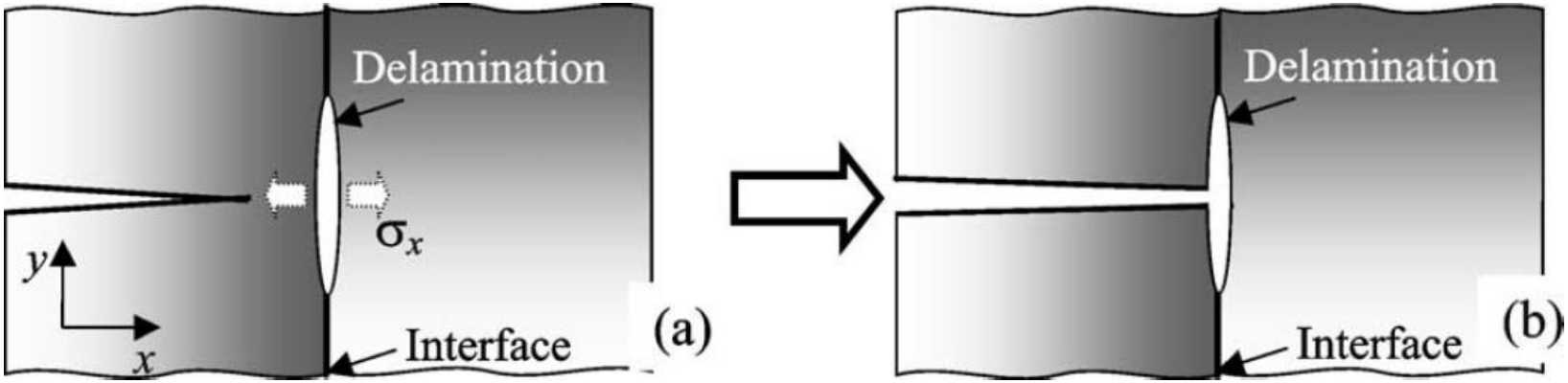
- Since no connectors are used it is avoided **stress concentrators**
- Percolation threshold found to be 0.59 (structure survives **59% random block failure**) using a tetrahedral configuration
- Cracks do not propagate from one block to another (**crack retardation**)

Advantages



Possible Advantages of Employing Topological Interlocking in Building Construction [Weizmann 2016]

Crack retardation



Mechanism of crack retardation [Dyskin 2003]

In short...

It's all about geometry

No connectors at all! Structure holds itself together by the contact between faces.

Convex pieces are useful

It is possible to have 3D interlocking configurations using convex shapes. Of course, a support structure is required.

Start with a tessellation or tiling

A tessellated/tiled surface with even-sided pieces works as starting point for generating a topological interlocking configuration.

Romans were right!

Colosseum Amphitheatre, Rome, Italy
http://wallpaperswide.com/colosseum_amphitheatre_rome_italy-wallpapers.html

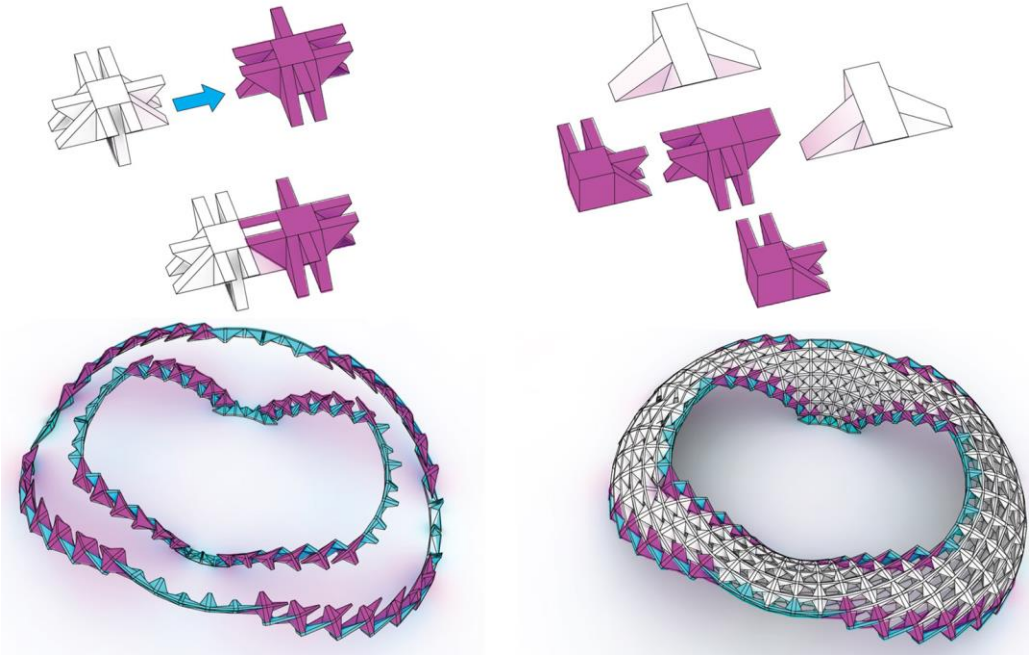
Incas were right too!

Walls of the Sacsayhuaman ruin at Cusco.
By Bcasterline at English Wikipedia [Public domain], via Wikimedia Commons
https://upload.wikimedia.org/wikipedia/commons/a/a8/Walls_at_Sacsayhuaman.jpg

3.
Current Approach

Let’s get creative for a moment

Let’s try a bit harder



Multiple interlocking within between two modules constraint the edges of the assembly [Tessmann 2012]

We have in mind...

Using only convex shapes

It seems to be more interesting if the topological interlocking configuration is based only (when possible) on such shapes.

Least number of different pieces

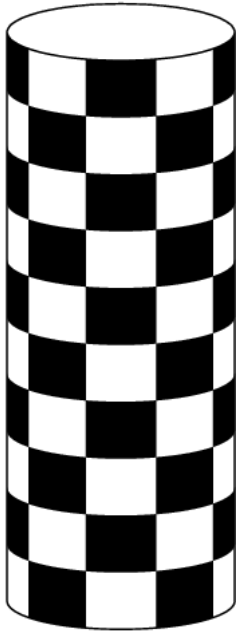
Let’s try to be uniform with the building blocks (when possible).

Build closed surfaces

Given a mesh, how can we build a topological interlocking configuration of it?

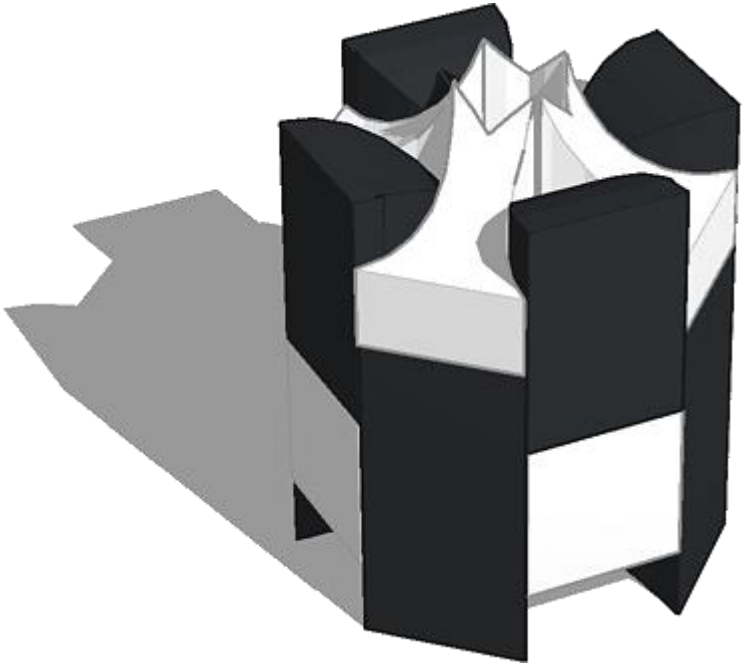
Let's work with a cylinder

- Have a cylinder
- Apply a chessboard texture
- Mark the arrows
- Place the planes
- Make the cuts
- Is that easy?



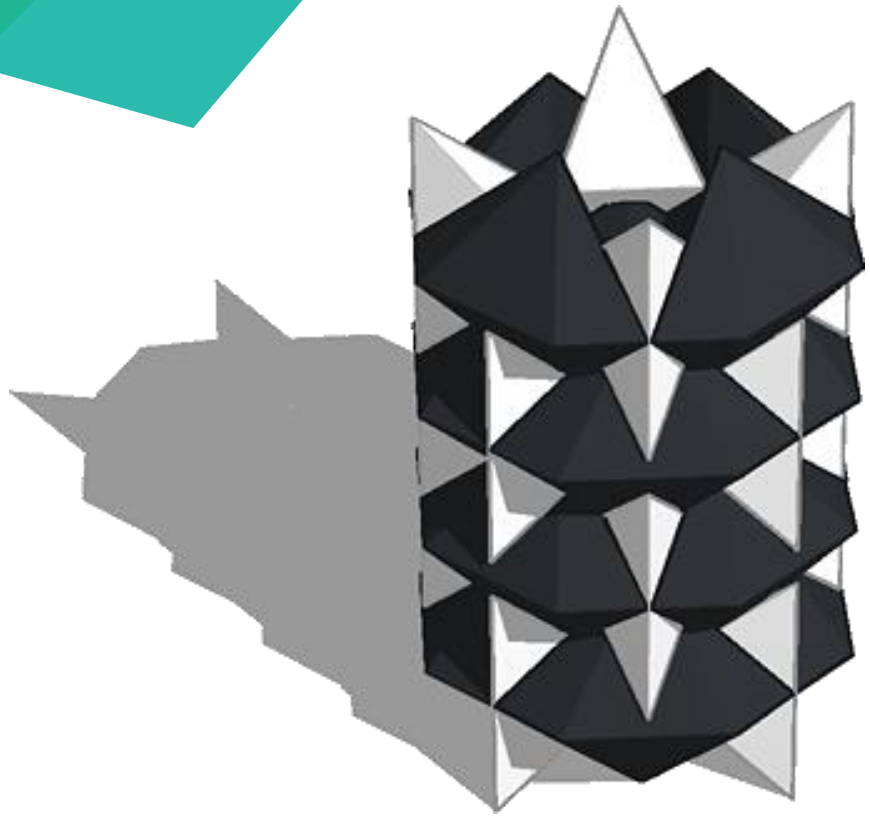
Cylinder Prototype I

- Based on curved faces
- Requires boolean operations using current pieces and conic segments
- Four different pieces



Cylinder Prototype II

- Based on tetrahedral shapes
- Requires simpler calculations
- Two different pieces



4.

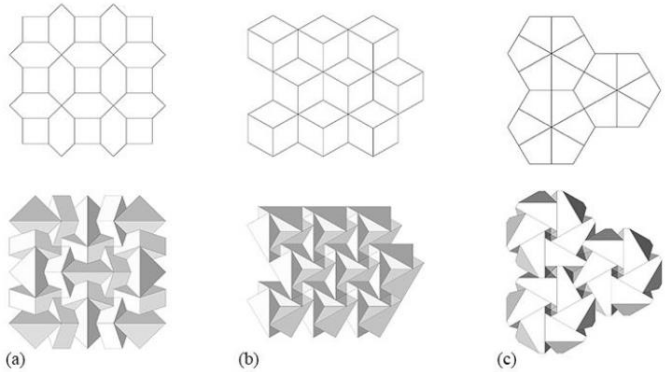
Ideas and Future Work

Going beyond what we know

There are some ideas to follow

Irregular Surface Tessellations

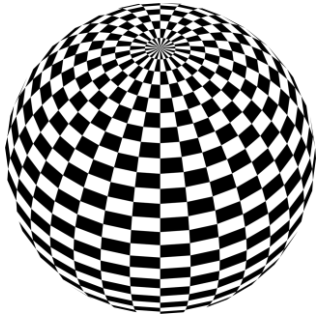
Any non-regular tessellation based on even-faced shapes can be used.



Topological Interlocking In Architectural Design [Weizmann 2015]

Topological Interlocking Sphere

How does it work for a sphere?

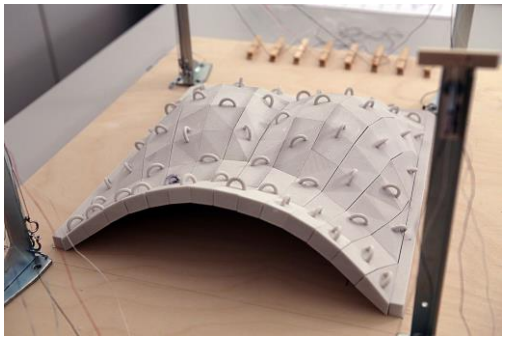


https://openclipart.org/image/2400px/svg_to_png/254937/chessboard-sphere-1.png

There are some ideas to follow

Reducing Support Structure

1) Required during the building process
2) Required for a stable state after building



http://vcl.cs.dartmouth.edu/news/2015/2/19/assembling-self-supporting-structures

Topological Interlocked Bunny

Let's add another one to the collection!

Global Conformal Parameterization - Holomorphic 1-Form [Gu, Zeng 2003]

Thanks!

Any questions?

You can find me at:

@andresbeja87

abejara@purdue.edu

https://www.cs.purdue.edu/homes/abejara/

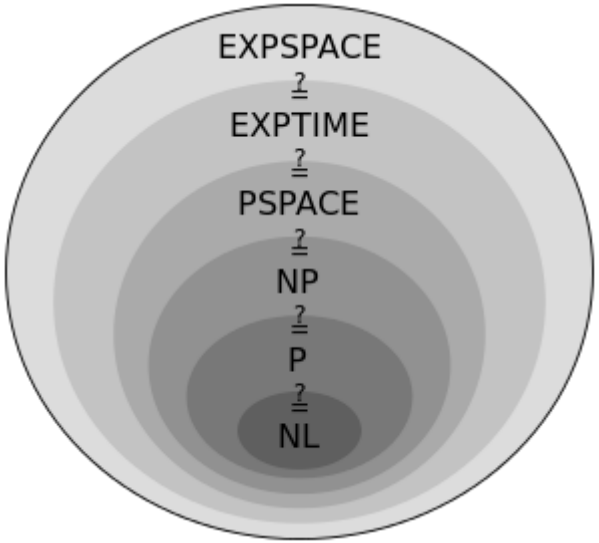
Credits

Special thanks to all the people who made and released these **awesome resources** for free:

- Presentation template by SlidesCarnival
- Photographs by Unsplash

PSPACE

- The set of all decision problems that can be solved by a Turing machine using a polynomial amount of space.
- P=PSPACE?



https://en.wikipedia.org/wiki/PSPACE