# Mechanical Comparison of Arrangement Strategies for Topological Interlocking Assemblies

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Dec 2023

# Topological Interlocking

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and triangular faces

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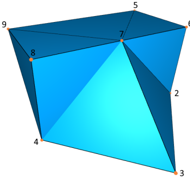

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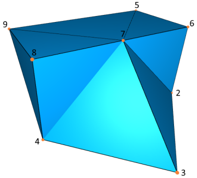


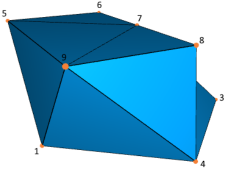

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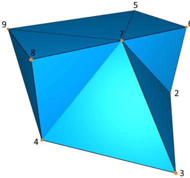

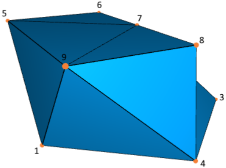

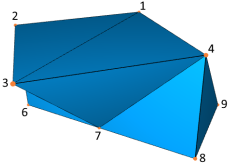

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Crystallograhpic/Wallpaper Groups Let $\Gamma \leq E(n)$ a subgroup of the group of isometries of dimension $n$.
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### Proposition ([1, Prop. 1.9])

Let $\Gamma \leq E(n)$.
Then $E(n)/\Gamma$ is compact iff the orbit space $\mathbb{R}^n/\Gamma$ is compact.

# Examples of wallpaper groups

$p1 :=$

$$\left\langle \left( \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \begin{pmatrix} 1 \\ -1 \end{pmatrix} \right), \left( \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \begin{pmatrix} 1 \\ 1 \end{pmatrix} \right) \right\rangle$$

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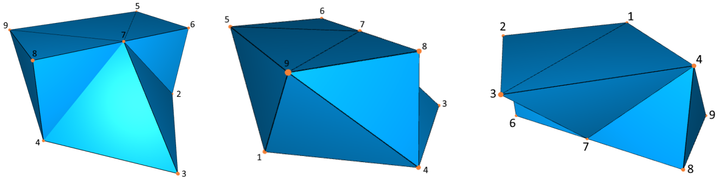

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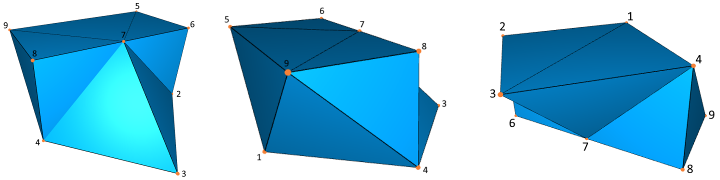


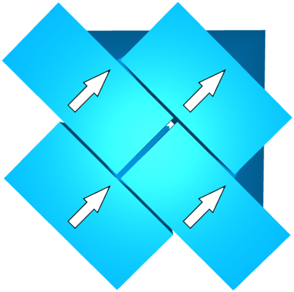

**Notice:** Versatile Block has only vertices with $z = 0$ and $z = 1$.
Now consider the an isometry $\varphi$ from before lifted to $\mathbb{R}^3$ by

$$\hat{\varphi} : \mathbb{R}^3 \to \mathbb{R}^3, \begin{pmatrix} x \\ y \\ z \end{pmatrix} \mapsto \begin{pmatrix} \varphi \begin{pmatrix} x \\ y \end{pmatrix} \\ z \end{pmatrix}$$

Applied to all coordinates of the vertices of the Versatile Block we get a Versatile Block between the same planes.

# Planar Assemblies of the Versatile Block

With the groups $p1$, $pg$ and $p4$ from before we get three interlocking assemblies consisting only of copies of the Versatile Block:



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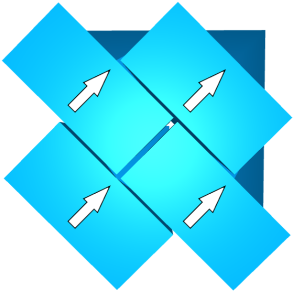

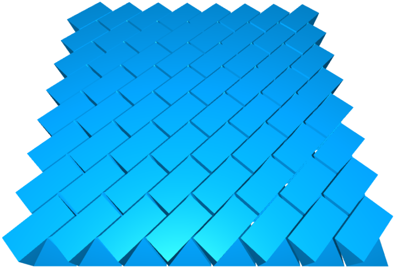

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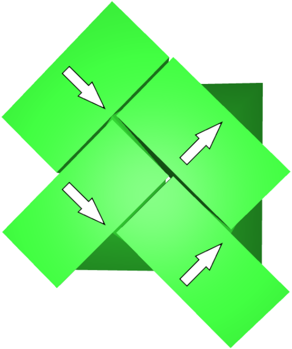

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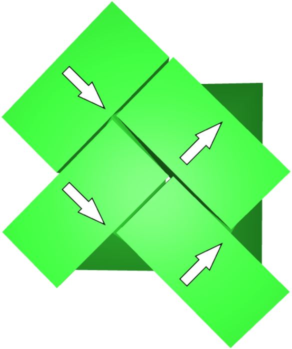

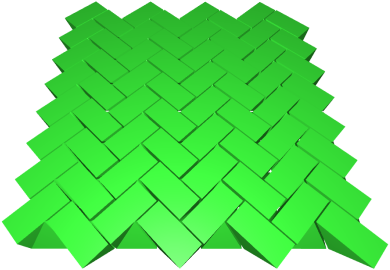

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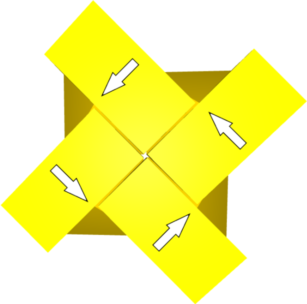

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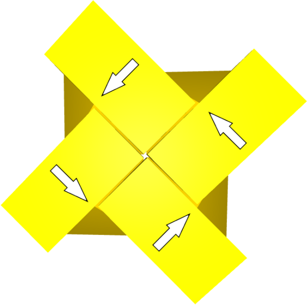

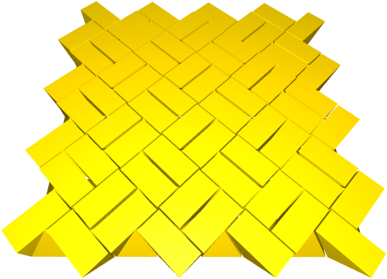

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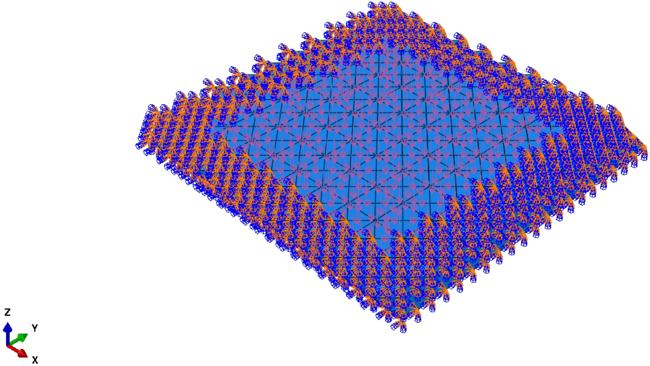

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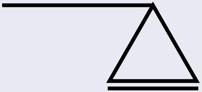

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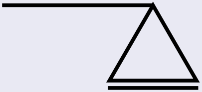

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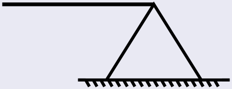

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# Simulation workflow

Generate geometries in GAP

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Run simulation

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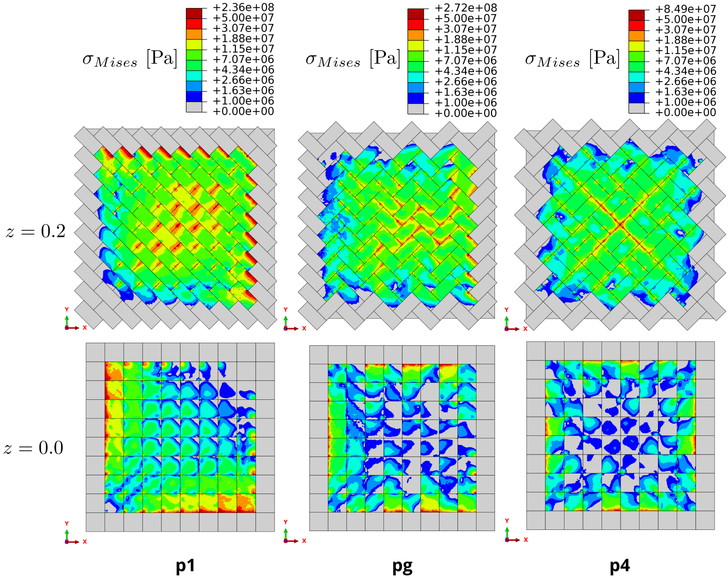
4. Make an Ansatz

# Stresses


$\sigma_{Mises}$ [Pa]
+2.36e+08
+5.00e+07
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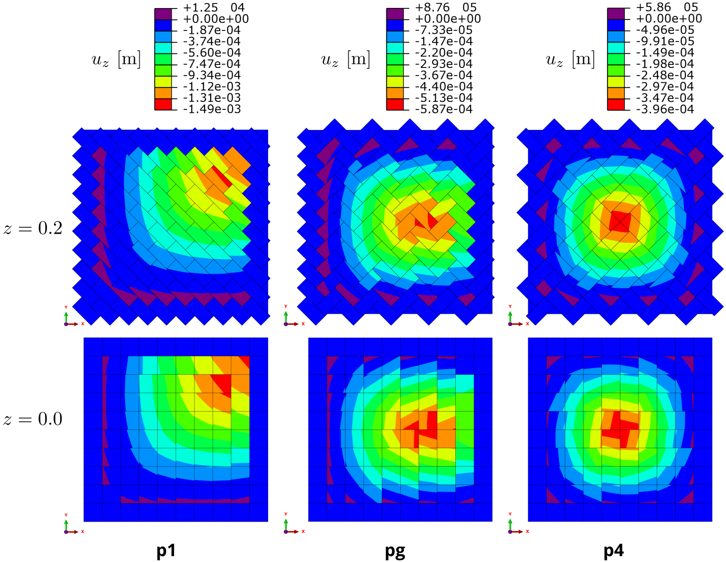
Y
X
p1
pg
p4

# Deformations



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The *Directional Blocking Graph* $\mathcal{G}(A, d)$ is defined as the directed graph with

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- arcs $i \to j$ if $X_i$ is restrained by $X_j$ in direction $d$ for $i, j \in I$.

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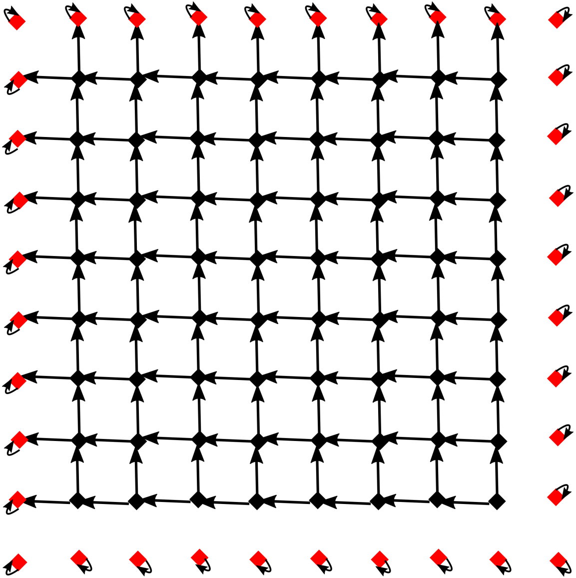
so a block divides the load between the two neighbors of it if it is in the core.

Can be viewed as a weighted *adjacency matrix* of $\mathcal{G}$ yielding a flow network with capacity function $v$. Let $x \in \mathbb{R}^{100}$ a load vector with the amount of force applied to block $i$ in $x_i$.
For $k$ high enough $A^k \cdot x$ yields the amount of load transferred into the frame.

# Combinatorial Results



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| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 6.43 | 5.93 | 5.32 | 4.61 | 3.81 | 2.92 | 1.98 | 1.00 | 0 |
| 6.43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.93 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.61 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3.81 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.92 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.98 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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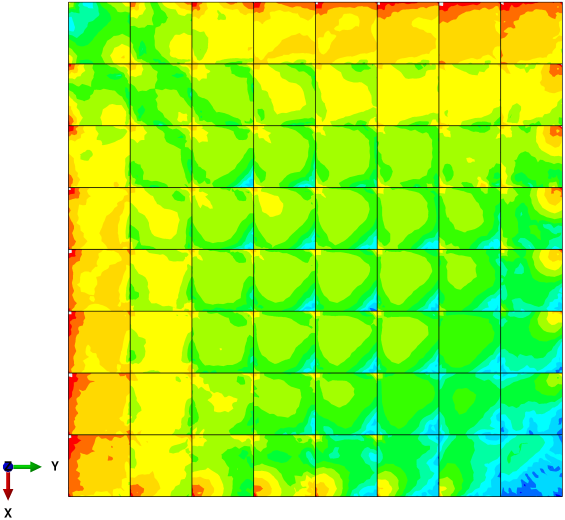

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- Satisfy a wallpaper group $\rightarrow$General Interlocking Assemblies
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The arrangement of a topological Interlocking has a profound influence on the mechanical performance.

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- Satisfy a wallpaper group →General Interlocking Assemblies
- Made from Versatile block →Made from other blocks
- Simulations without friction →Consider friction

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Thank you for your attention

[1] A. Szczepański. *Geometry of Crystallographic Groups*. Algebra and discrete mathematics. World Scientific, 2012.