MIT Class 6.S080 (AUS)

Mechanical Invention through Computation

Expanding Structures – 2D

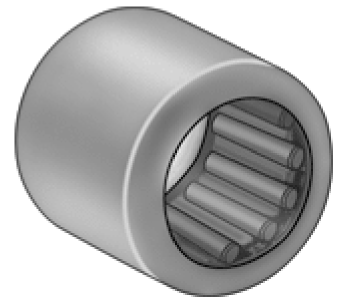
Hardware / Construction Terms

- Slip fit
- Press fit
- Knurl
- Tolerances
- Bearing
- Bushing
- Radial and pivotal forces
- Clearances
- Chamfers
- Sliding friction
- Rolling friction

Bearing types

Ball bearing (sealed)

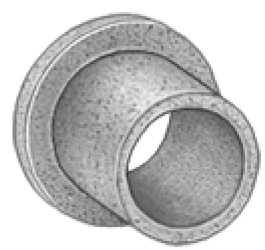
Ball bearing (unsealed)



Needle bearing

Spherical bearing

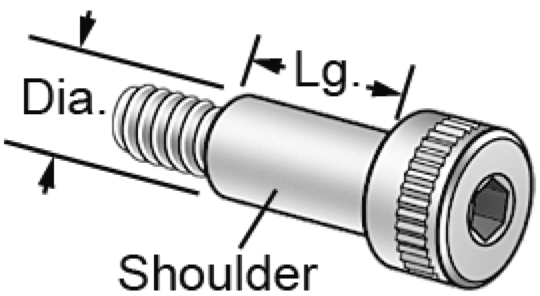
Sleeve bearing (bushing)



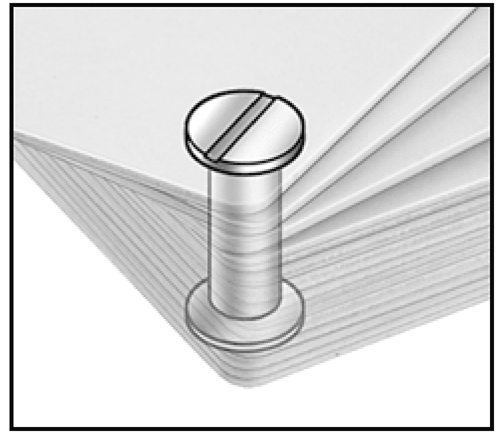
Flanged Sleeve bearing

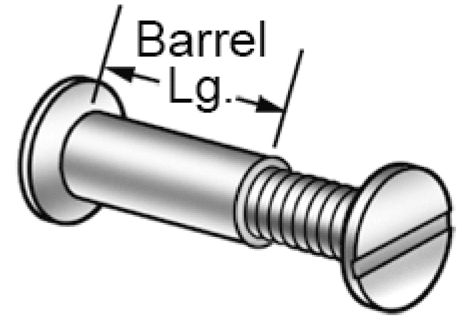
Angled roller bearing

Shaft hardware

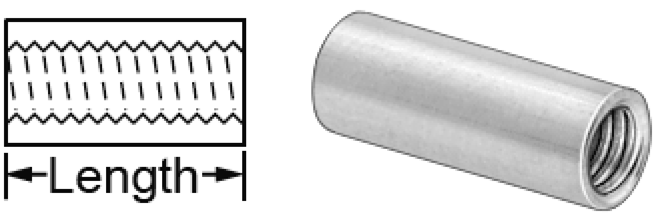


Shoulder screw

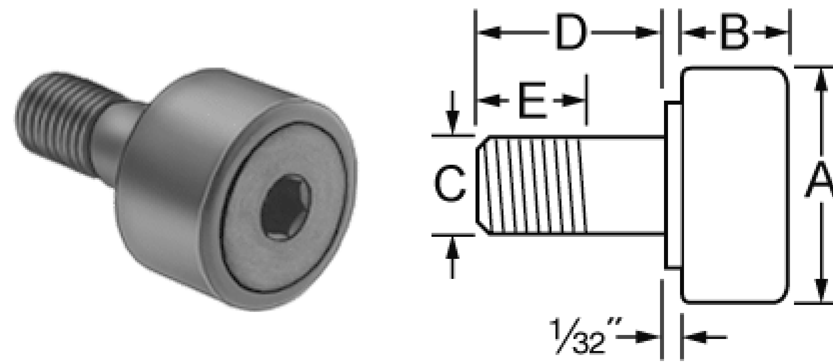




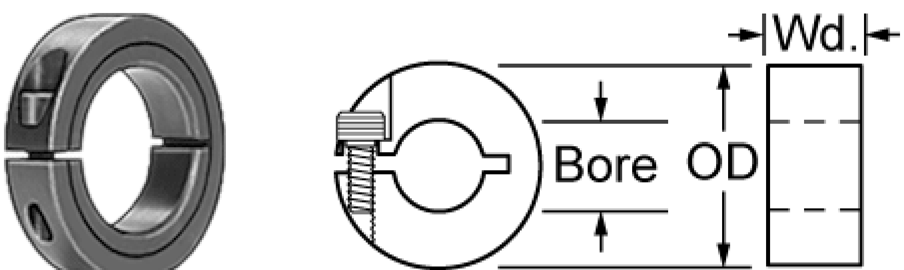
Binding post



Threaded standoff



Cam follower

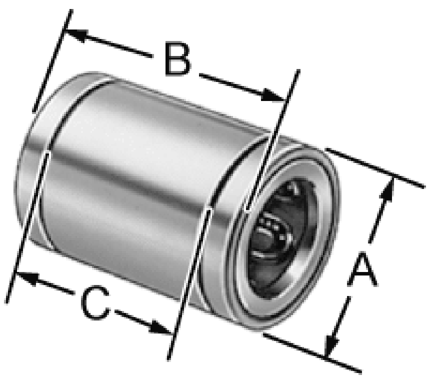


Collar clamp

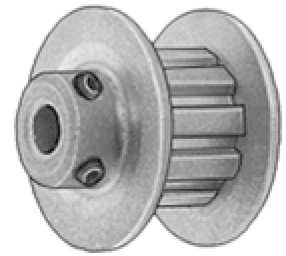
Other motion hardware

http://www.mcmaster.com/

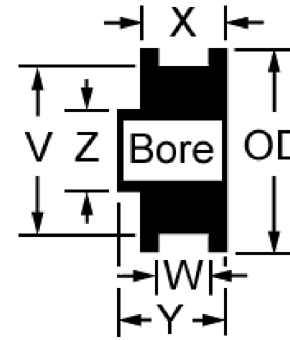
Linear bearing

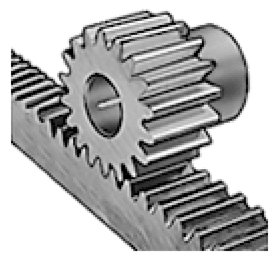


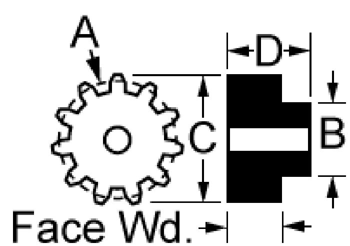
Timing belt



Timing belt pulley





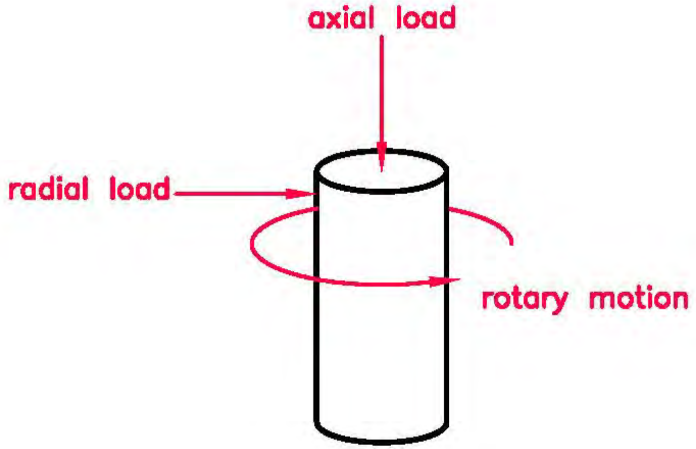


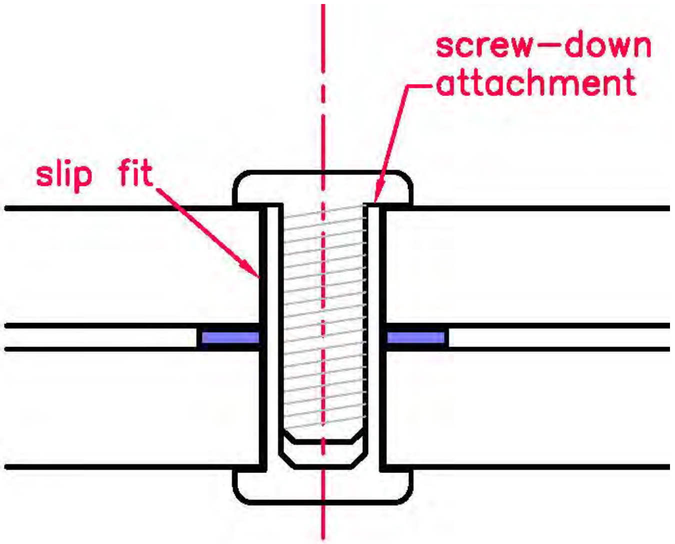
Rack & pinion

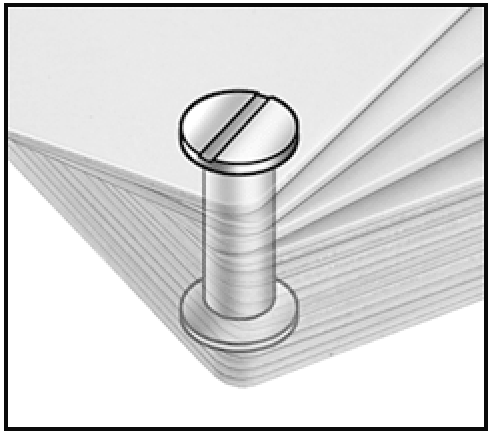
Bearing with rod end

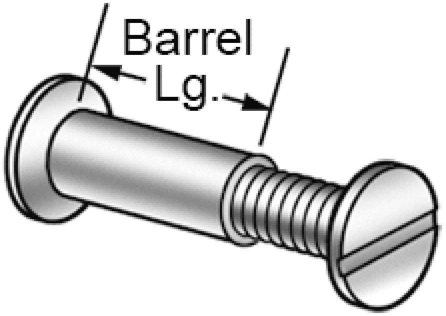
Pivot construction

Binding post connection



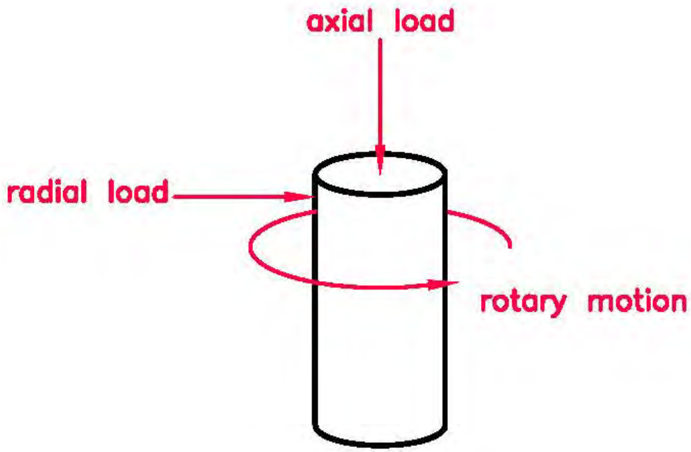


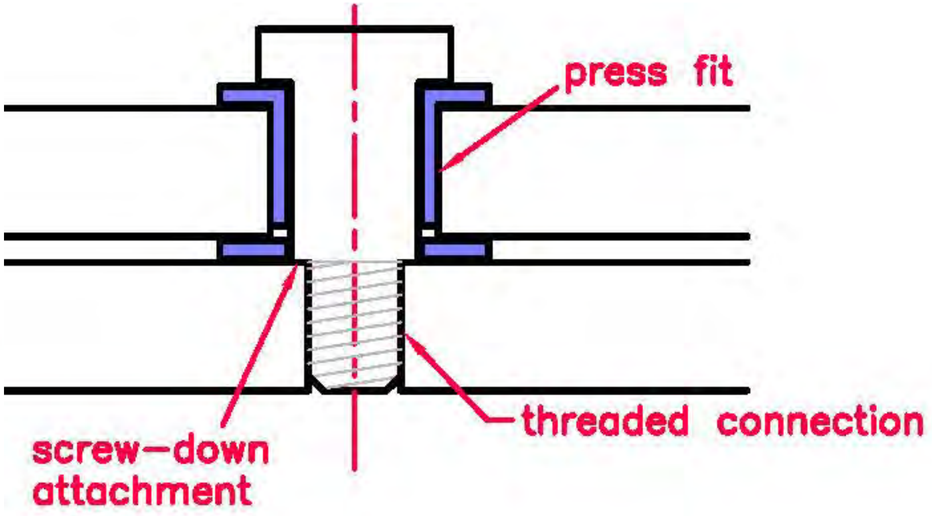


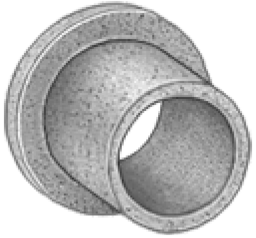


Pivot construction

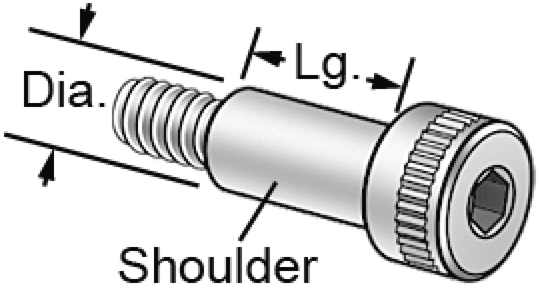
Shoulder screw connection





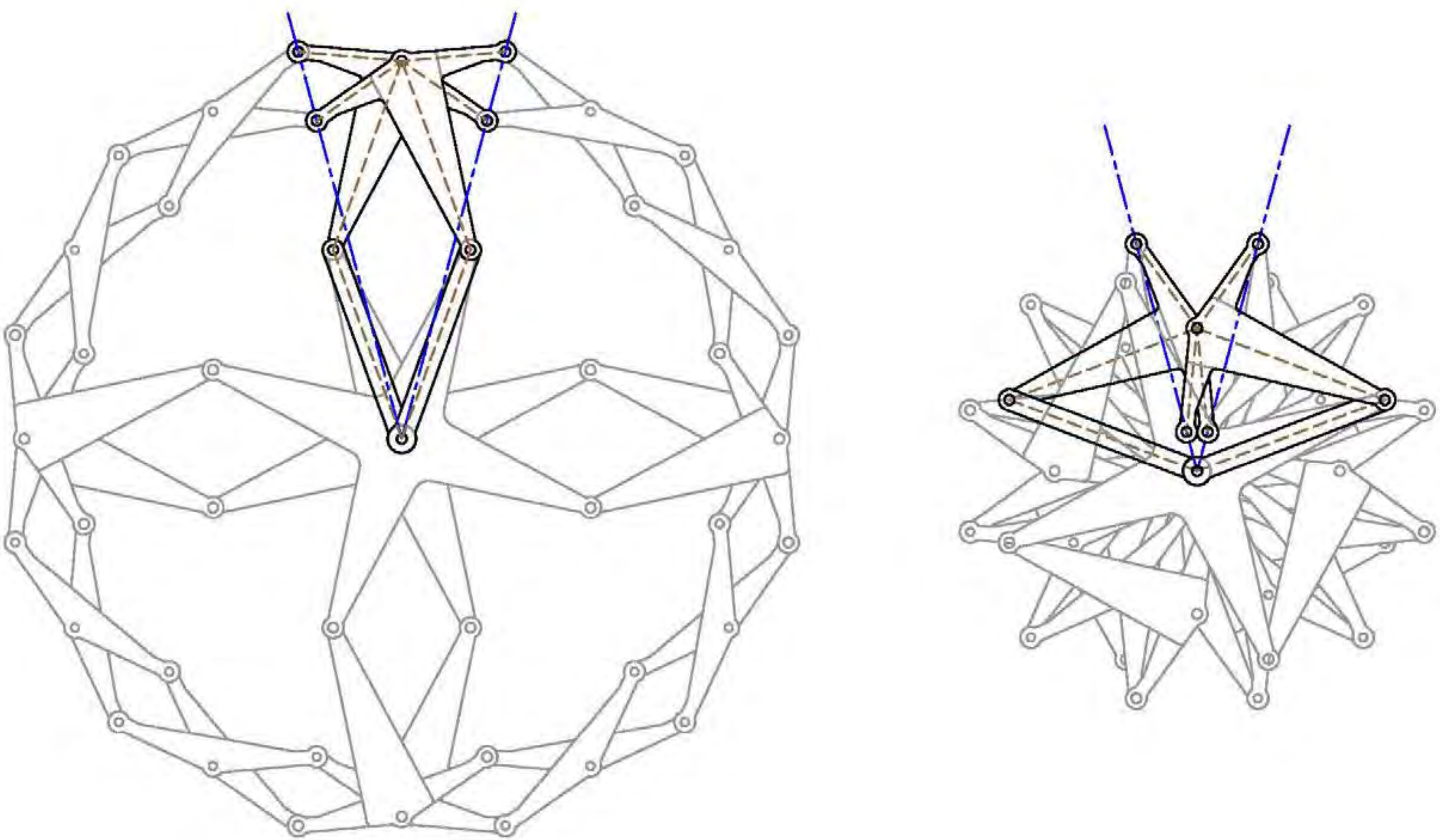


Flanged Sleeve bearing

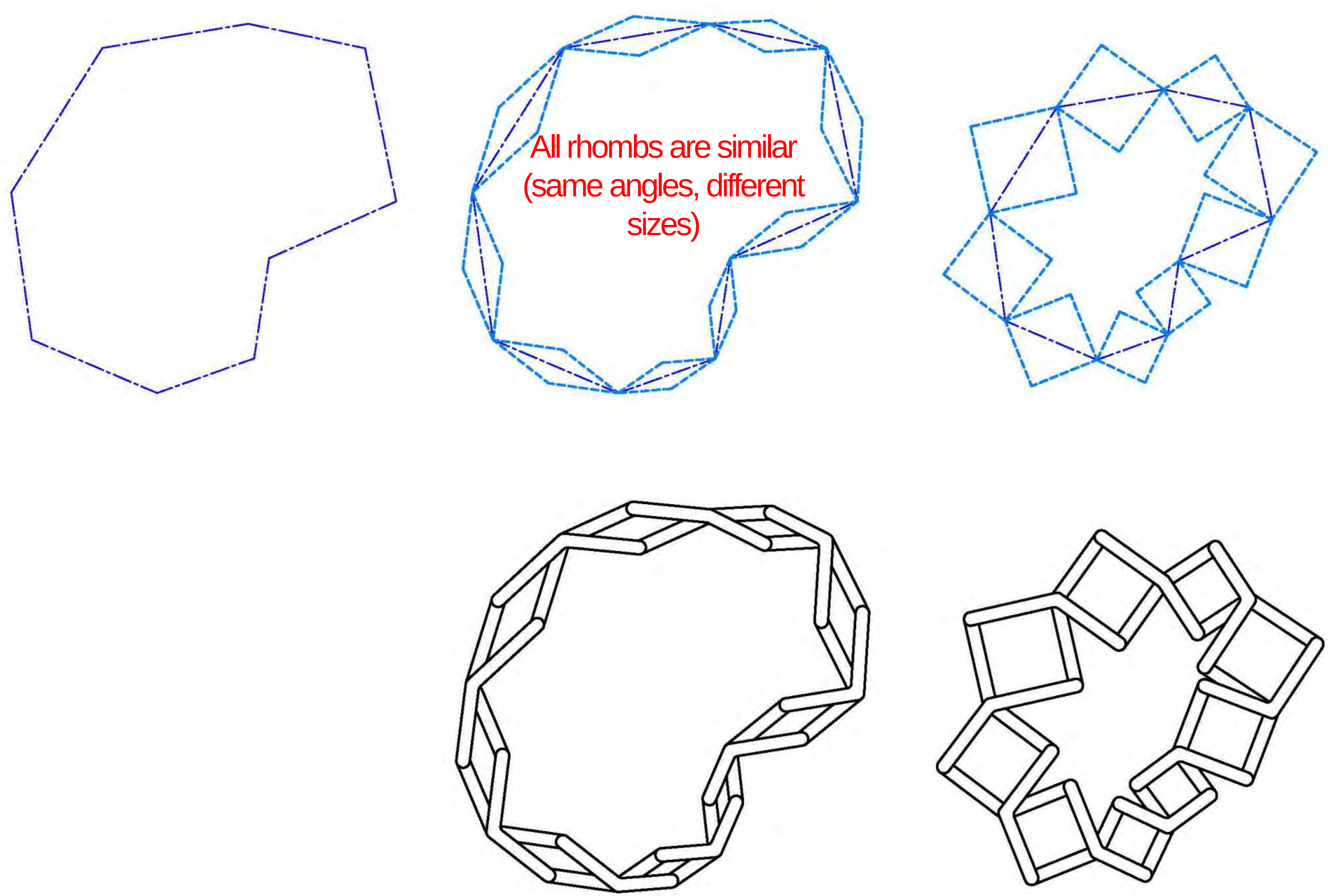


Shoulder screw

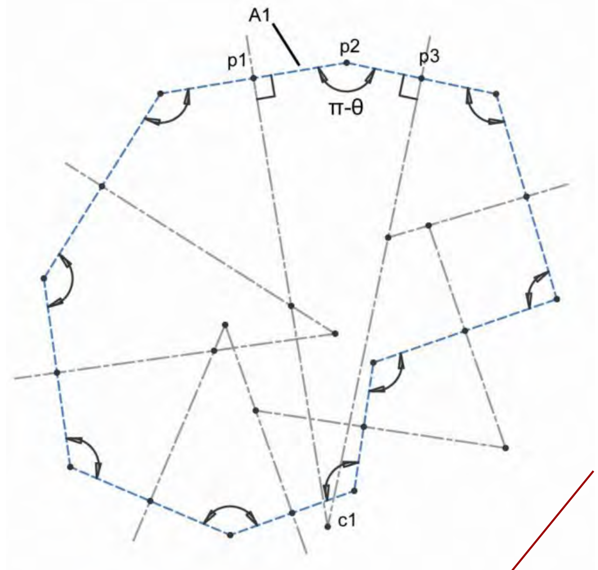
circular linkage with fixed center (four spokes)



Irregular polygon – geometric construction

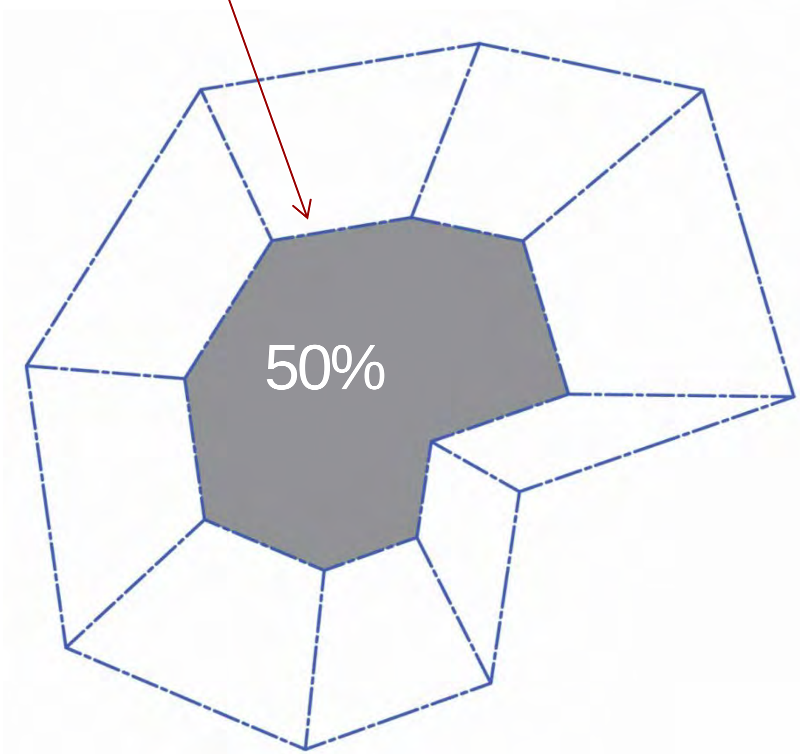


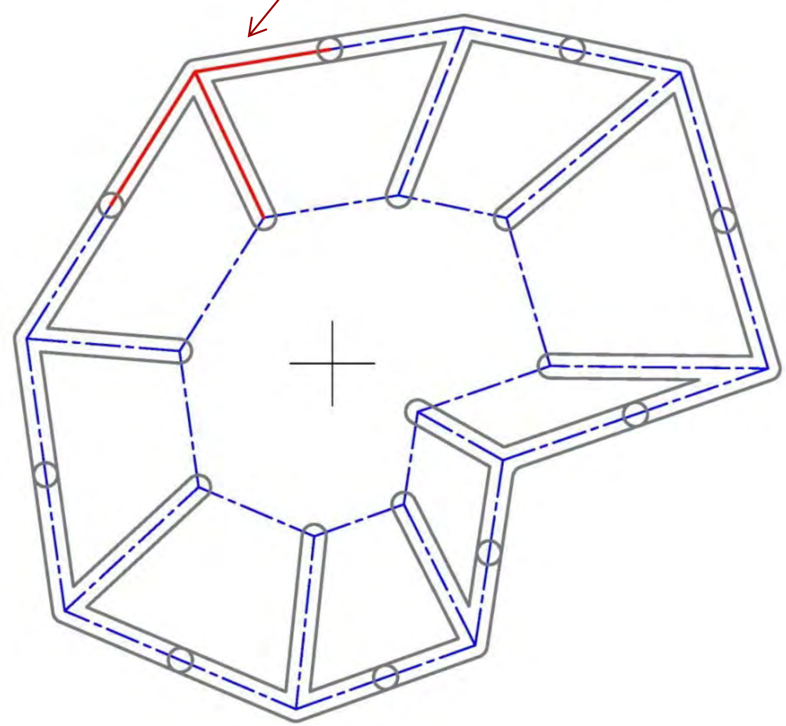
Center link for asymmetric polygon linkages



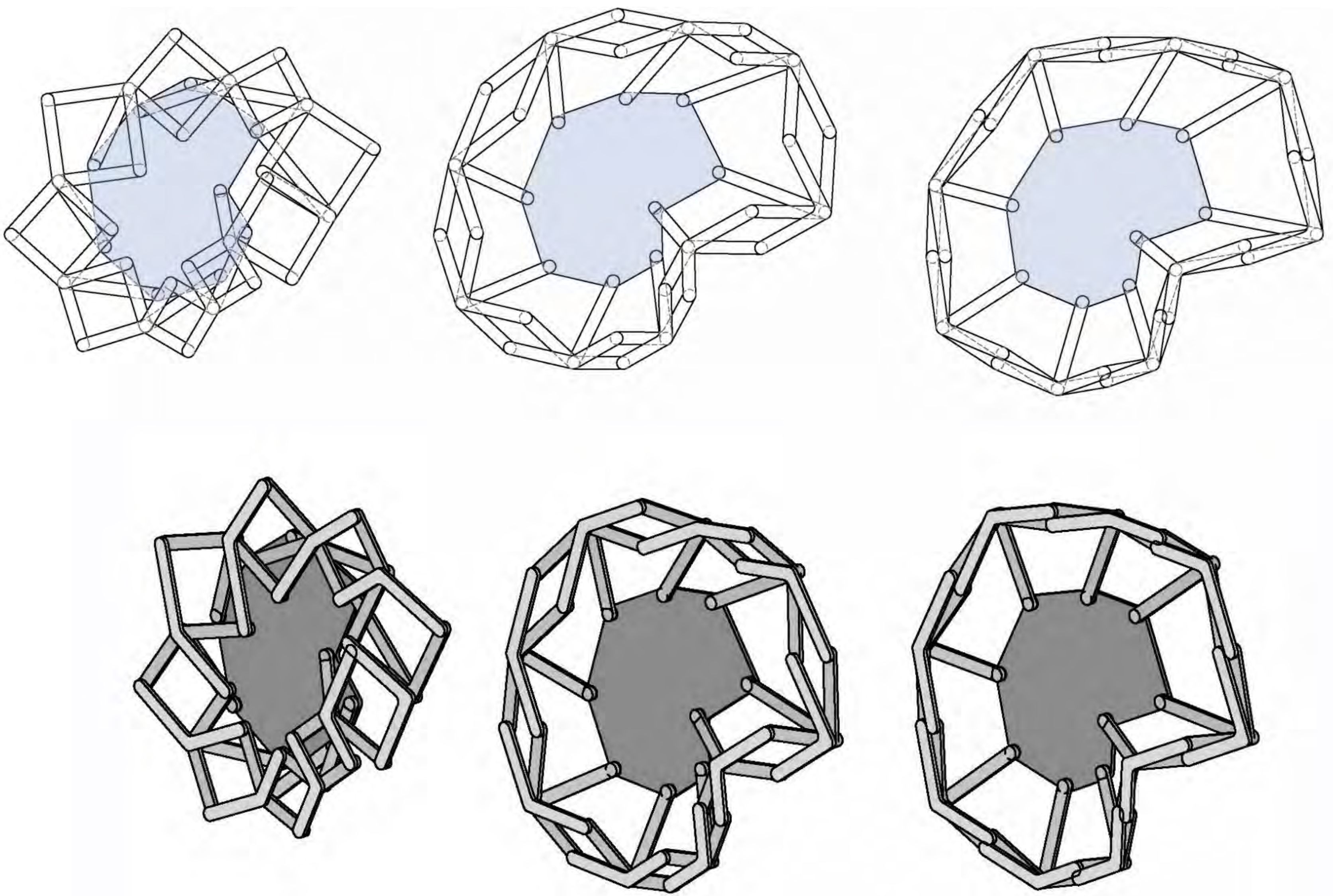
Define center link at 50% scale to original polygon

Define 3-pivot links
As shown

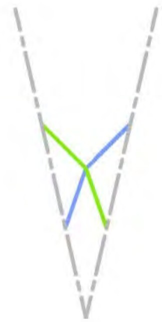




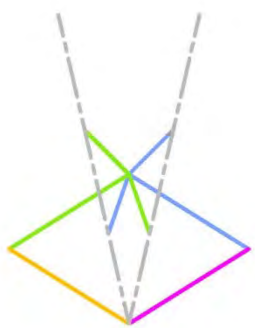
Center link for asymmetric polygon linkages

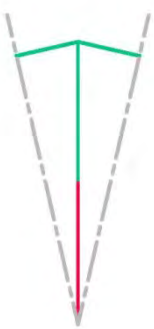


Geometric construction - wheel



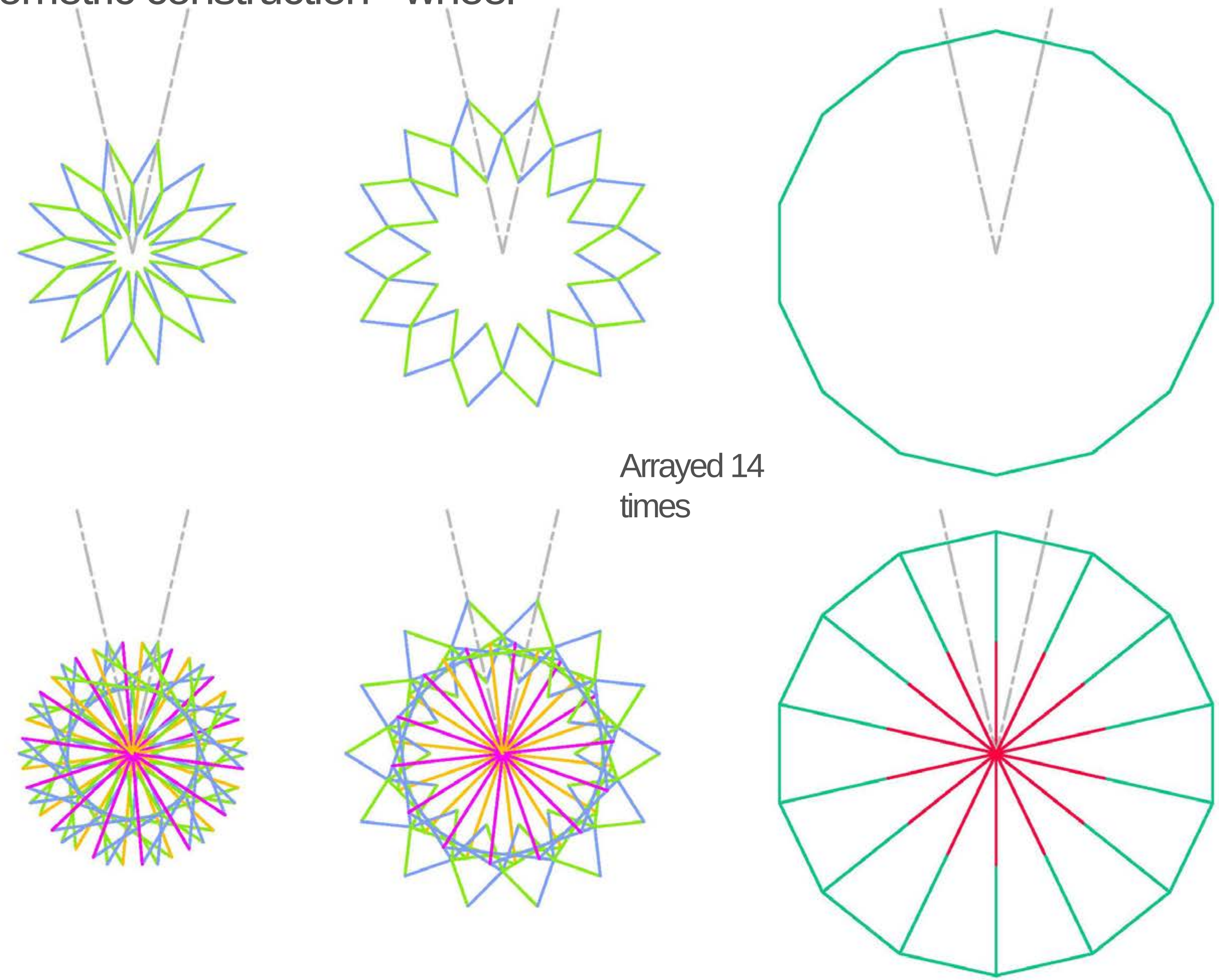
scissor element





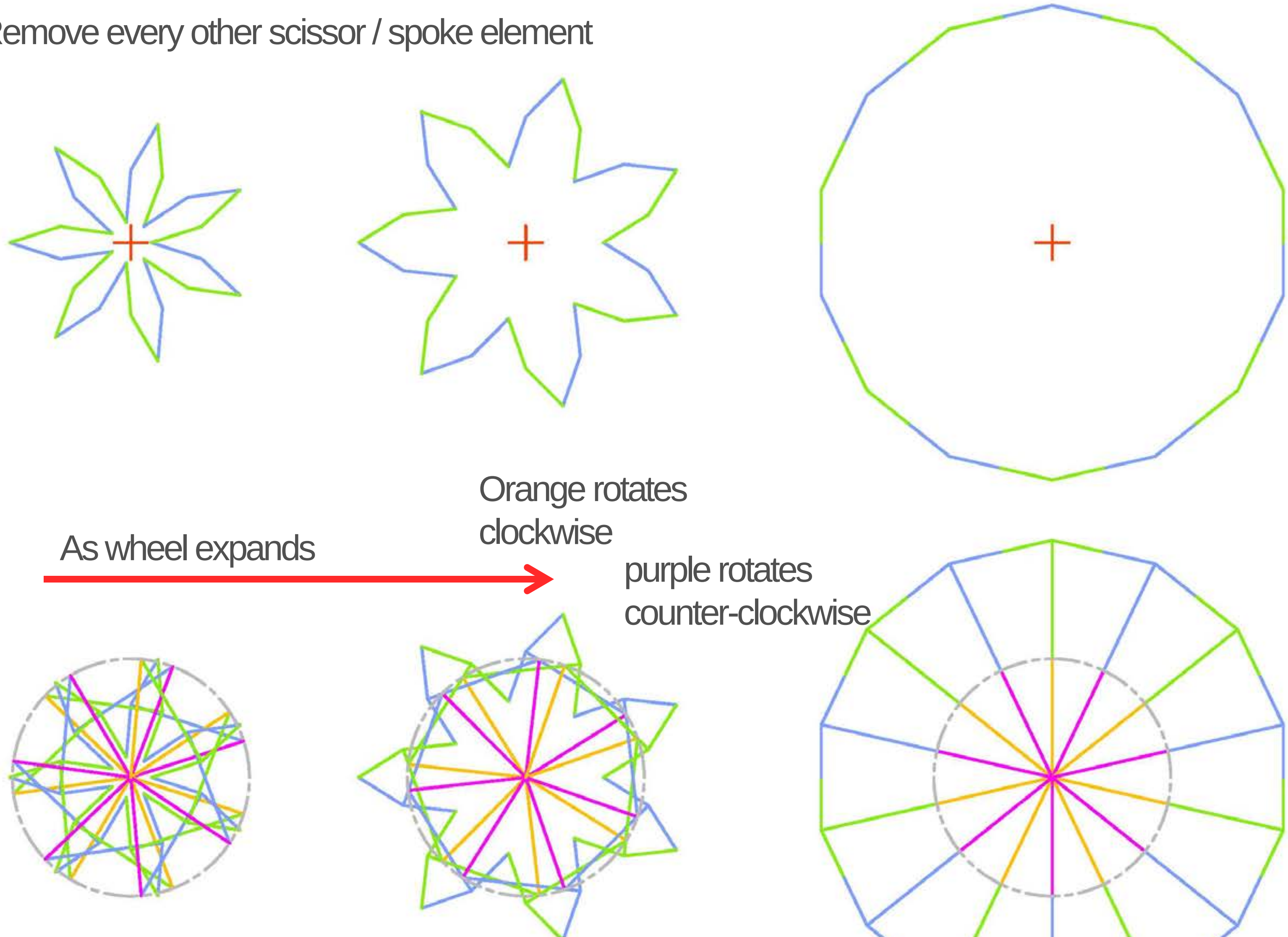
Scissor / spoke element

Geometric construction - wheel

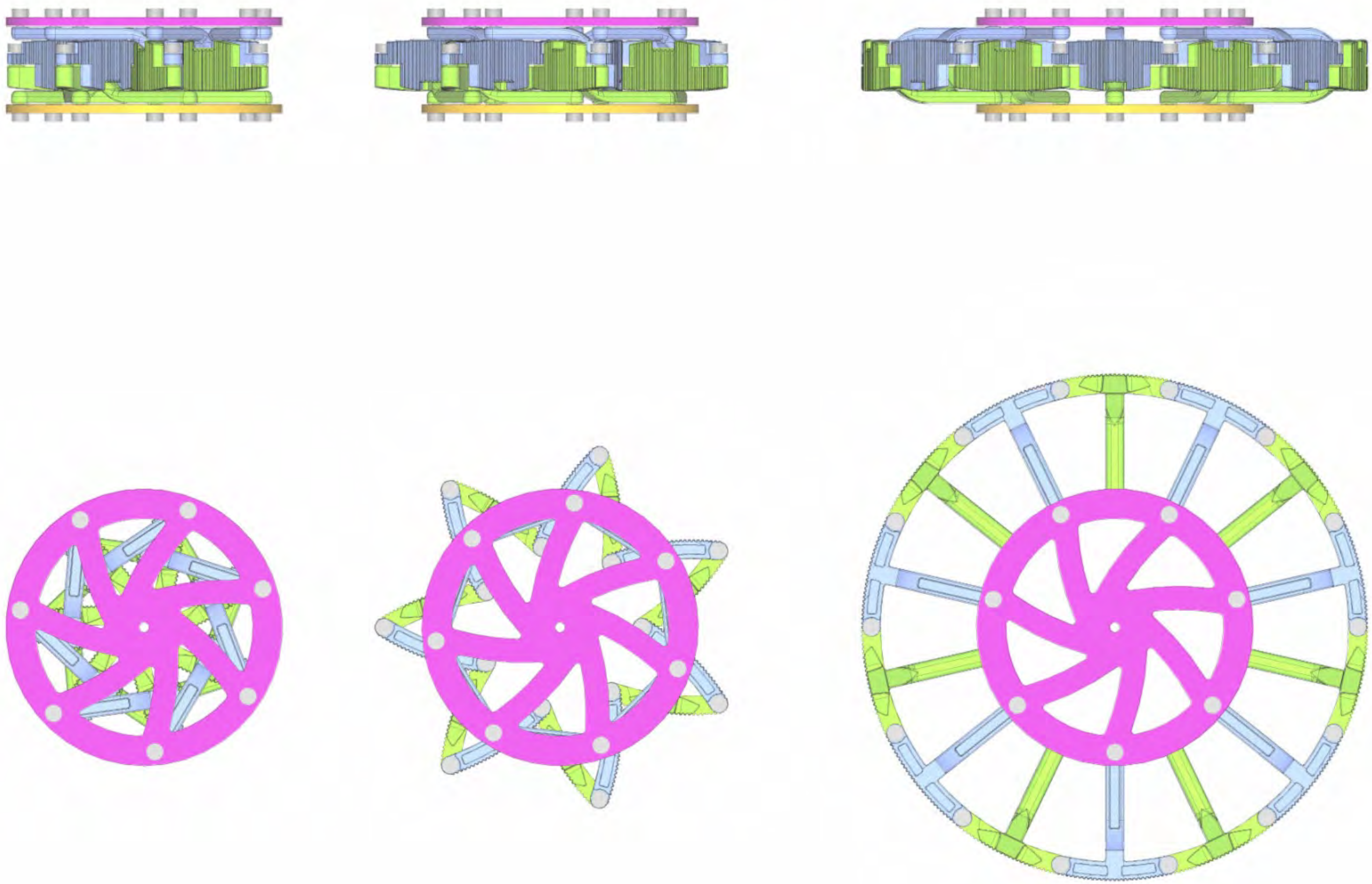


Geometric construction - wheel

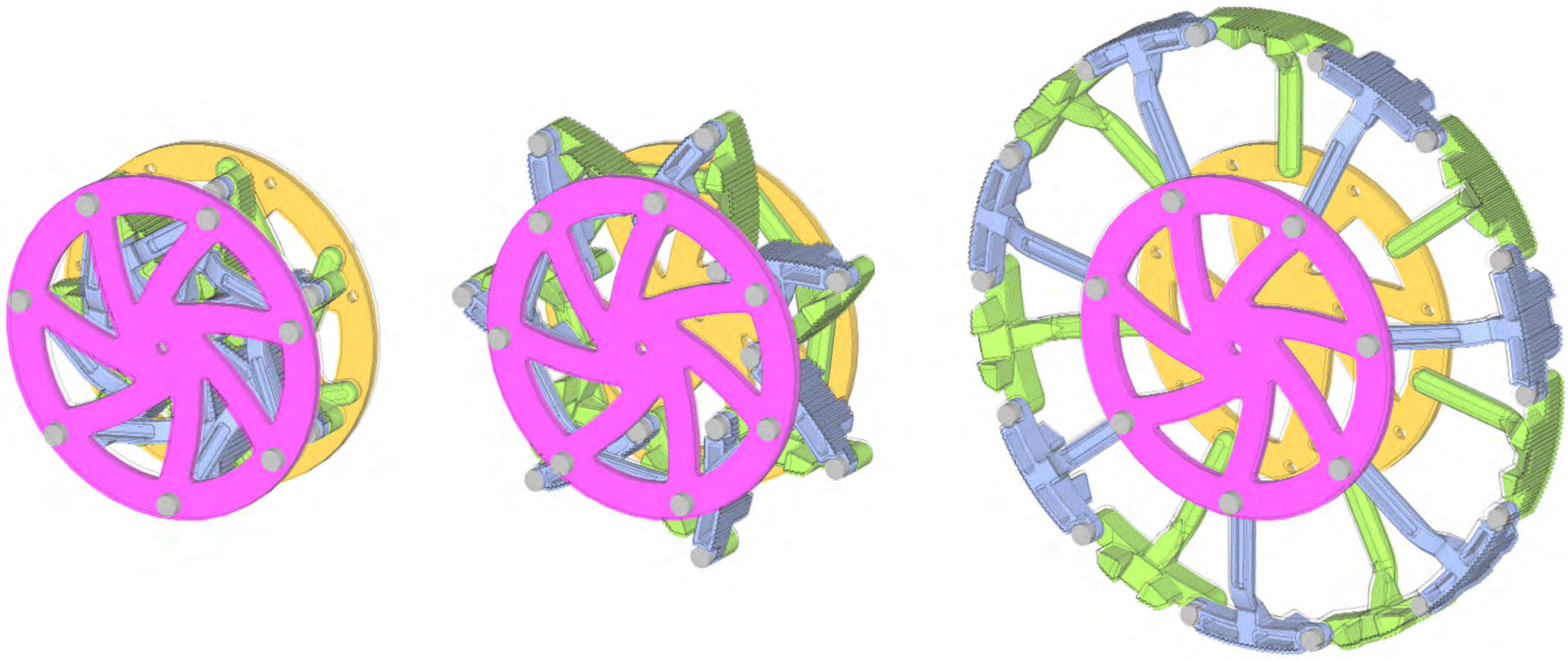
- Remove every other scissor / spoke element



Geometric construction - wheel



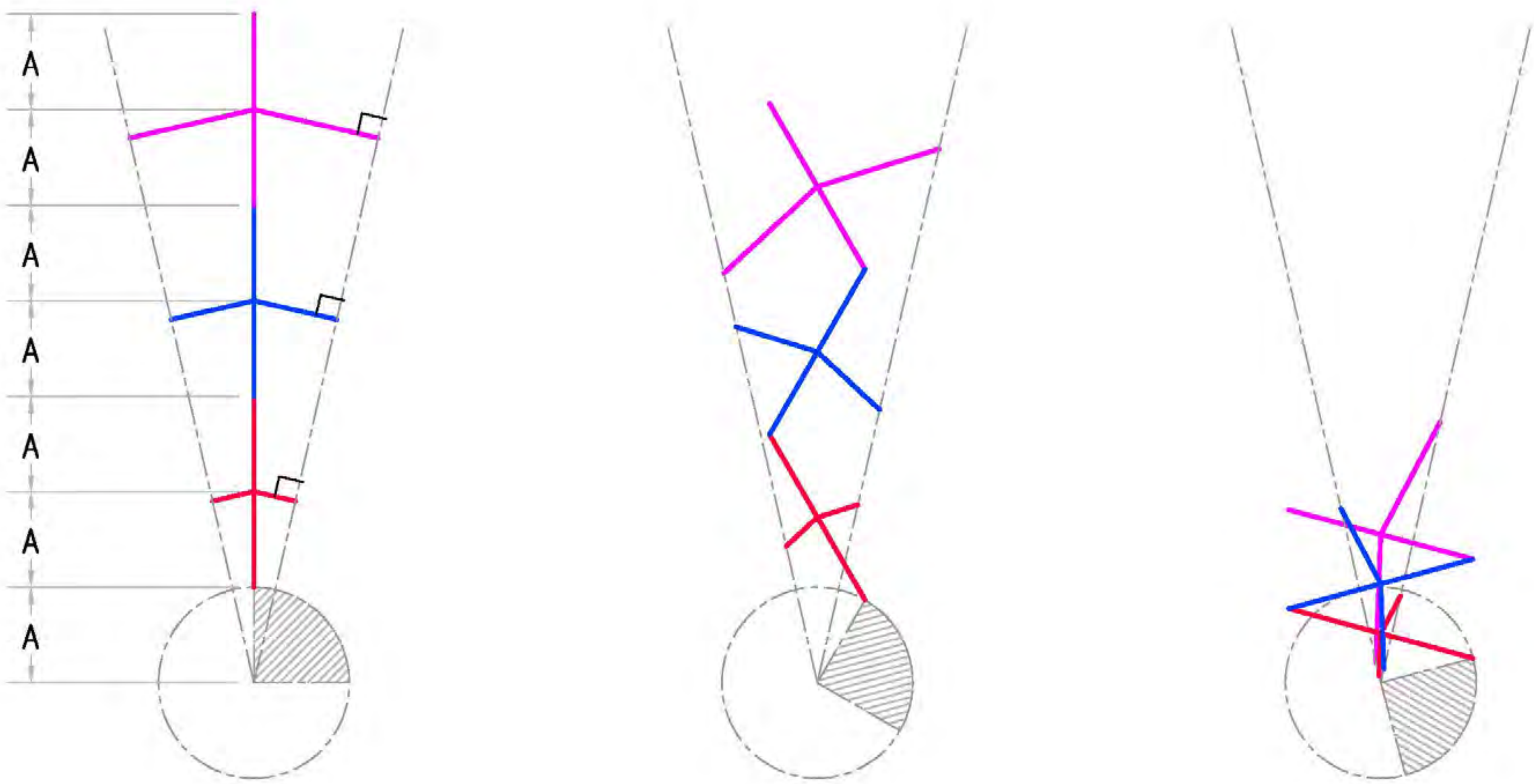
Geometric construction - wheel



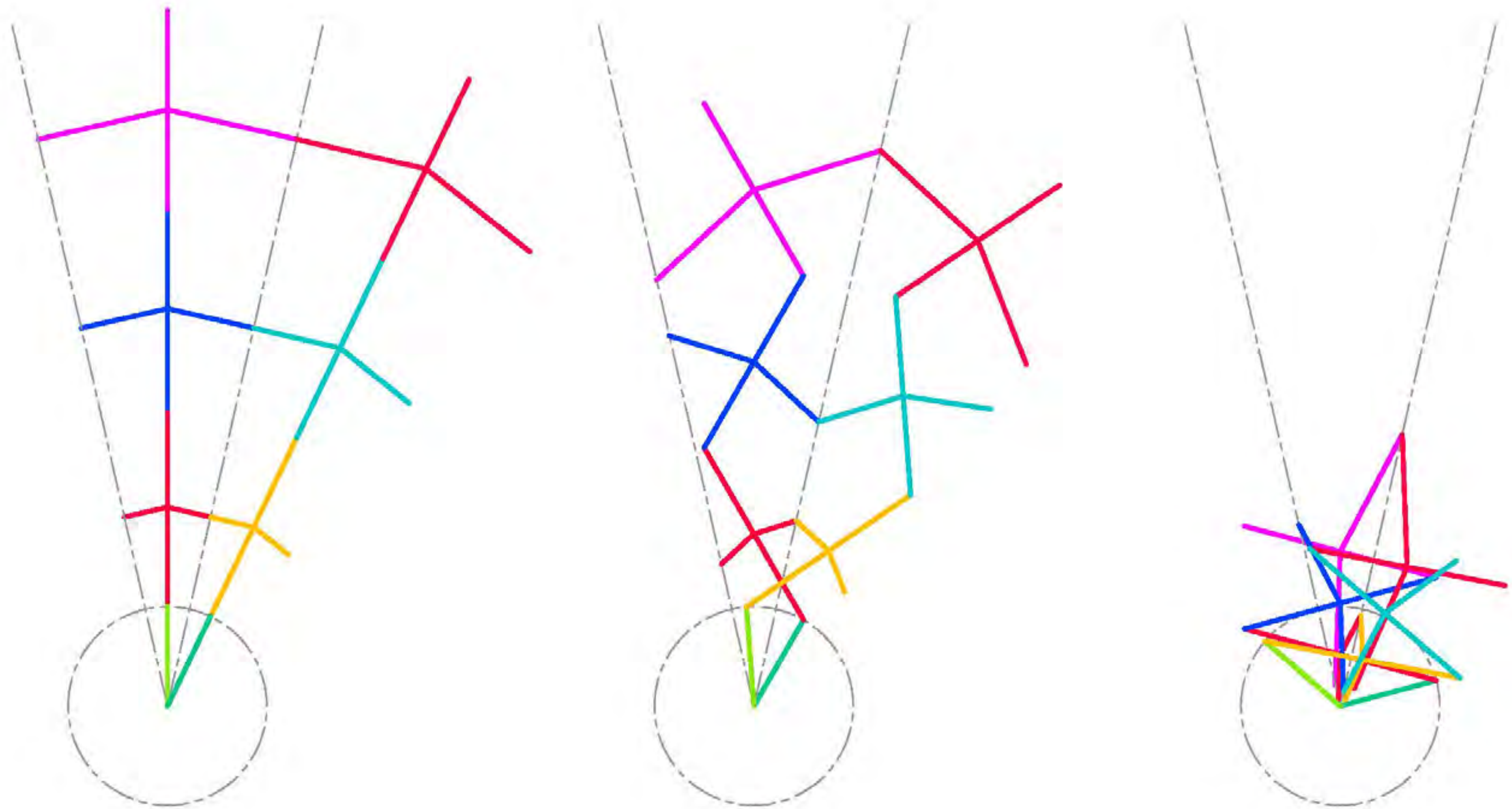
Wheel

Extended expanding wheels

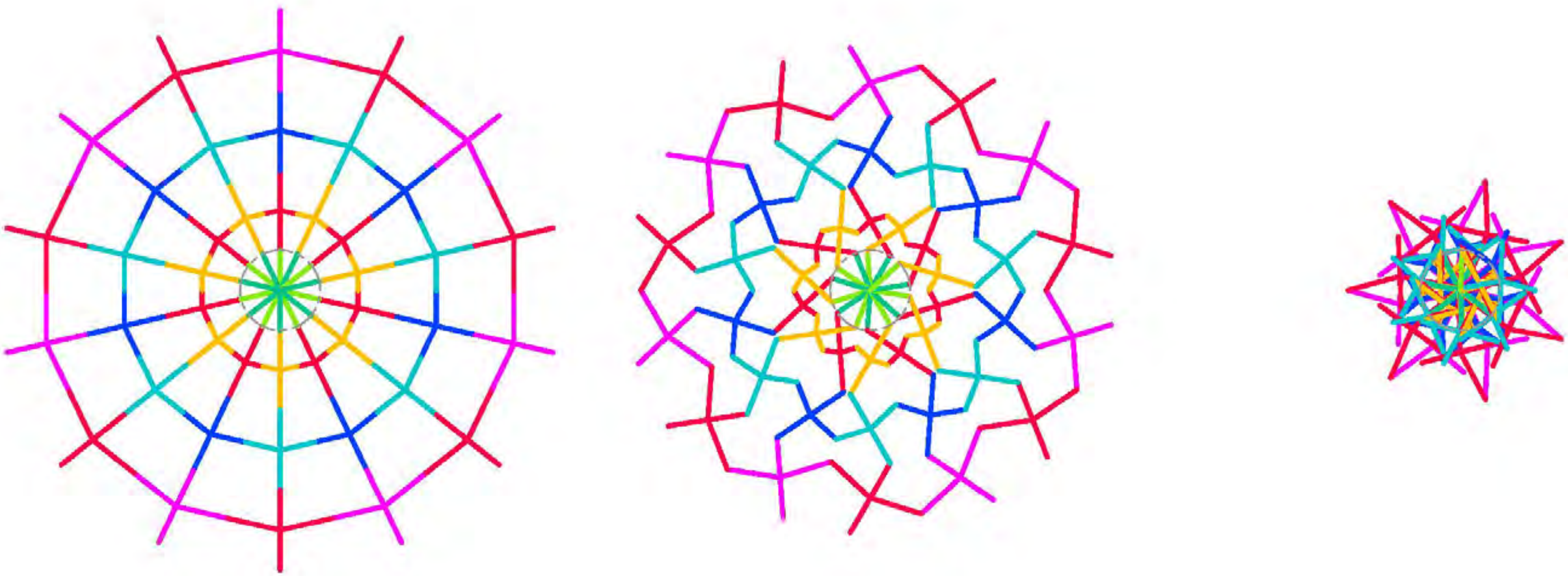
Extended wheel geometry



Extended wheel geometry

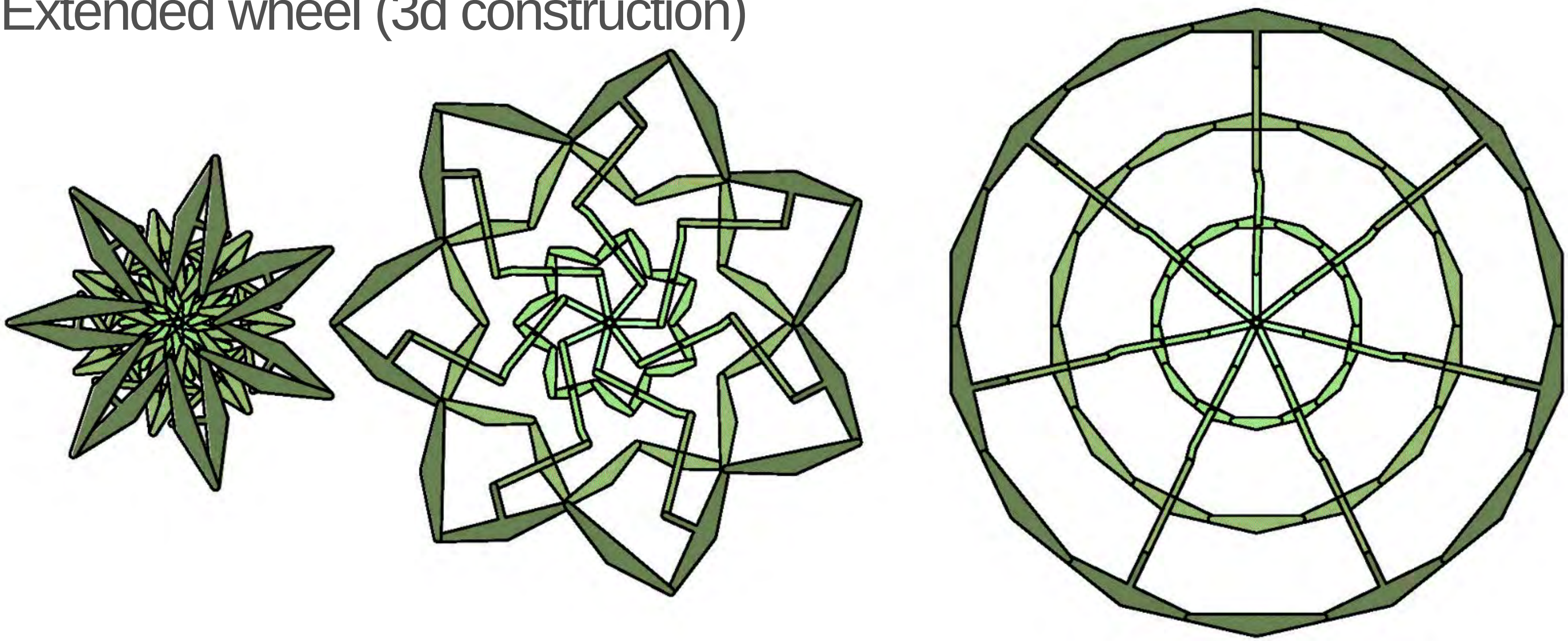


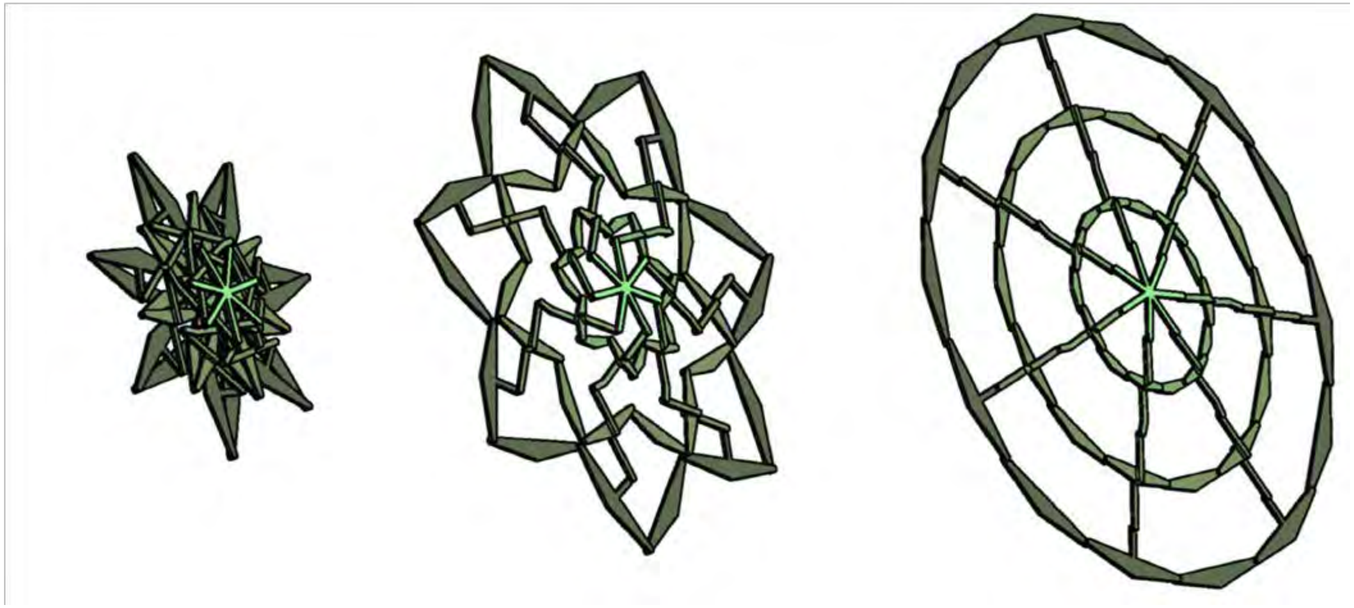
Extended wheel geometry



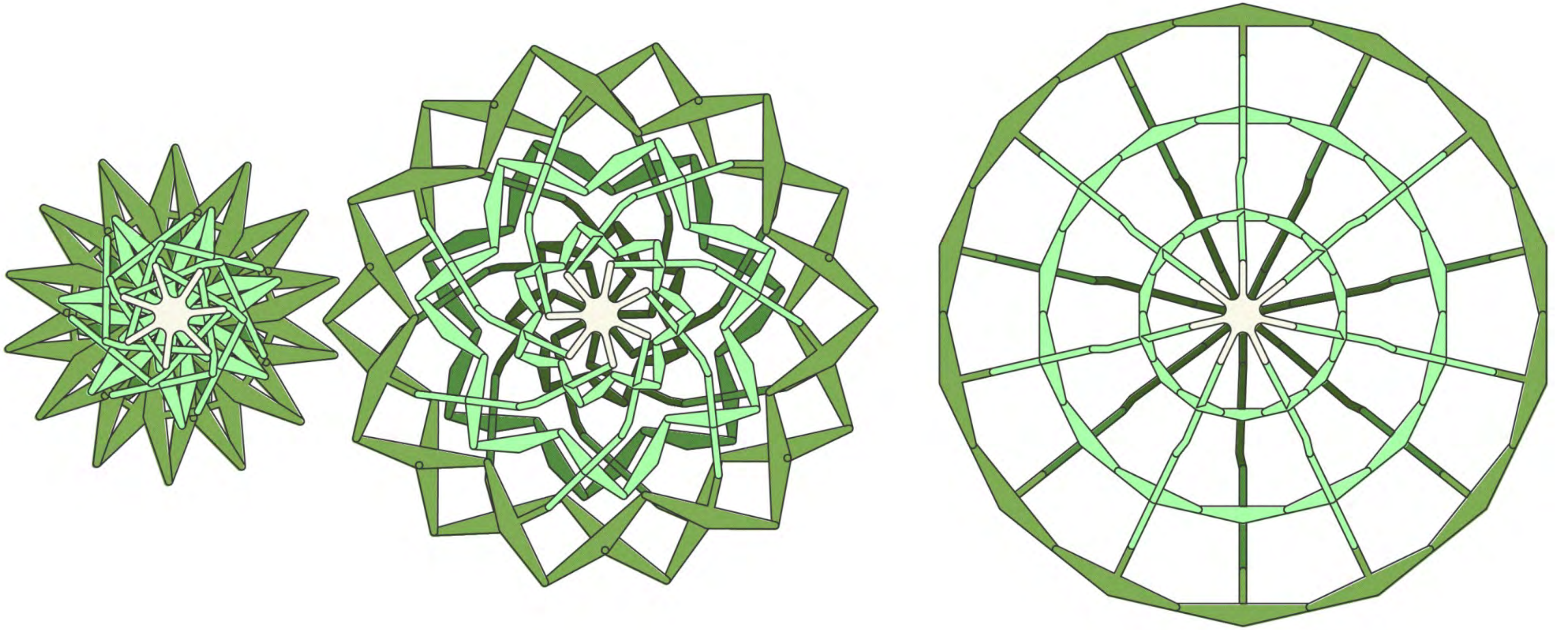
Extended wheel (3d construction)

Extended wheel (3d construction)

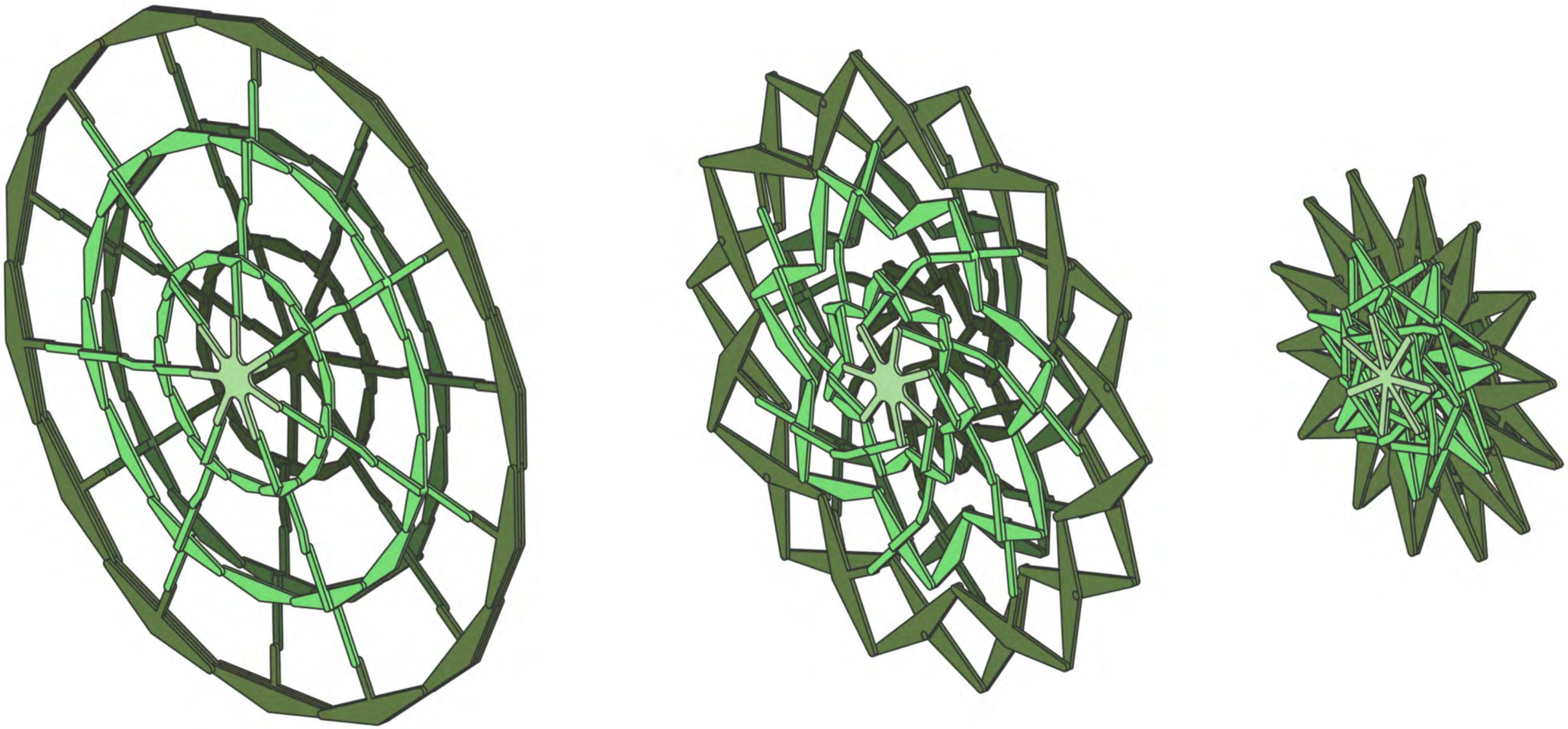




Extended wheel (doubled construction)

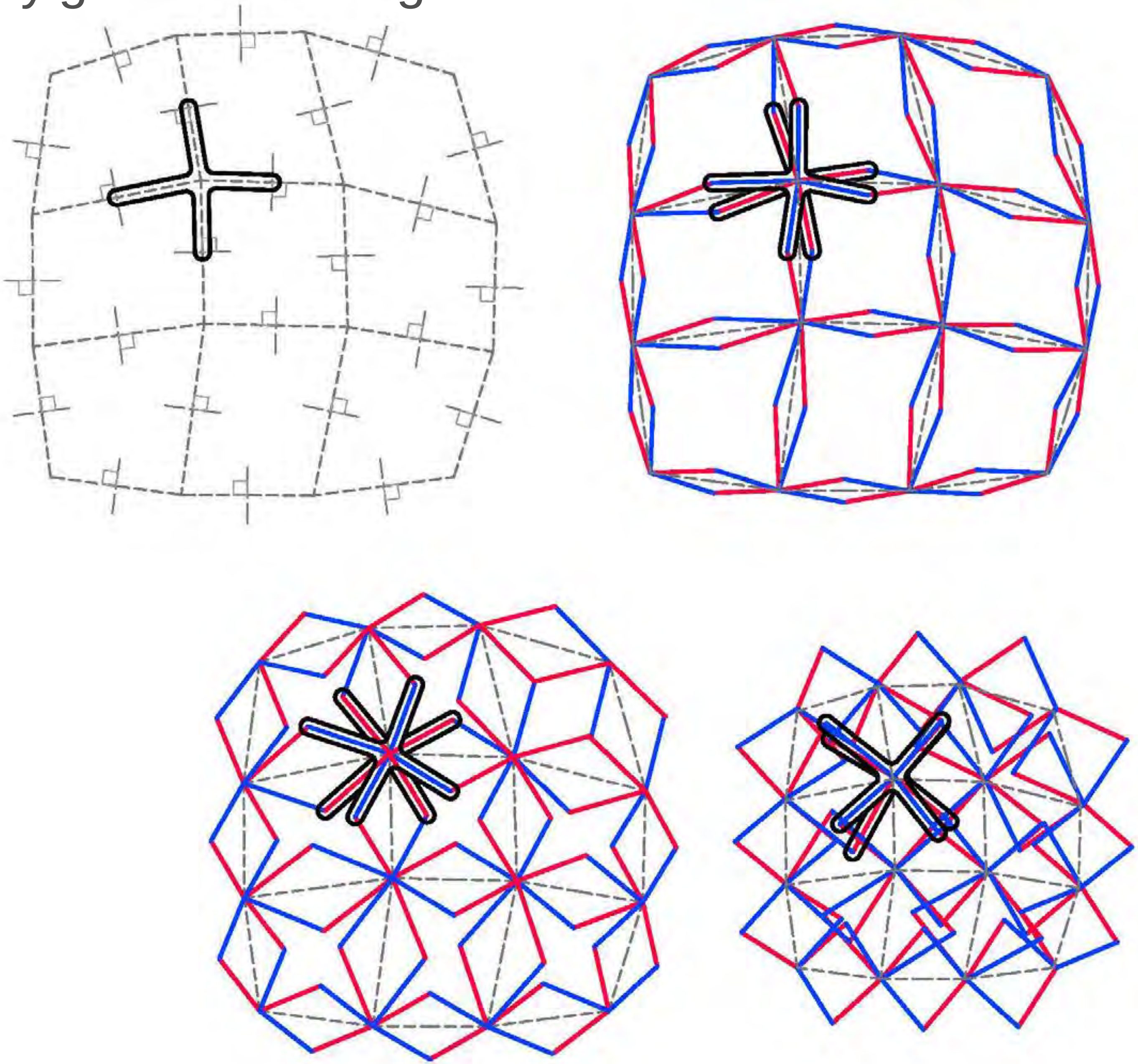


Extended wheel (doubled construction)

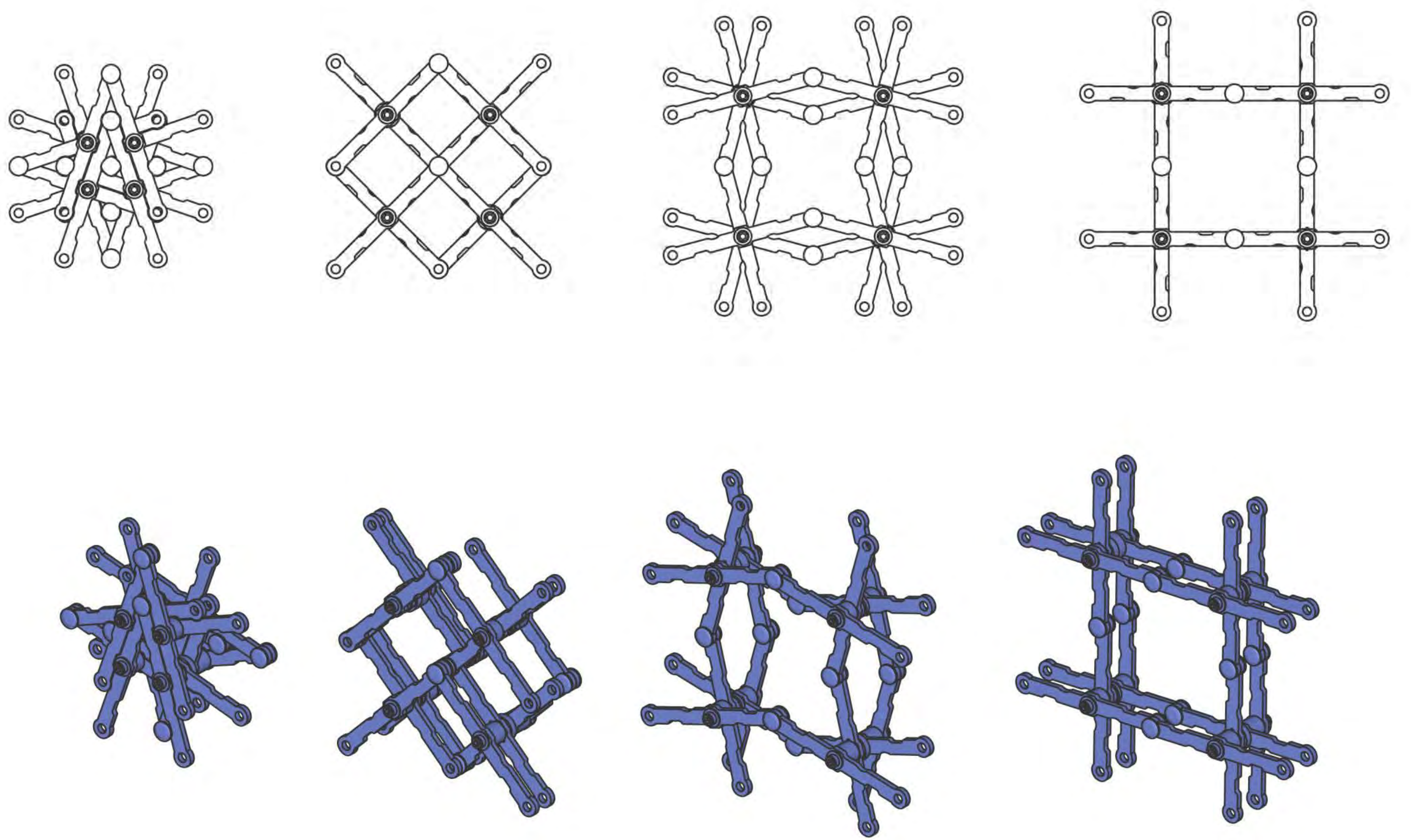


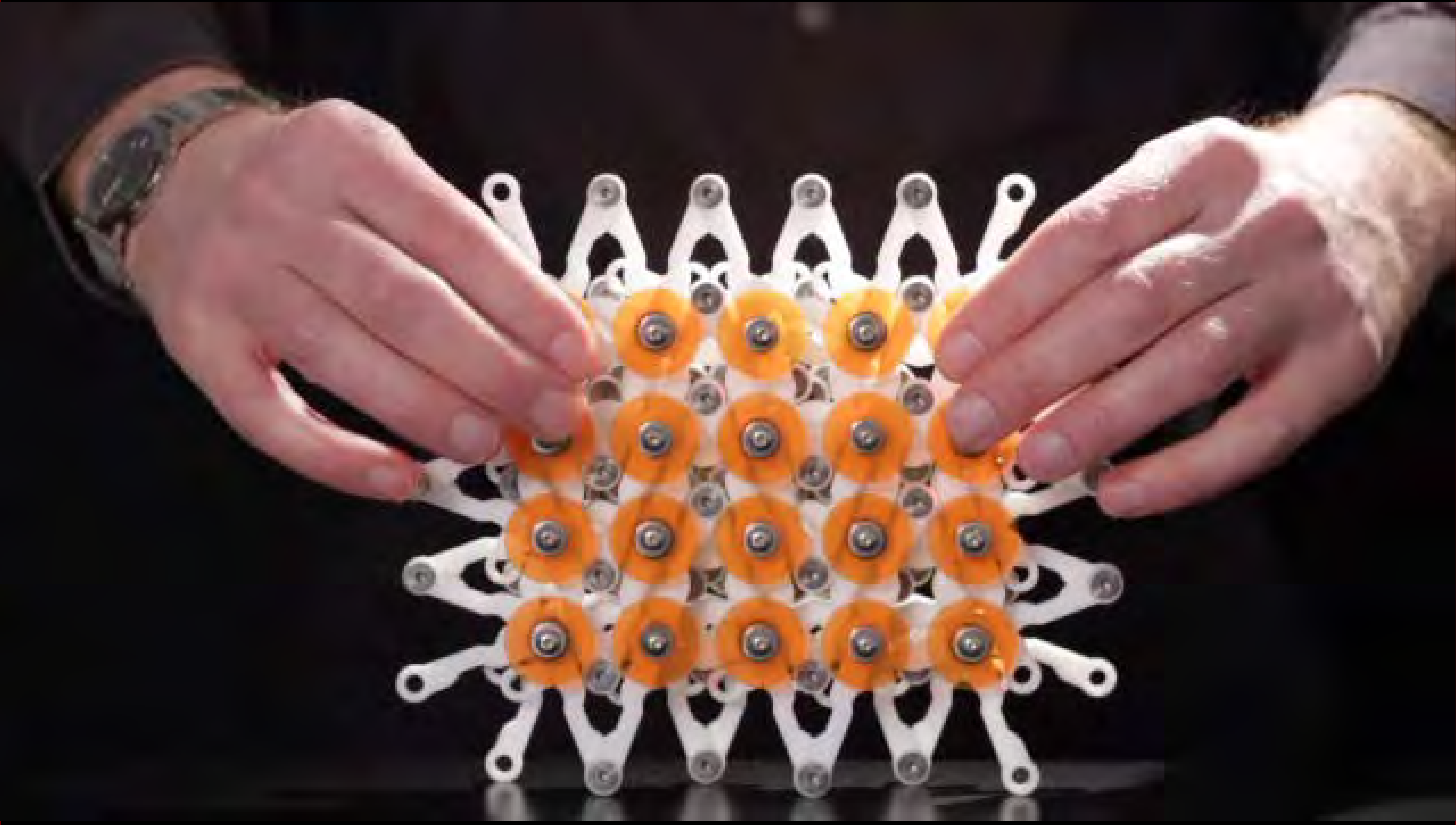
Expanding polygon arrays

4-way grid made of angulated scissors

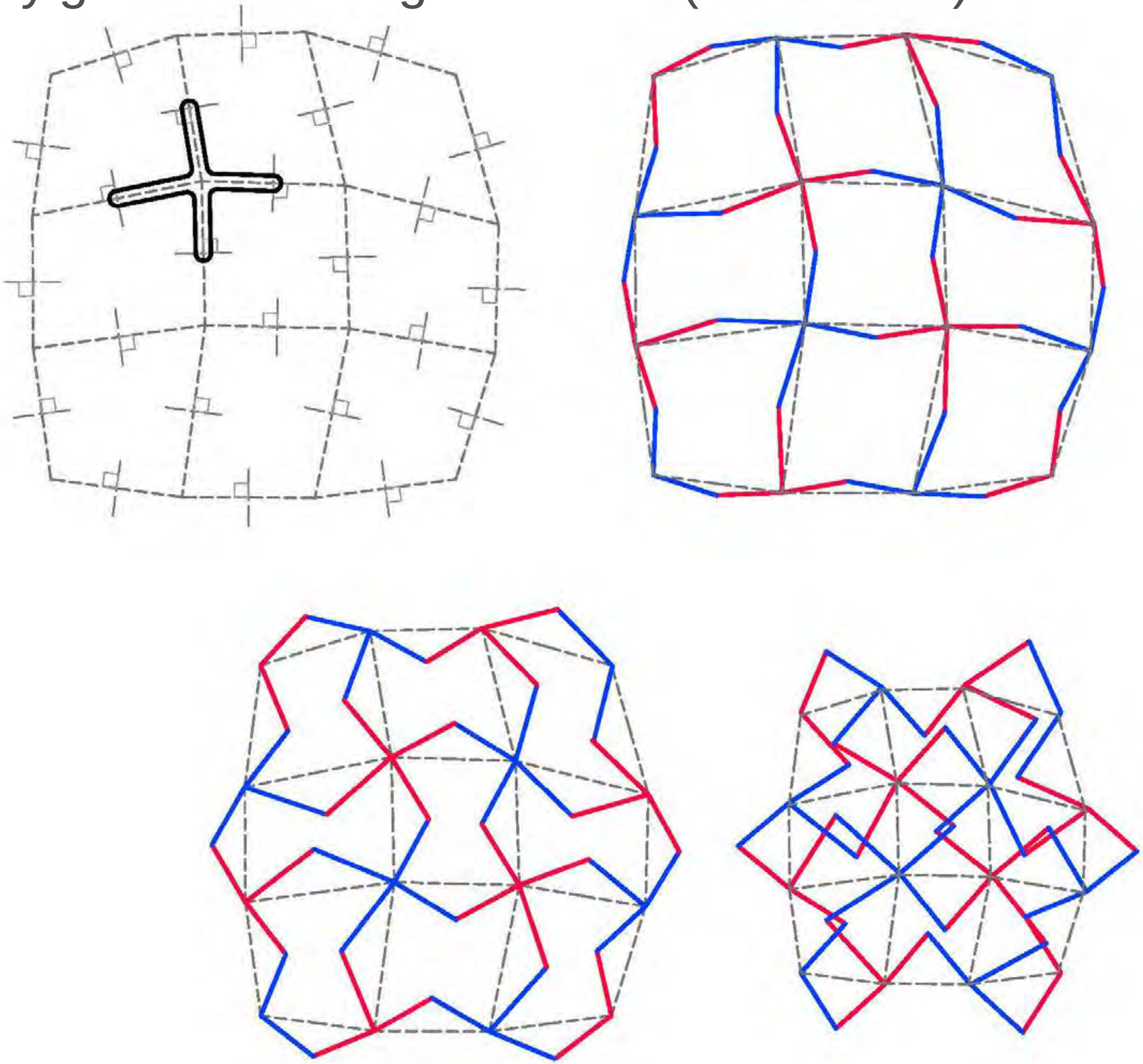


4-way grid made of angulated scissors

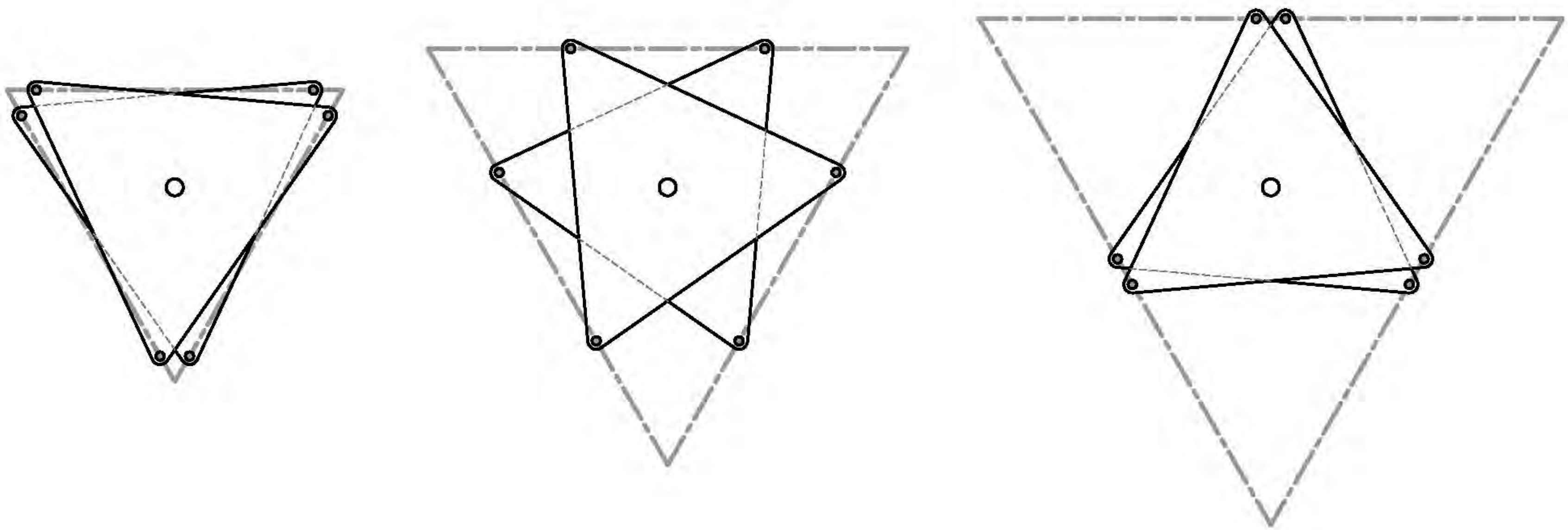




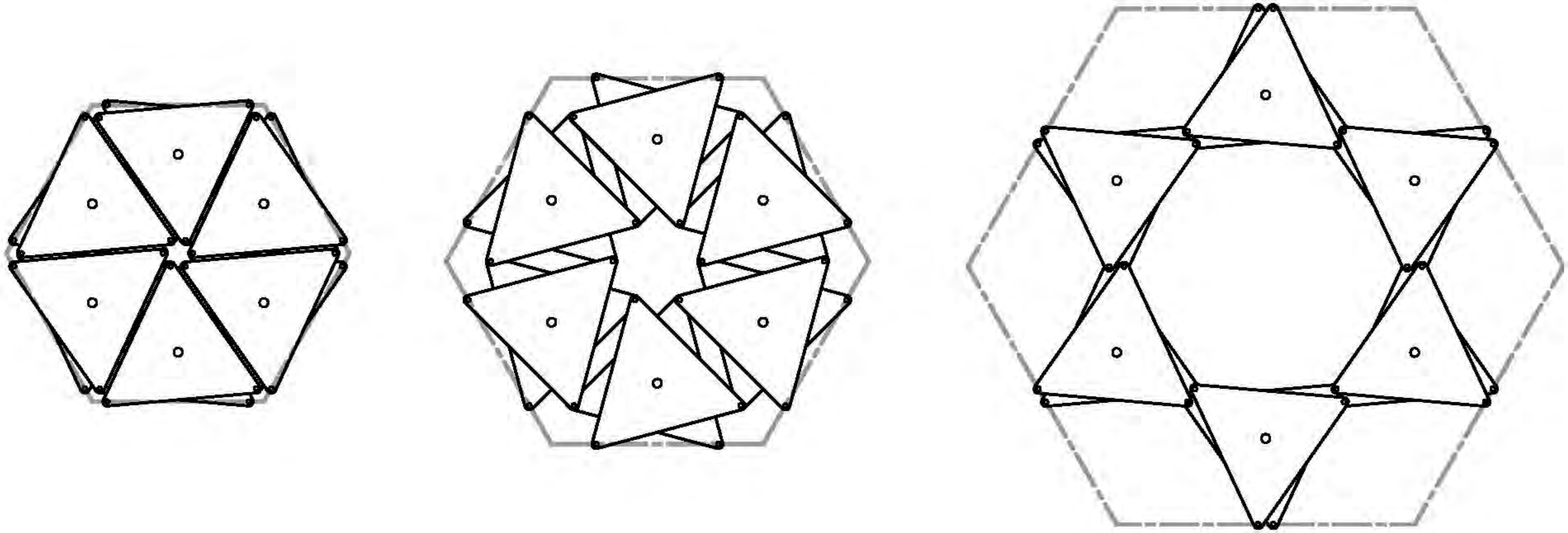
4-way grid made of angulated links (not doubled)



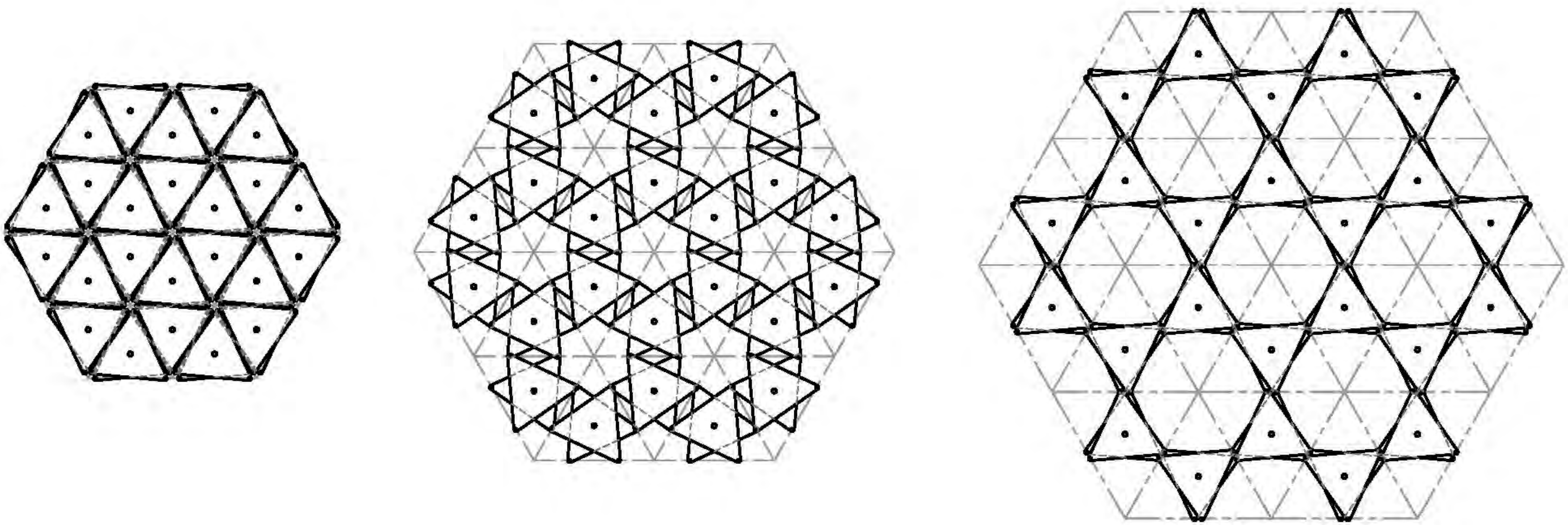
3-way scissor (doubled triangle)



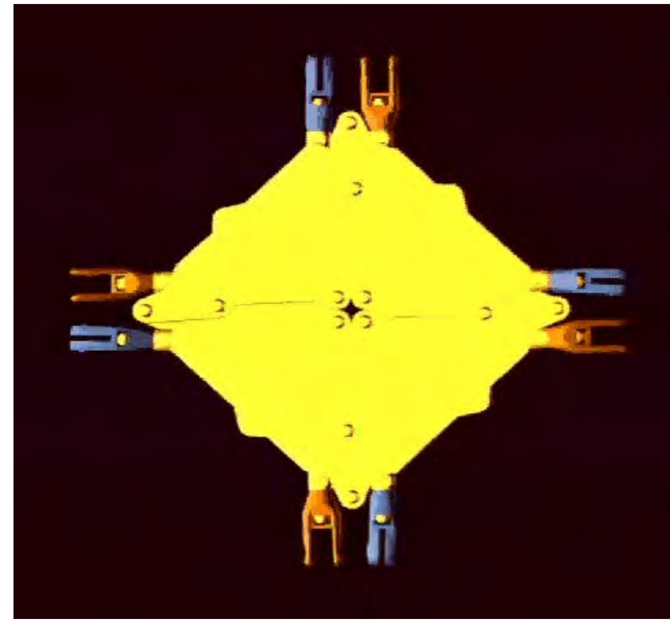
3-way scissor (doubled triangle)



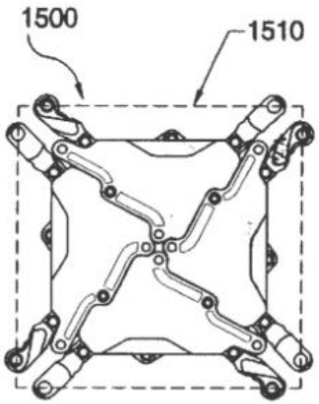
3-way scissor (doubled triangle)

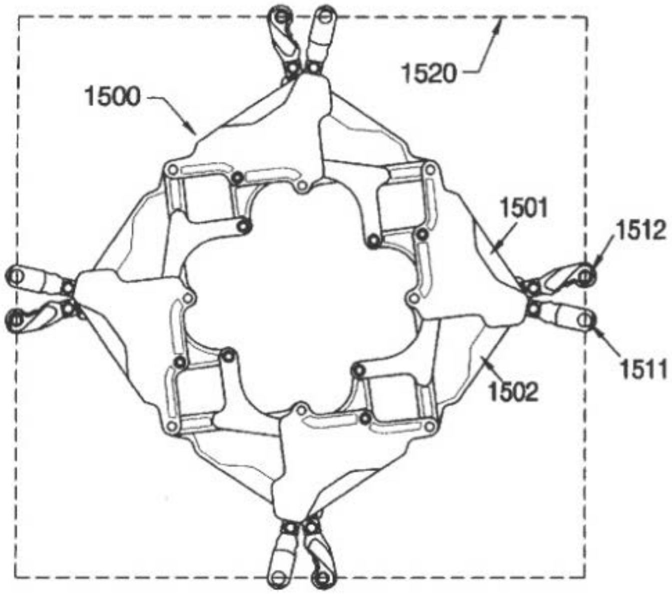


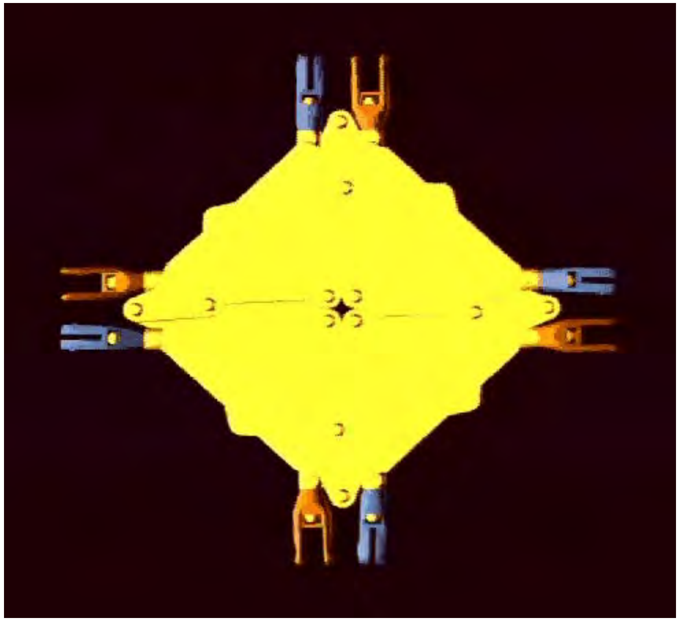
Expandagon construction system



Dynamic envelope

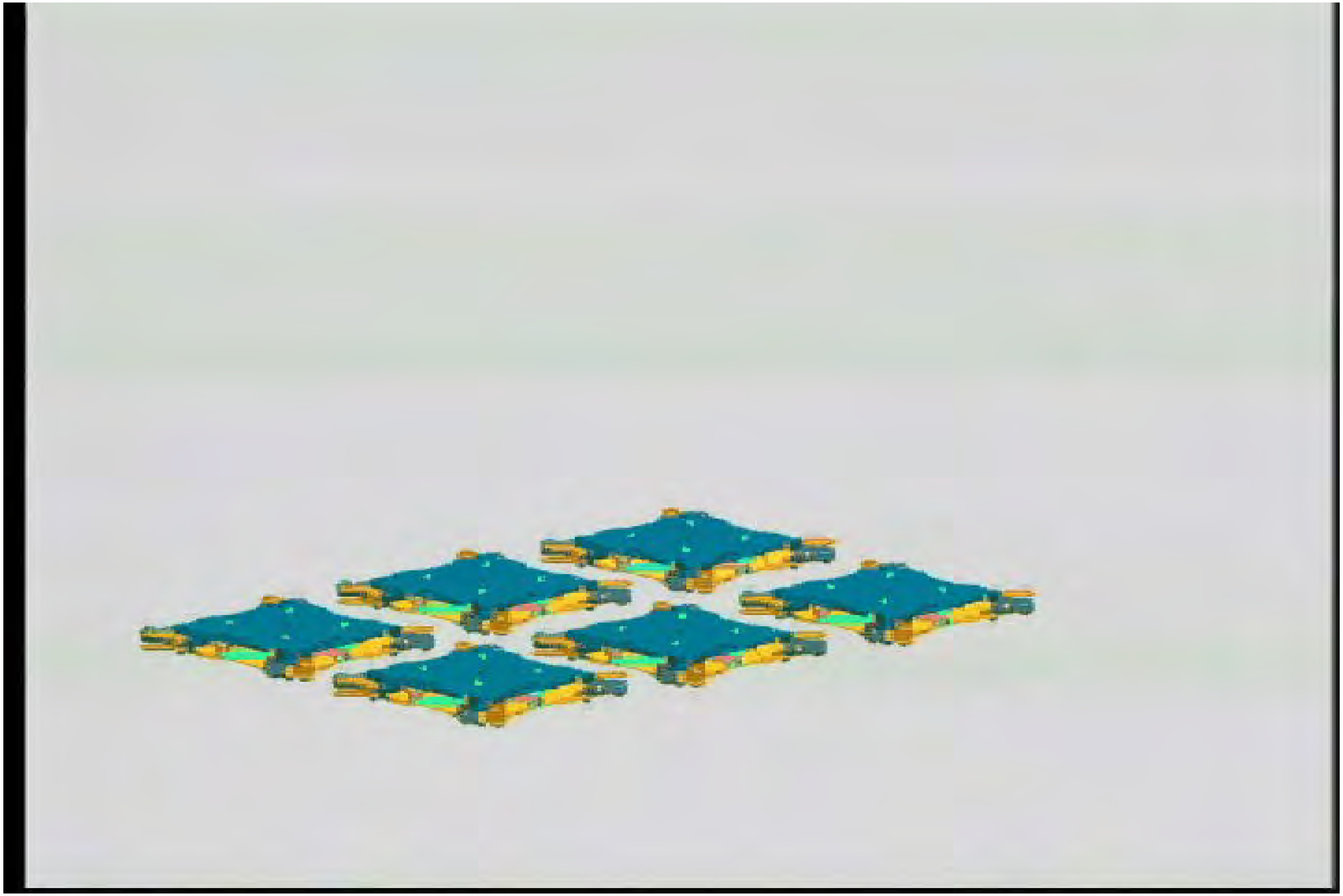




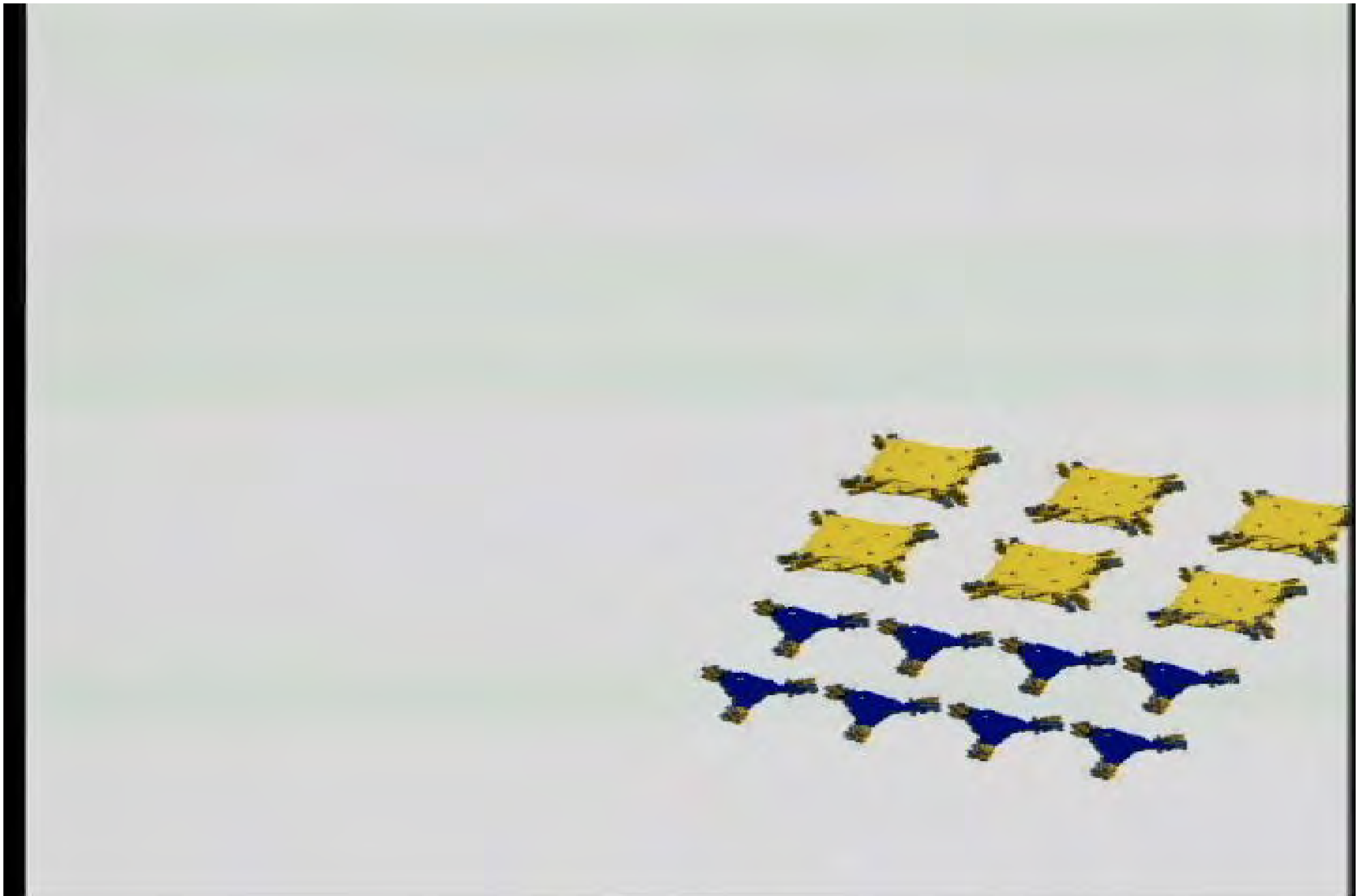


Expandagon assembly

Expandagon assembly

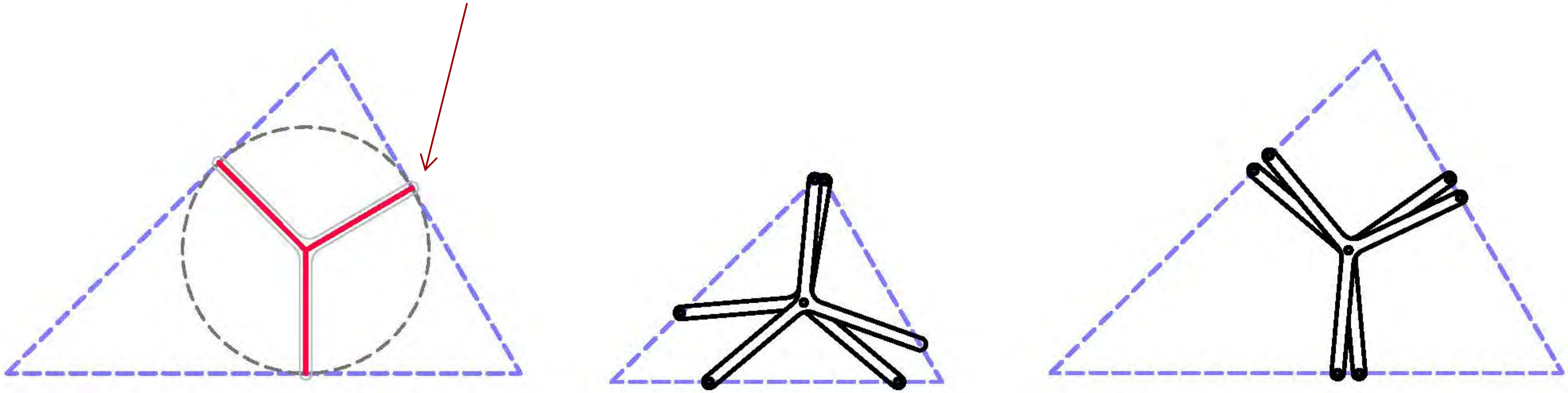


Expandagon assembly

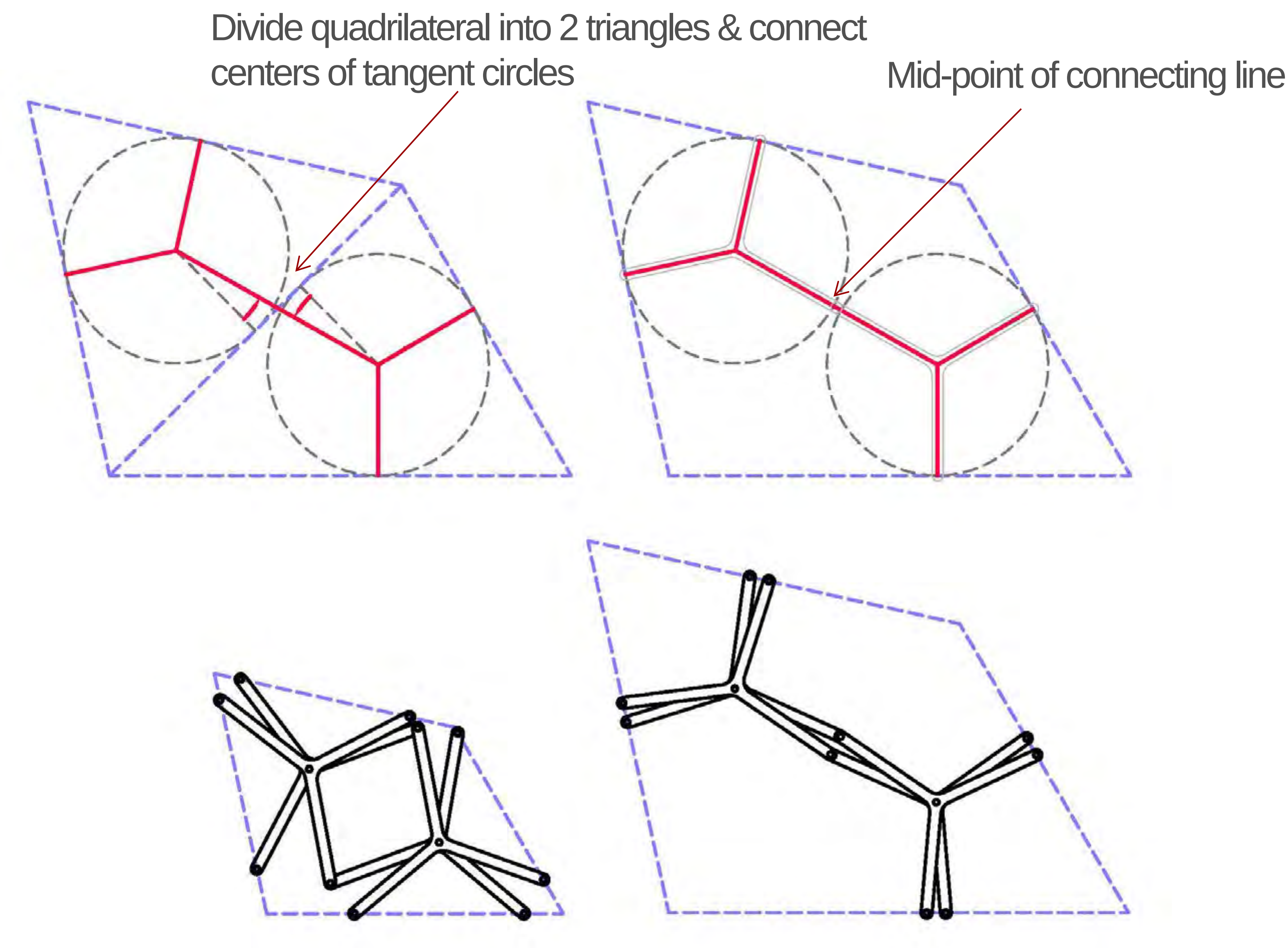


General method for expanding triangle (edges preserved)

Draw lines orthogonal to edges that connect to center of tangent circle



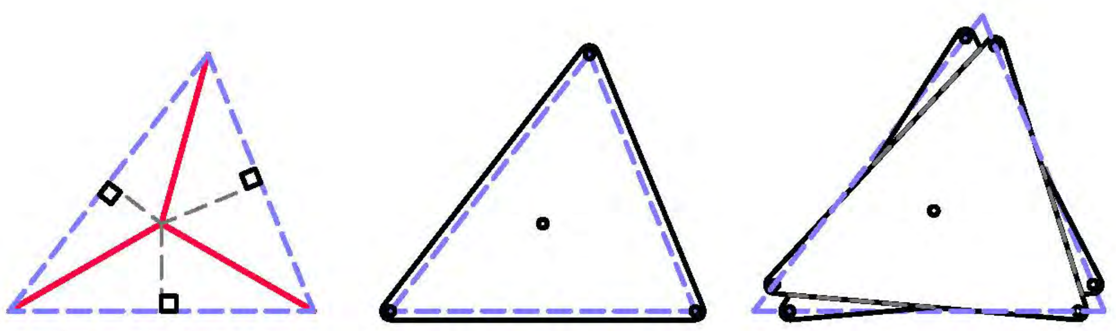
General method for expanding quadrilateral (edges preserved)

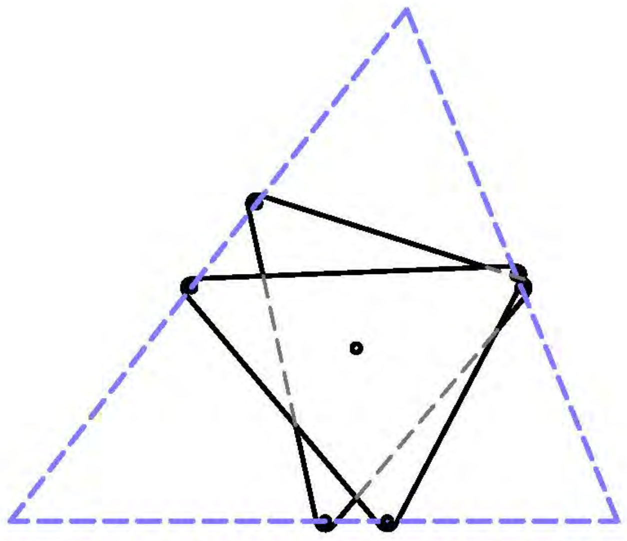


Alternate method for expanding triangle (edges preserved)

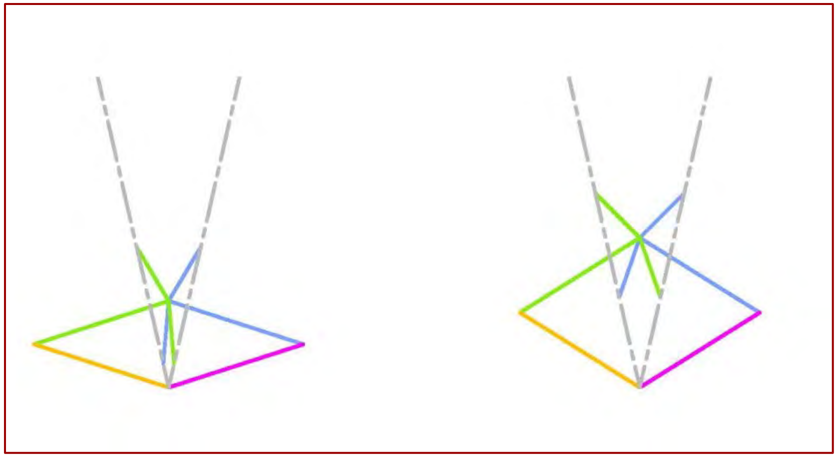
Draw lines orthogonal to edges to find center point

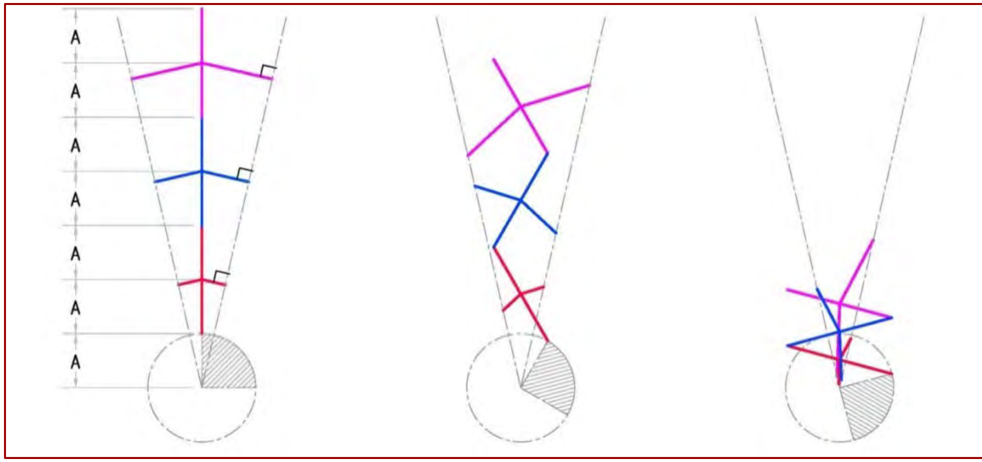
Construct link from Original triangle

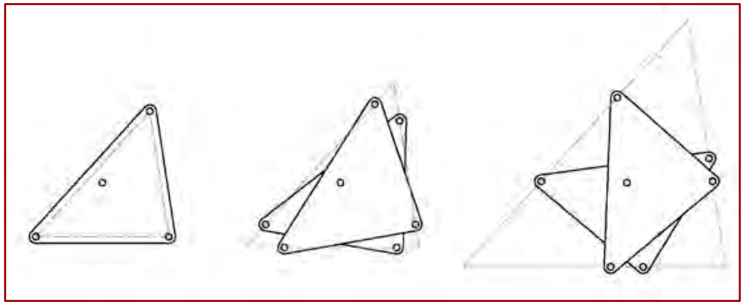


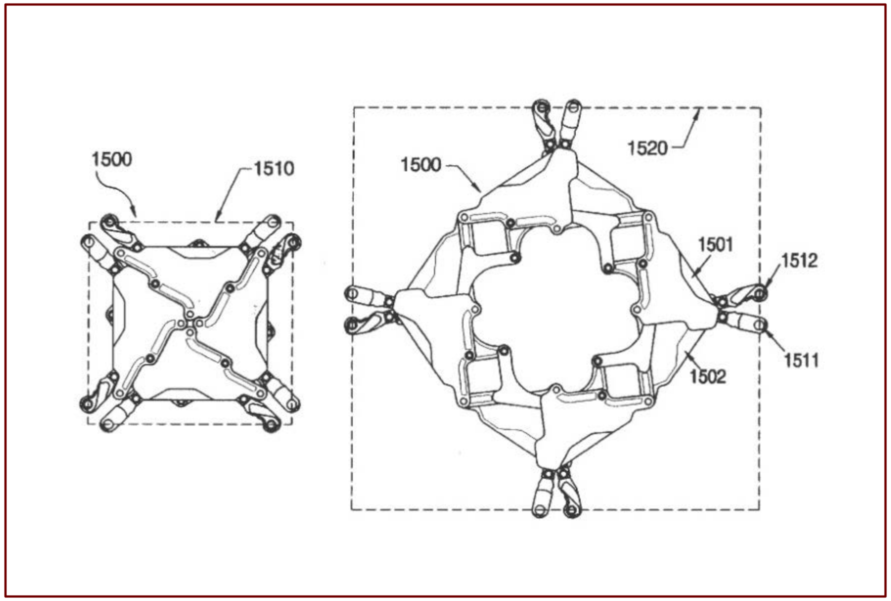


Kinematic units



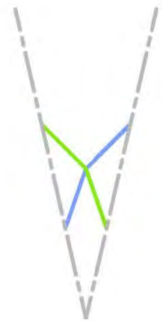


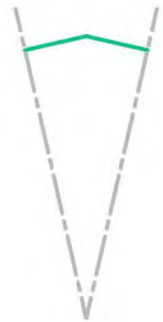




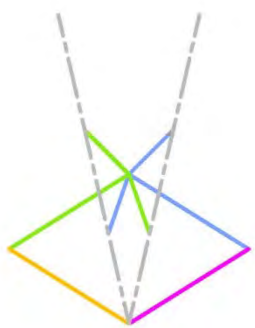
Constant angle perimeter linkages

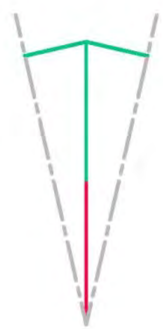
Geometric construction - wheel





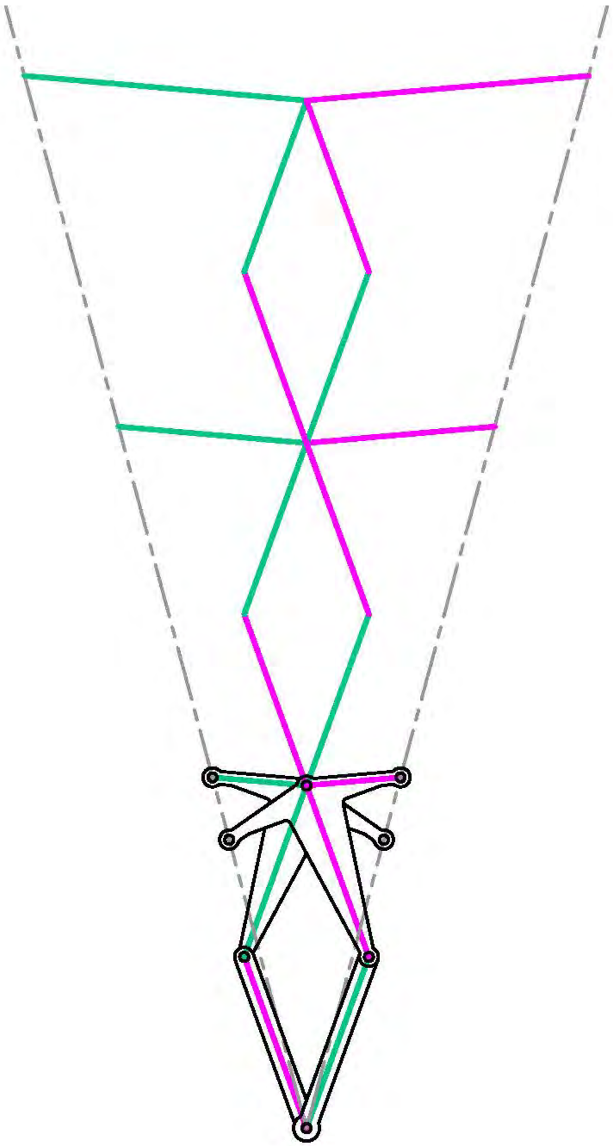
scissor
element

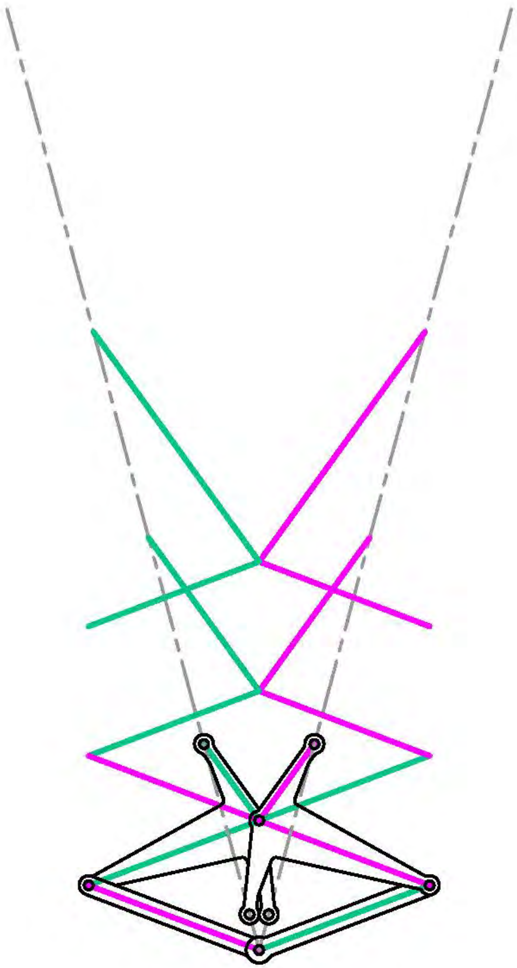




Scissor / spoke
element

Tong linkage with points forming constant angle

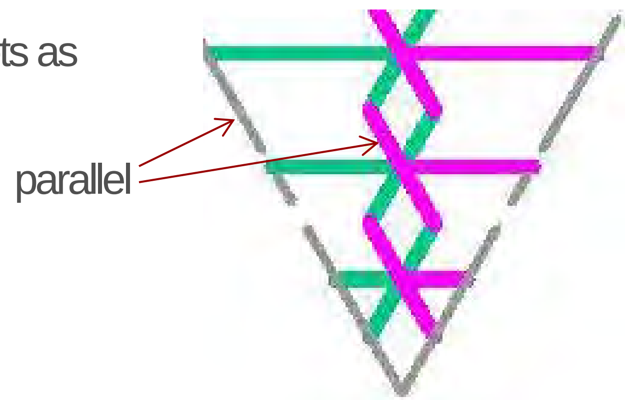


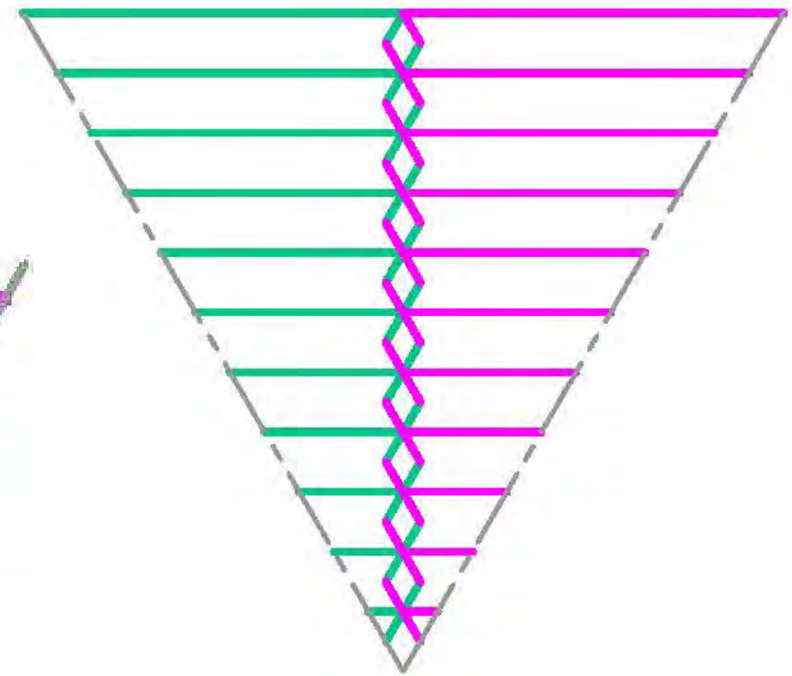


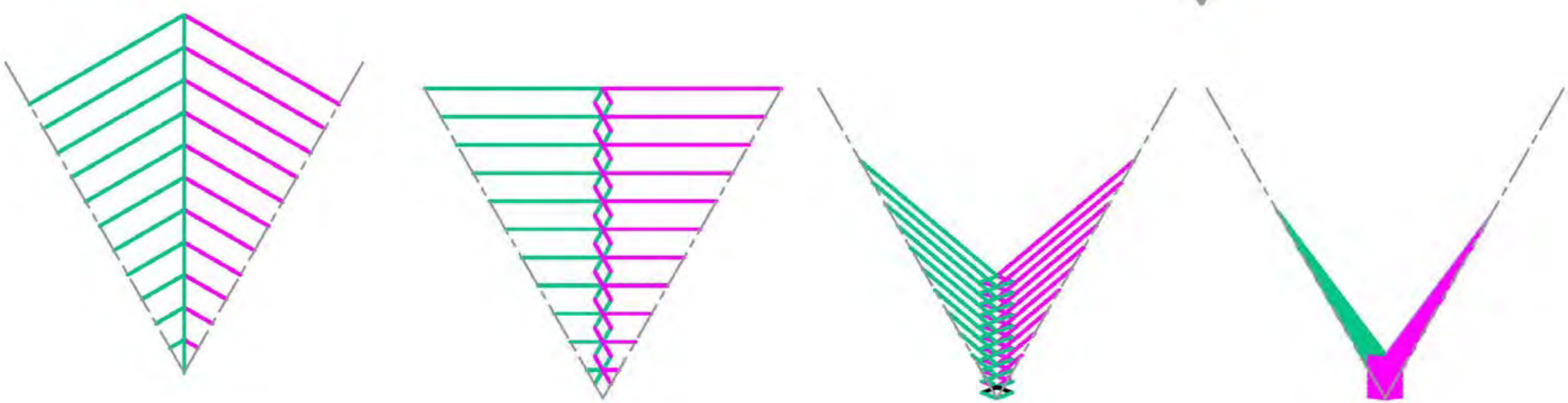
Tong linkage with points forming constant angle

Construction method:

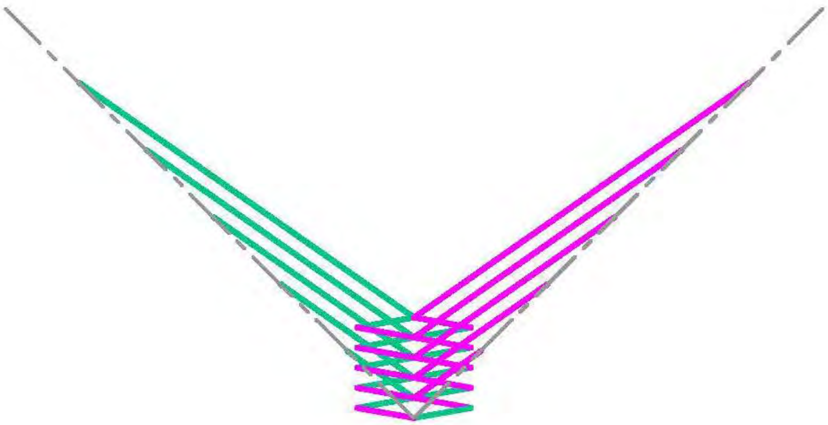
- Set tong linkage with deployment angle parallel to perimeter
- Draw lines (orthogonal to main axis of tong) from crossing points to perimeter lines
- Form links with 3 pivots as indicated

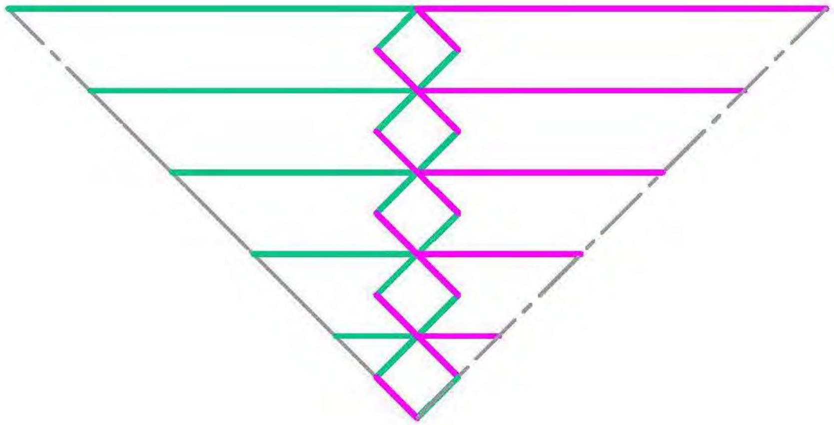


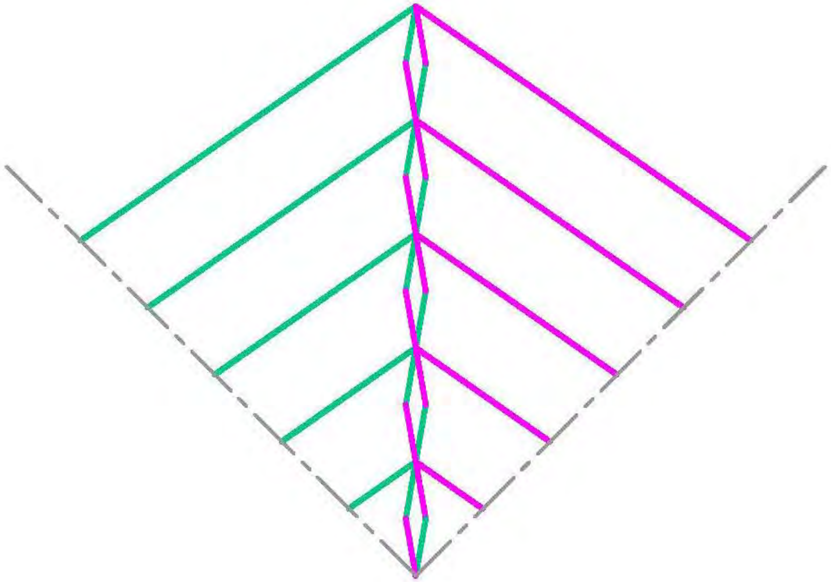




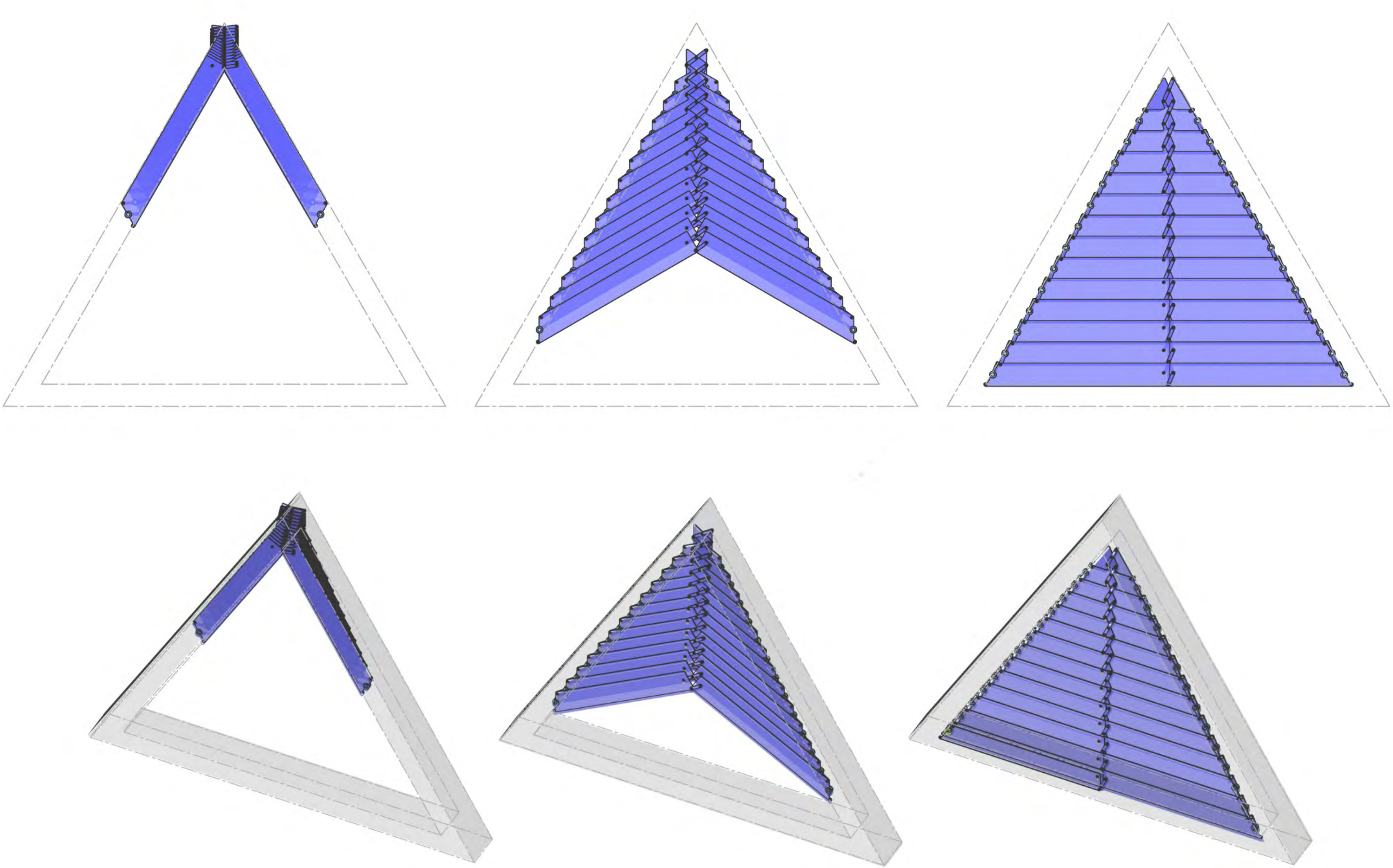
Scissor with perimeter of constant angle

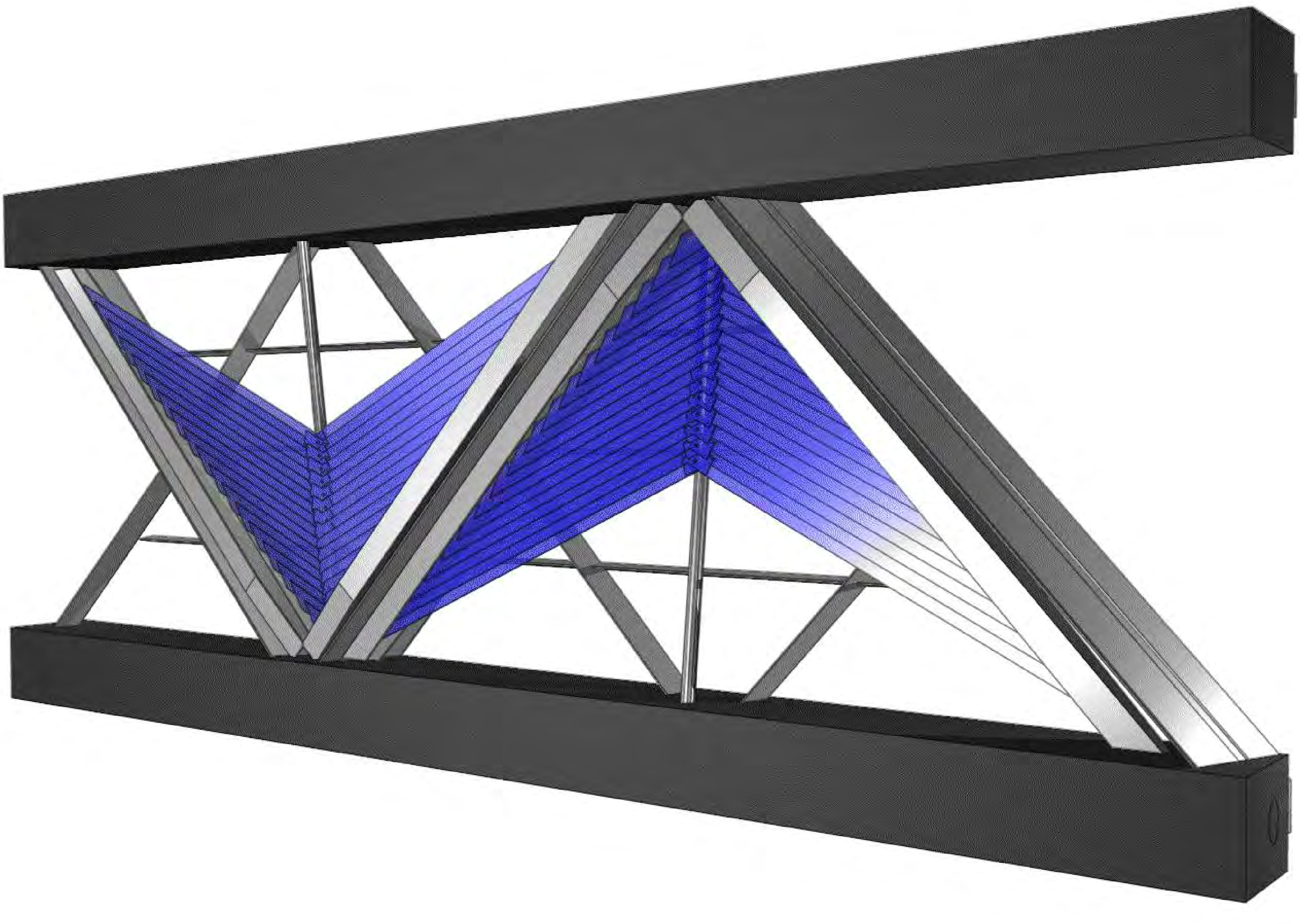




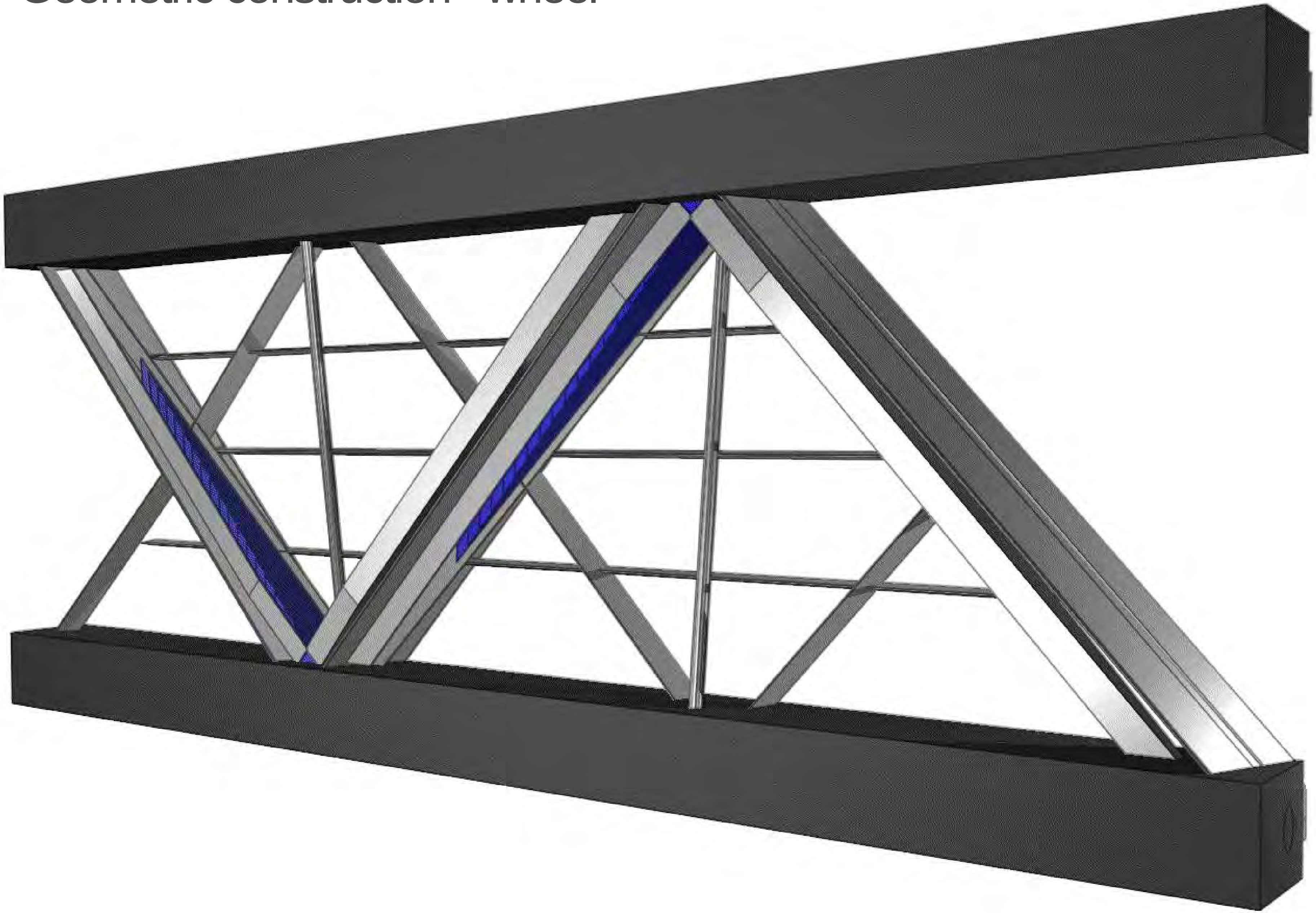


Scissor with perimeter of constant angle





Geometric construction - wheel



CSAIL
MIT COMPUTER SCIENCE AND ARTIFICIAL INTELLIGENCE LABORATORY

Building Programmable Matter

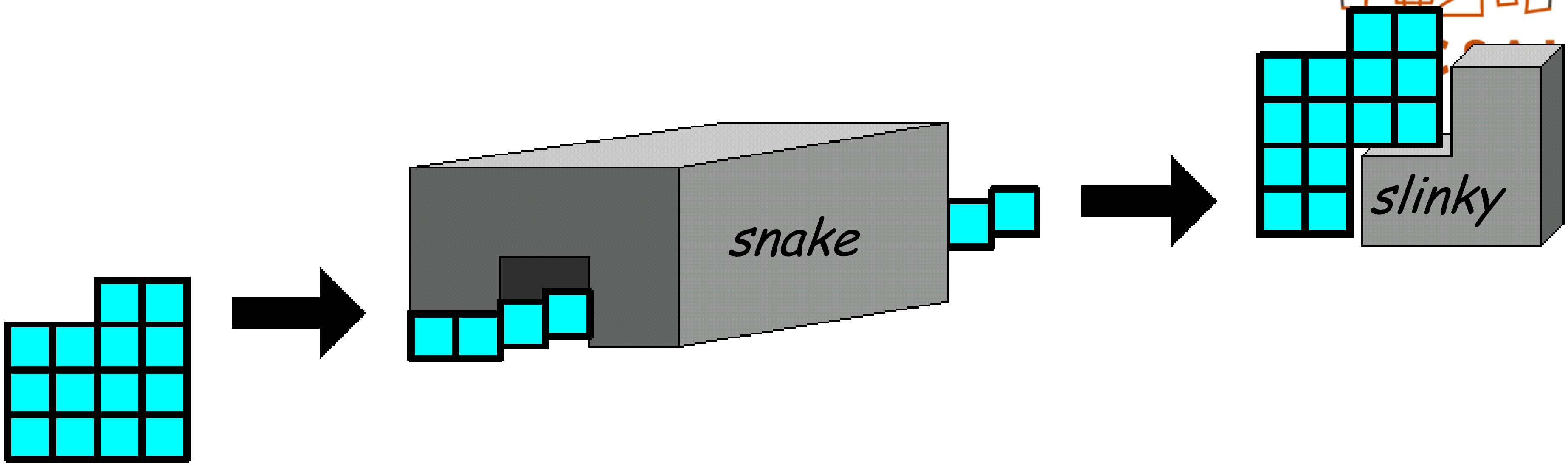
Daniela Rus
CSAIL, MIT
B. An, E. Demaine, C. Detweiler, K. Gilpin, K. Kotay,
M. Schwager, M. Vona, R. Wood, S-K. Yun

2/25/2013

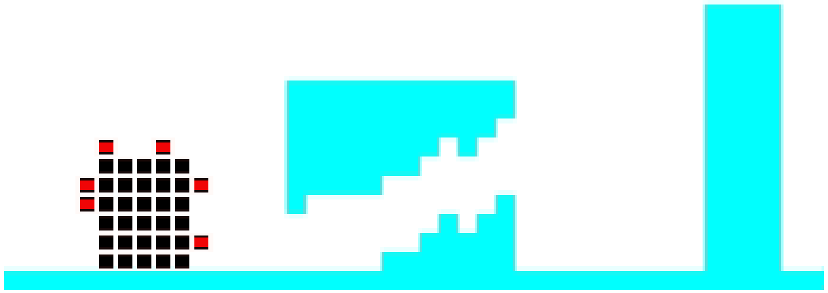
Convergence of Materials and Machines

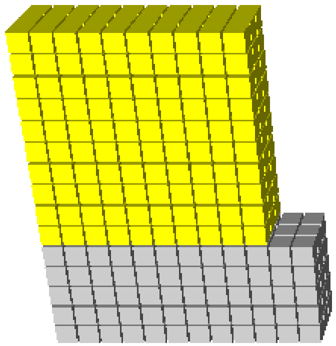
- Great progress in materials
- Machines are increasingly more powerful and smaller
- Convergence of machines and material

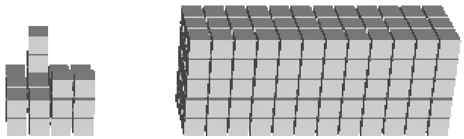
Self-reconfiguring machines



- *Multiple modules*
- *Physically connected*
- *Autonomous structural change*
- *Multiple functionalities--reusable*
- *Robots with variable architecture*
- *Self-assembly*
- *Self-reconfiguration*
- *Self-repair*

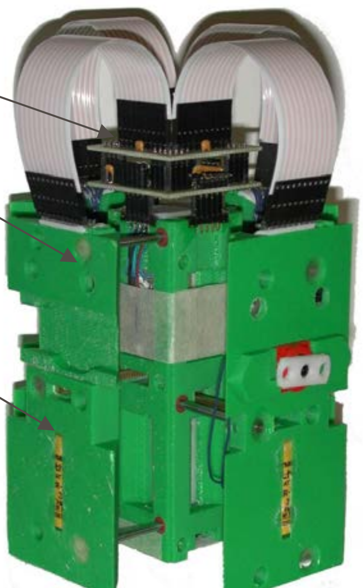


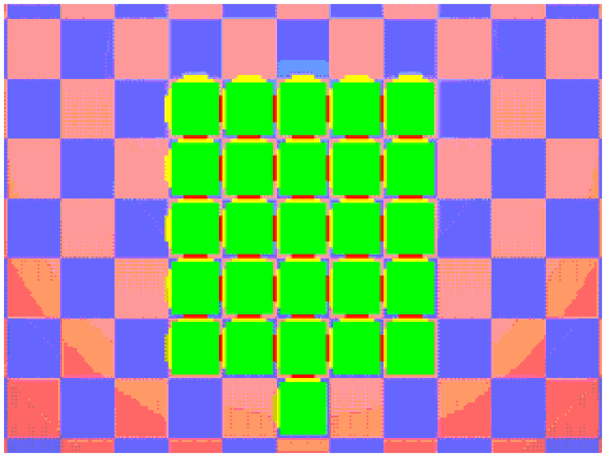




Actuation by Scaling: Crystal Module (1999)

- *Unit-compressible*
- *Self-contained units*
    - *Computation*
    - *Communication*
    - *Power*
- *28 built*
- *Local comm*
- *~ 200 g*





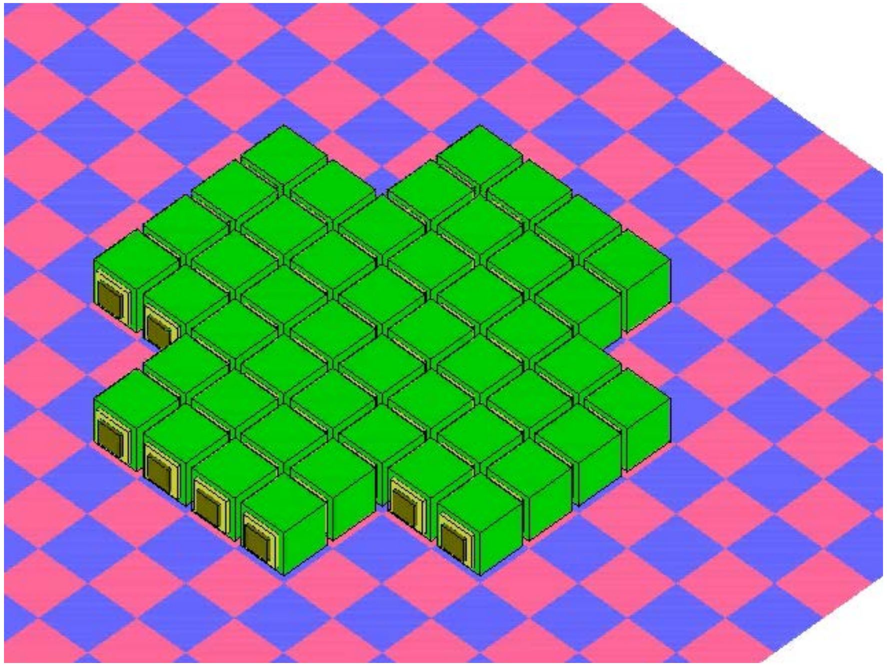
module relocation O(1)

Computing Challenges:

•Self-reconfiguration (SR) planning when modules can travel through the volume of the structure (not just on the surface)
•Defining the class of achievable structures, defining force/torque requirements
•Scalability: Parallelism and Decentralization

Group Locomotion

Distributed Reconfiguration Planning



- Provably correct
- Distributed matching on difference between start and goal
- No deadlock
- Maximal parallelism
- Relies on actuation by scaling

The Umbrella Project

Crystalline Theory [Aloupis, Collette, Damian, Demaine, El-Khechen, Flatland, Langerman, O'Rourke, Pinciu, Ramaswami, Sacristán, Wuhrer 2007–2009]

- Algorithms to morph n modules in 2D or 3D from one configuration to any other (up to constant resolution) using
  - $O(n)$ moves — simulation
  - $O(\log n)$ time (rounds)* — simulation
- With constant-strength robots:
  - $O(n^2)$ moves
  - $O(n)$ time (rounds)

*currently only in 2D, $O(n \lg n)$ moves, not in place