

PINO TROGU – SAN FRANCISCO STATE UNIVERSITY, USA

VISITING SCHOLAR, SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY
(SUSTech) 2024–2025, SHENZHEN, CHINA

DESIGN OF FLAT-FOLDABLE AUXETIC METAMATERIALS

2025 SPRING INTERNATIONAL WORKSHOP

CHINA–POLAND JOINT WORKSHOP ON ADVANCED LIGHTWEIGHT STRUCTURES
AND ENERGY ABSORPTION

SOUTHEAST UNIVERSITY, NANJING — MAY 22, 2025, 11:20 AM
ROOM 304, CIVIL ENGINEERING BUILDING, JIULONGHU CAMPUS



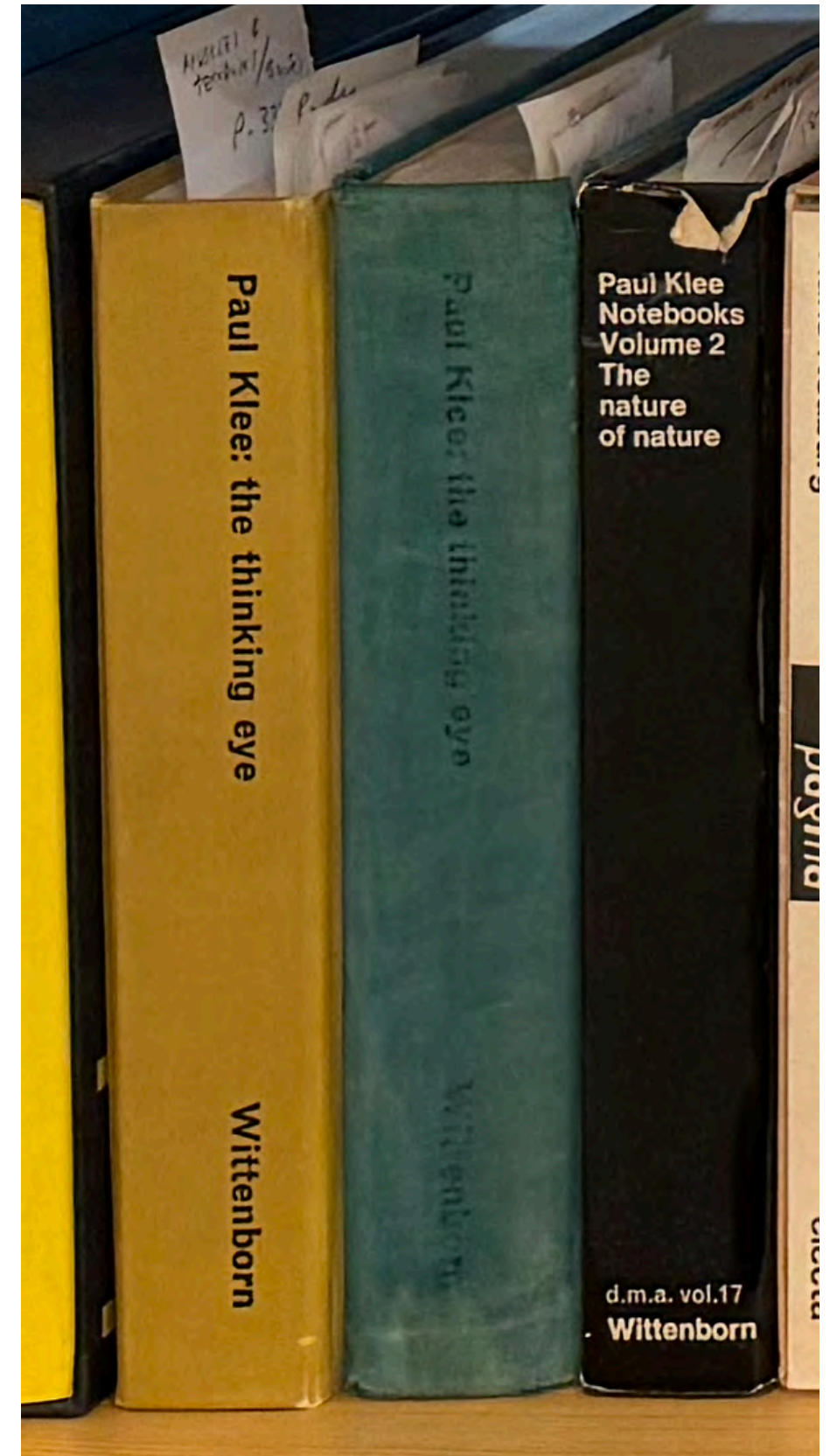
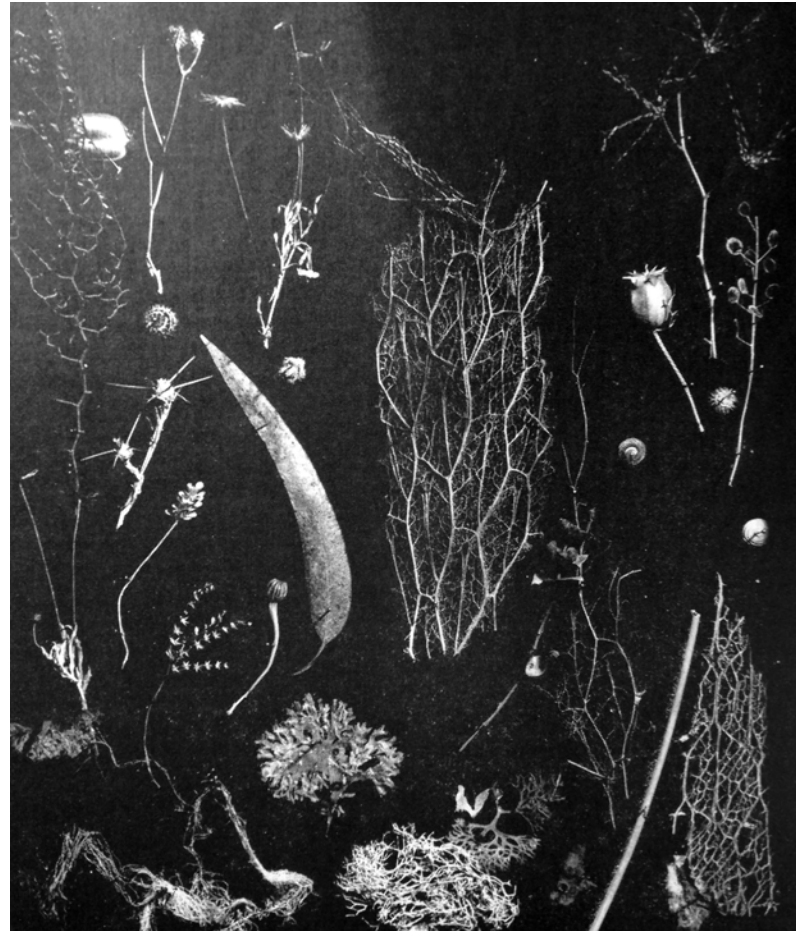
[go to last slide](#)

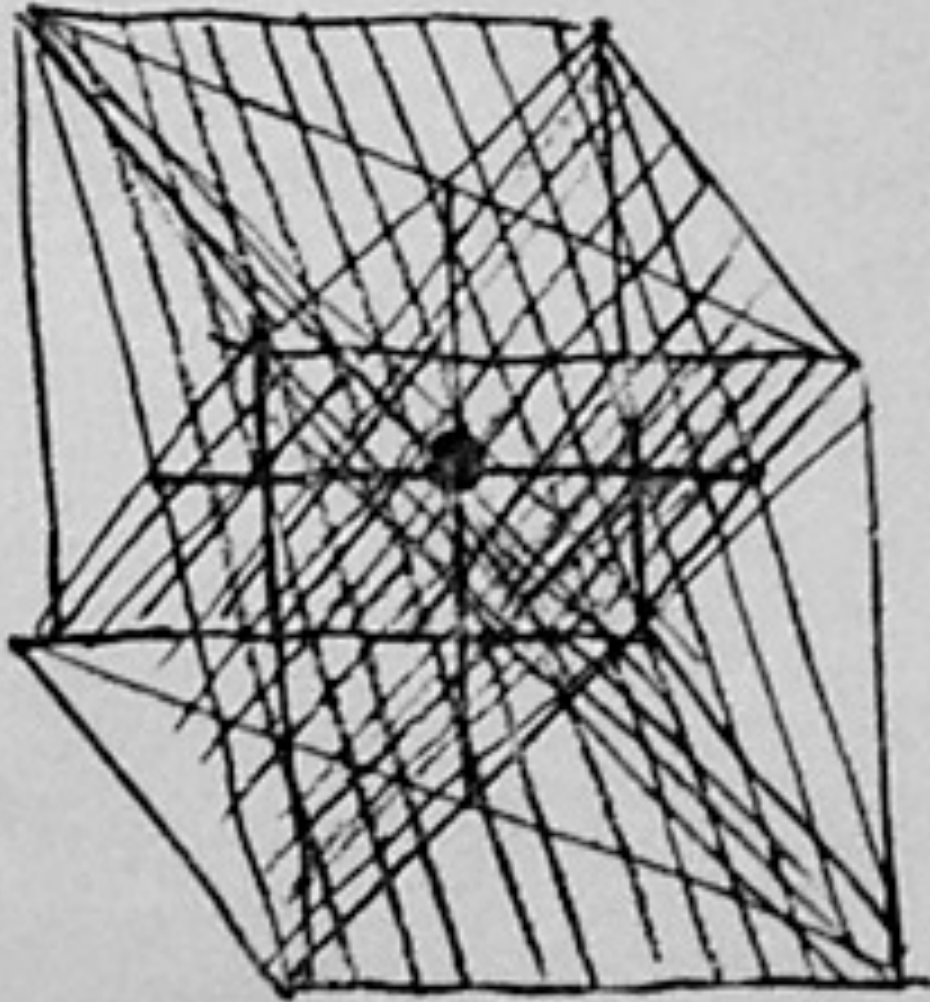
ORIGINS AND INFLUENCES: GIORGIO SCARPA





PAUL KLEE AT BAUHAUS: 1921–1931





The inward
plays the dominant part.
The whole inward territory
designated by the word 'content'

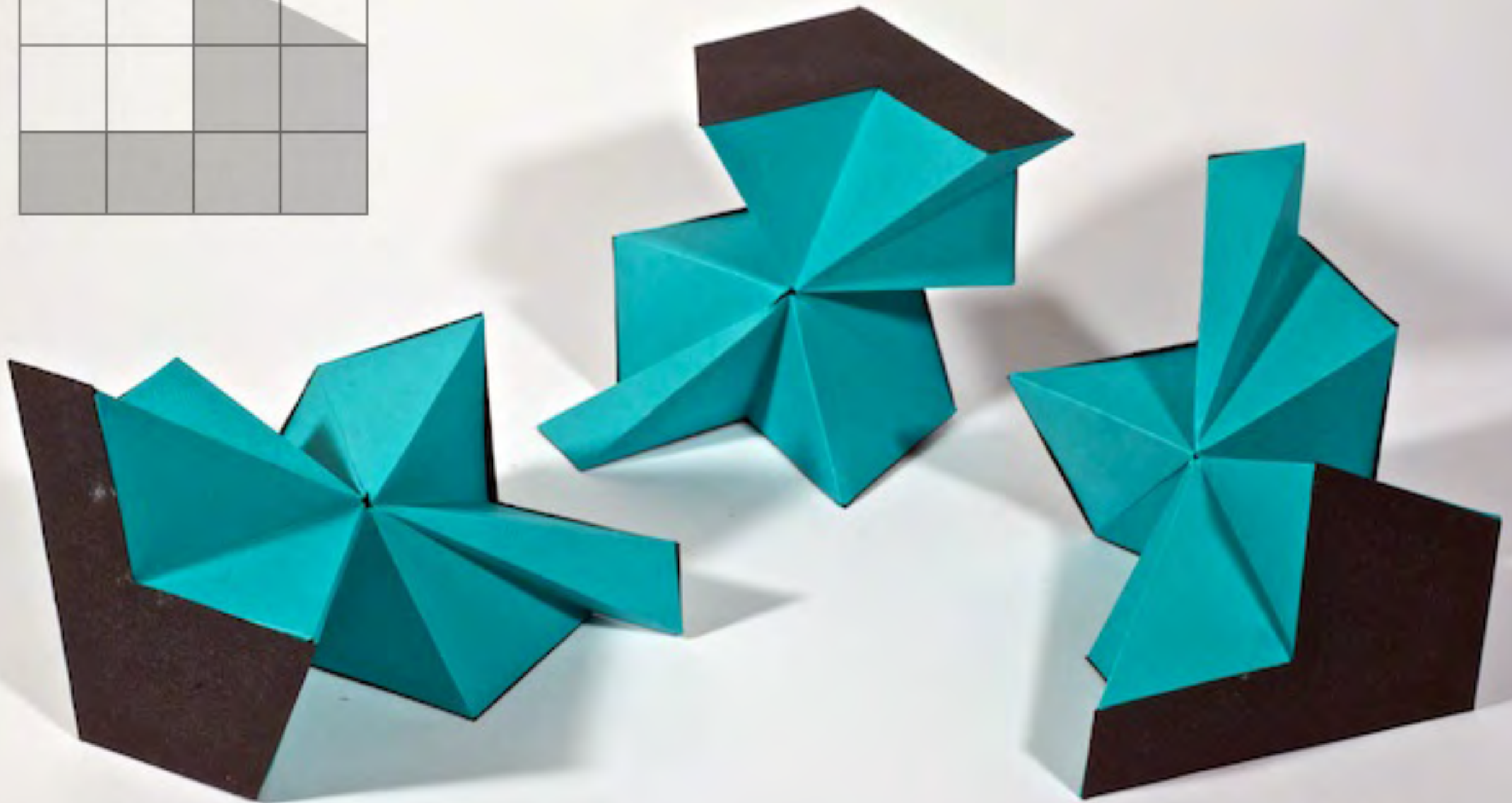
Paul Klee, *Notebooks Volume I: The Thinking Eye*
New York: Wittenborn, 1961) p. 127

TEACHING: TECHNICAL DRAWING & PERSPECTIVE.

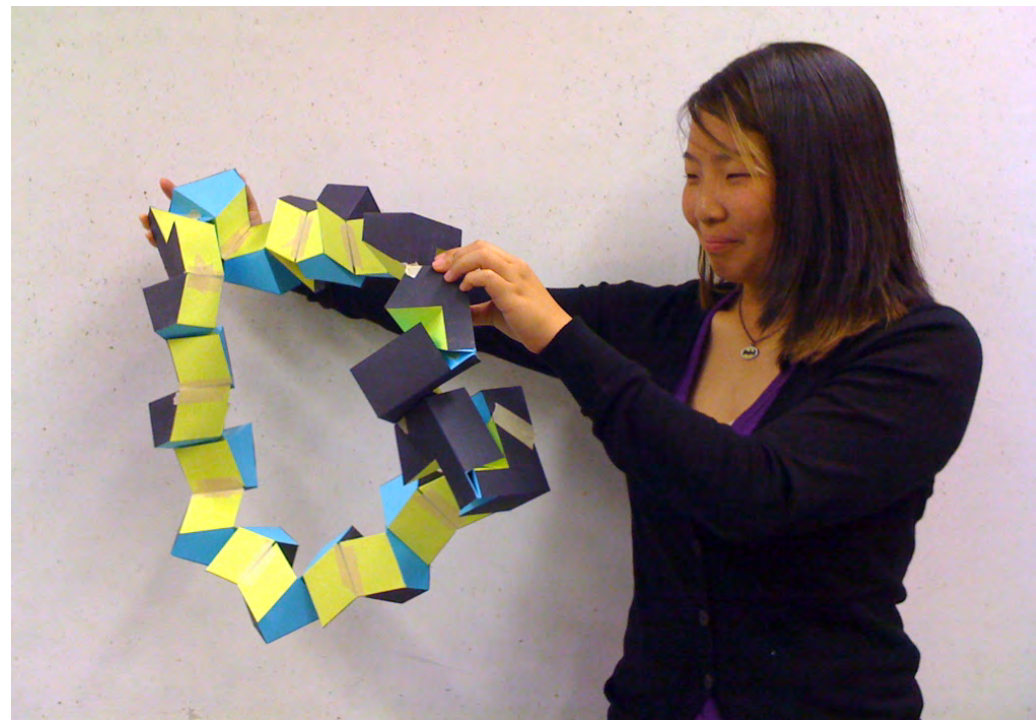
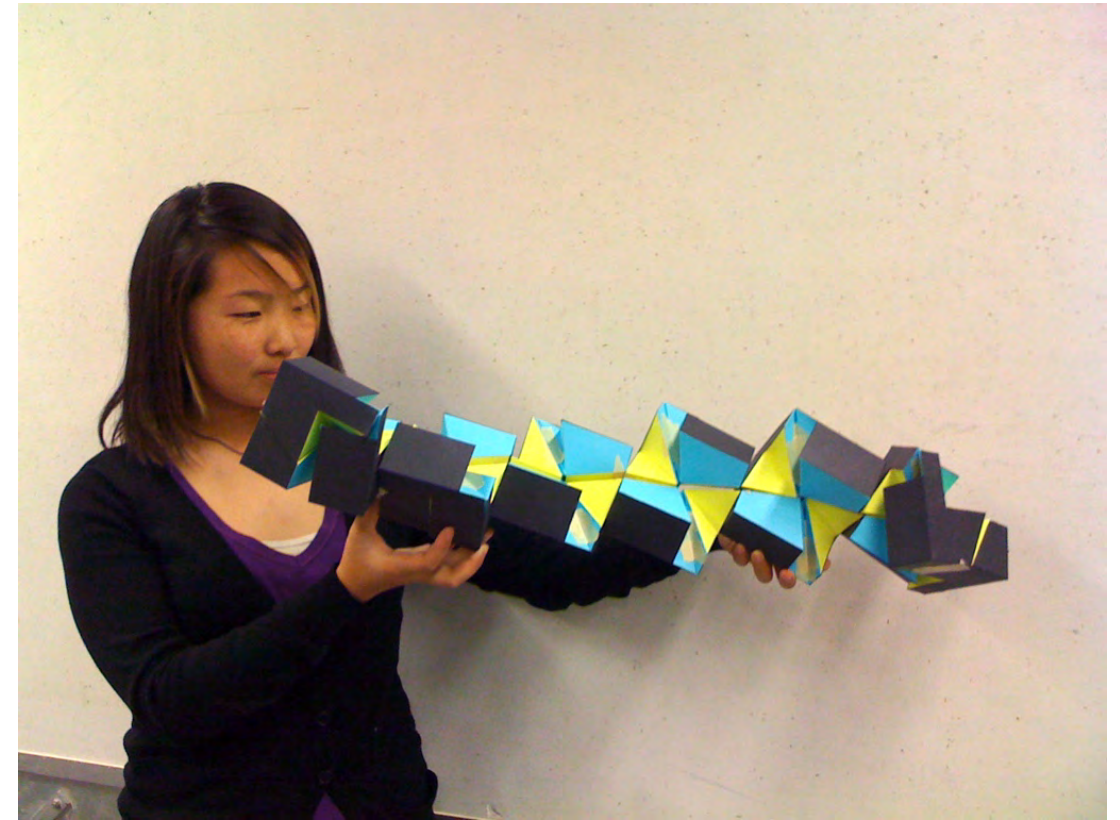
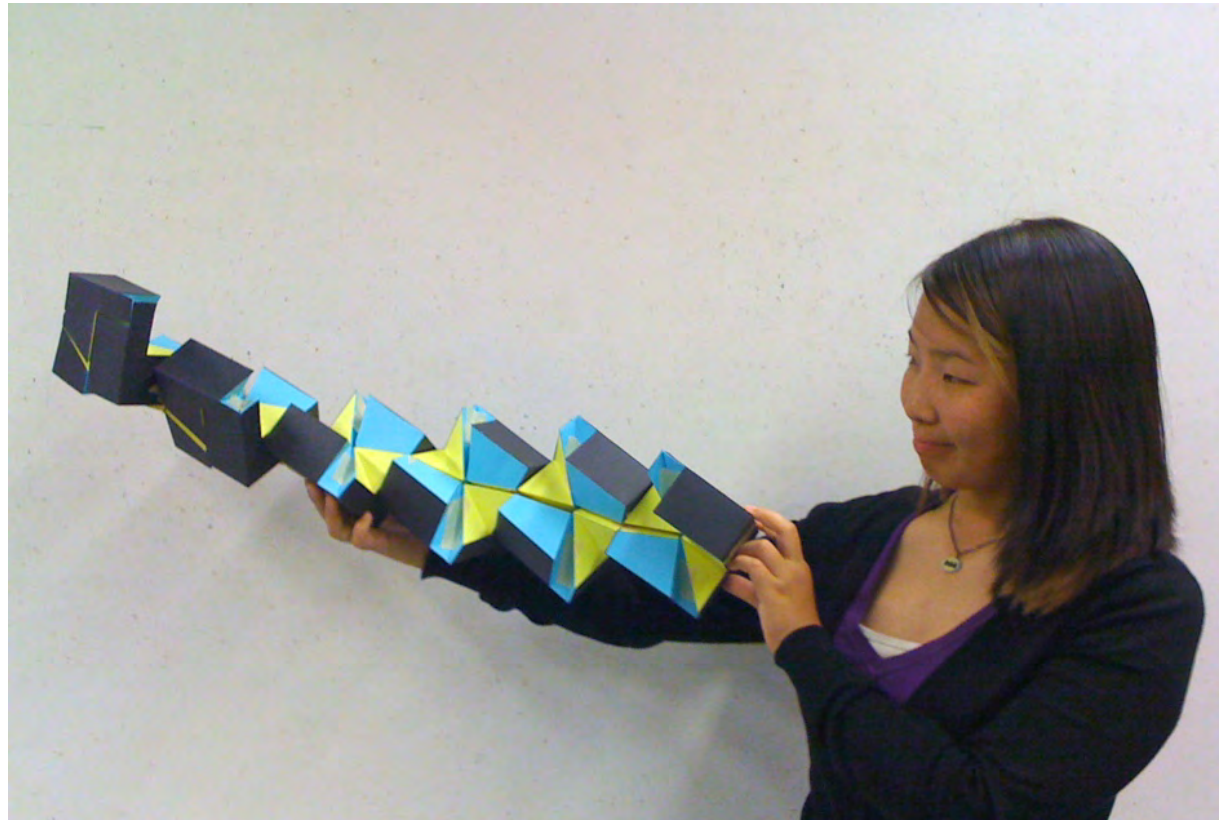
SCARPA'S CLASSROOM, ITALY, C.1975



CUBE SECTION PROJECT

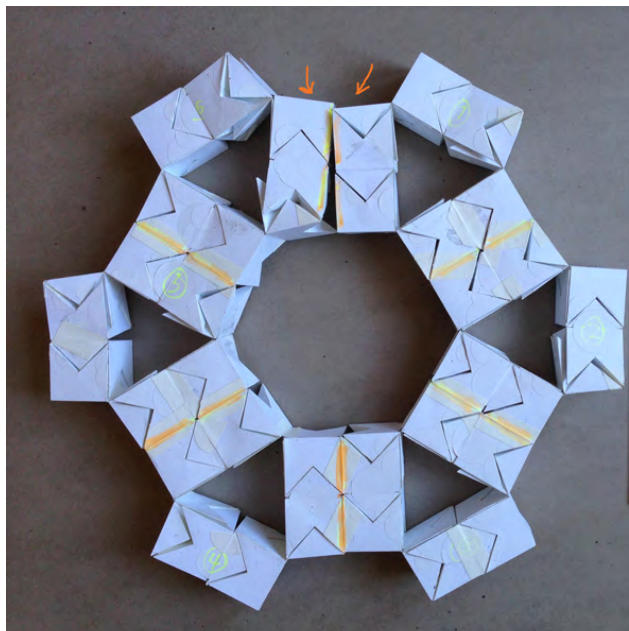
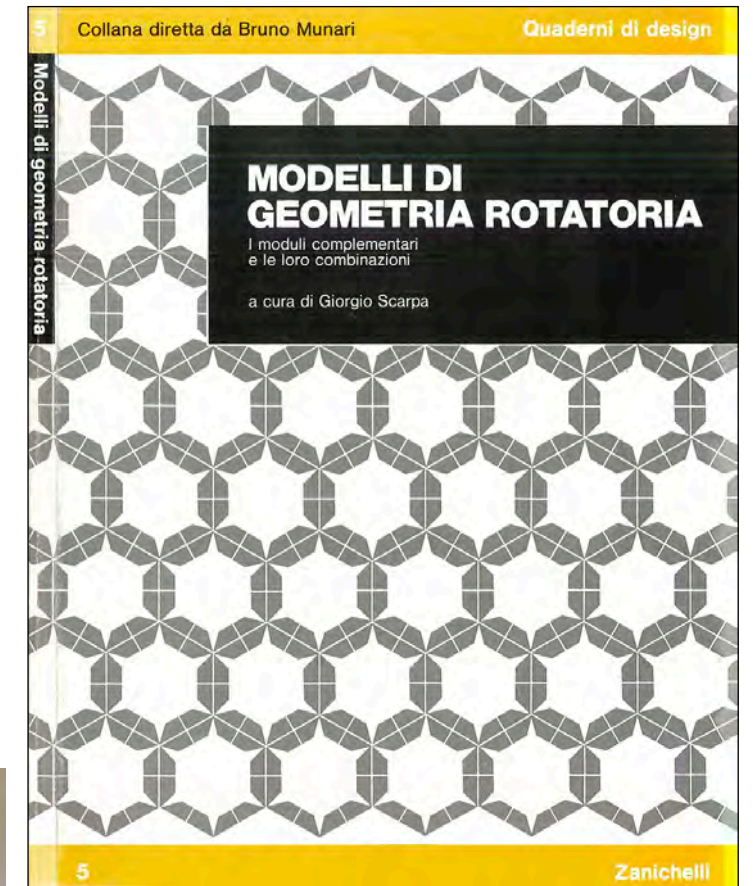
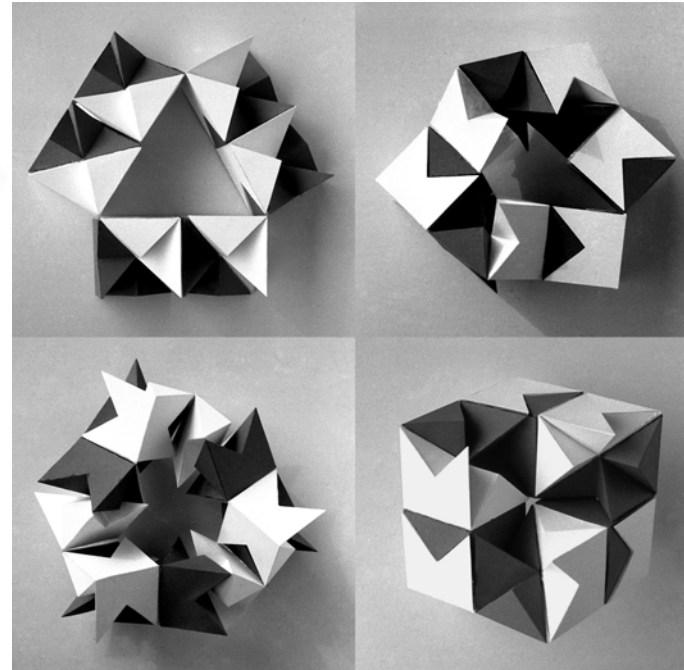
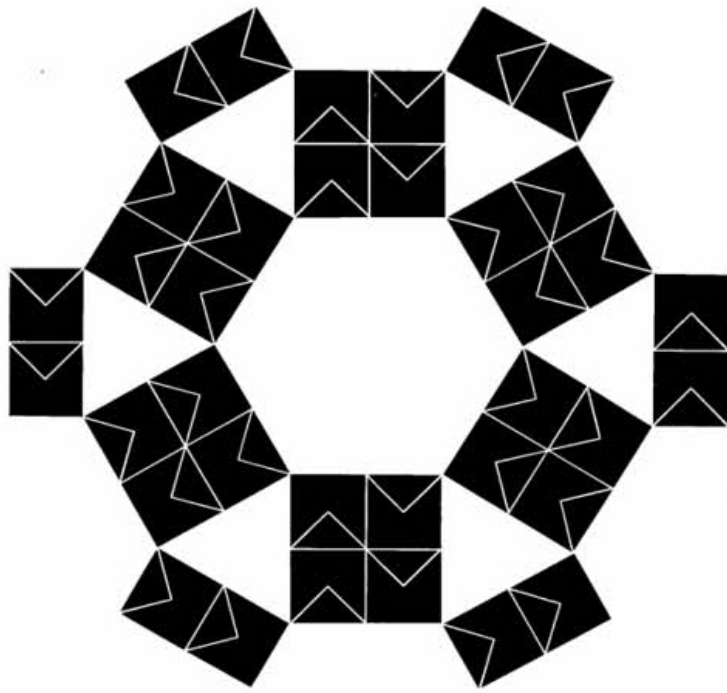


Trogu – Drafting & Sketching Course
San Francisco State university



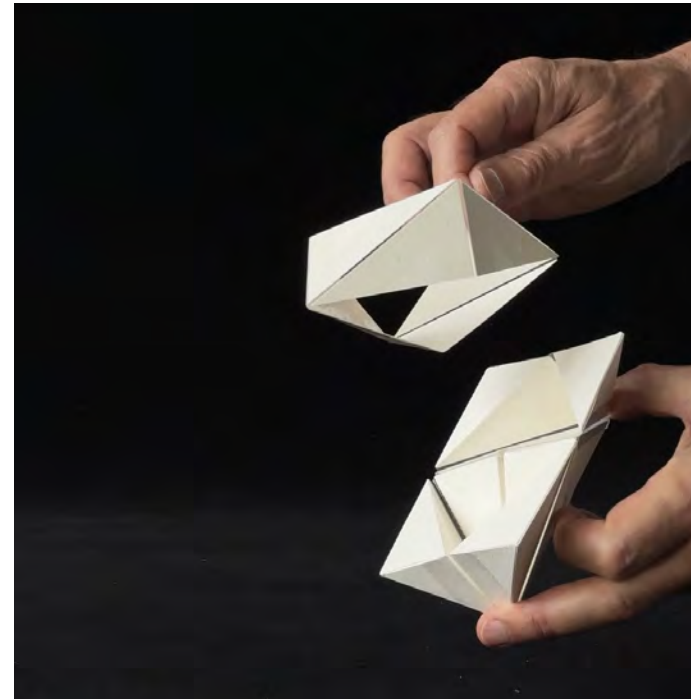
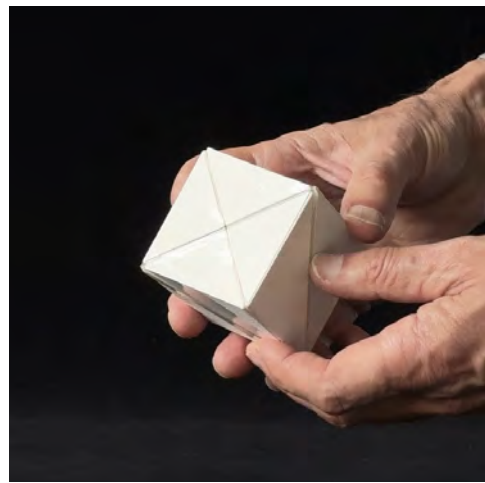
**24-MODULE CLOSED CHAIN
FLORENCE YUEN
SAN FRANCISCO STATE UNIVERSITY
2012**

SCARPA: MODELS OF ROTATIONAL GEOMETRY “TRANSFORMABLE FABRICS” 1978

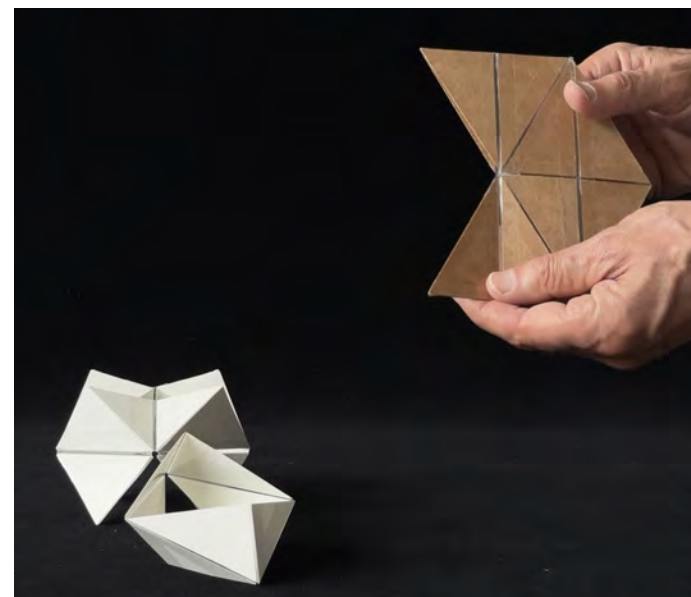


SCARPA TROGU

Pod: housing for the tetrahedral strip composed of eight right-angle pyramids equal in volume to the octahedron with the same face as the housed tetrahedron

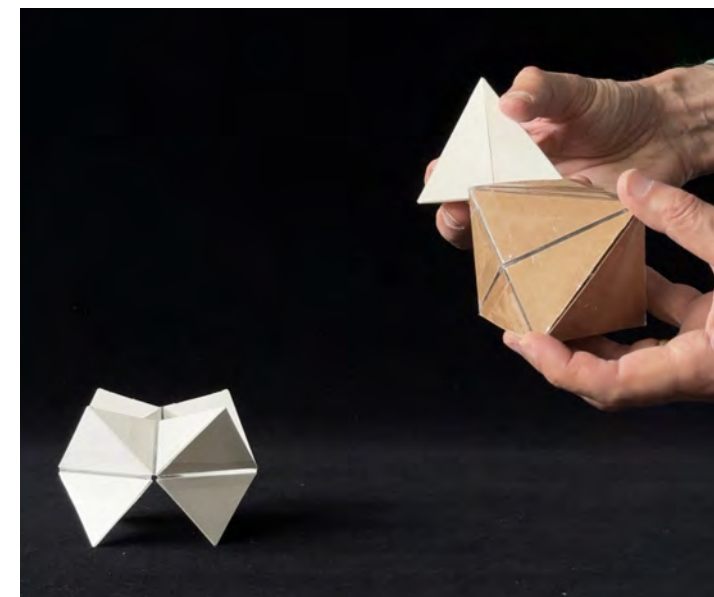
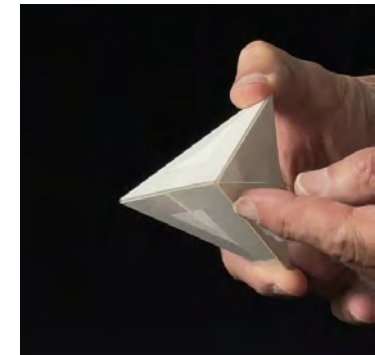
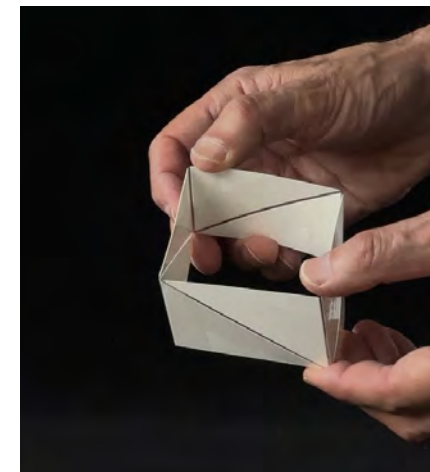


Octahedral strip transforms into an octahedron as well as a tetrahedron by the folding and doubling up of the faces.



TETRAHEDRAL STRIP, C. 1980 TETRAHEDRAL POD, 2025

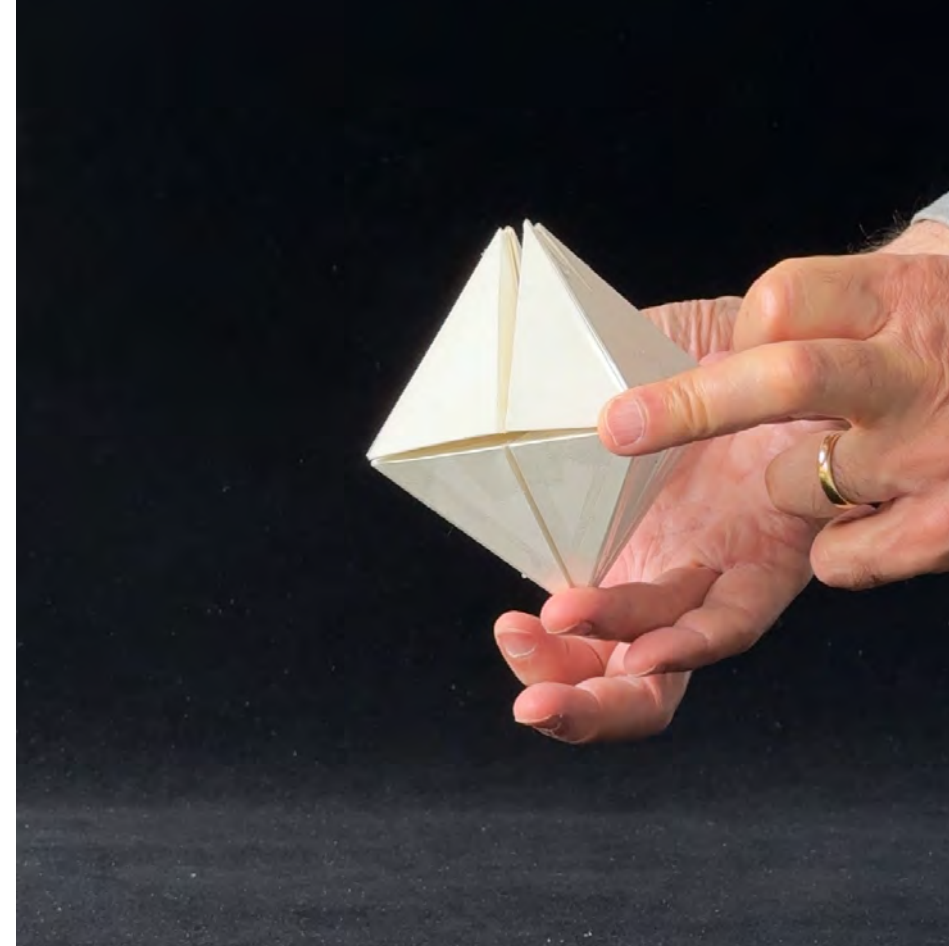
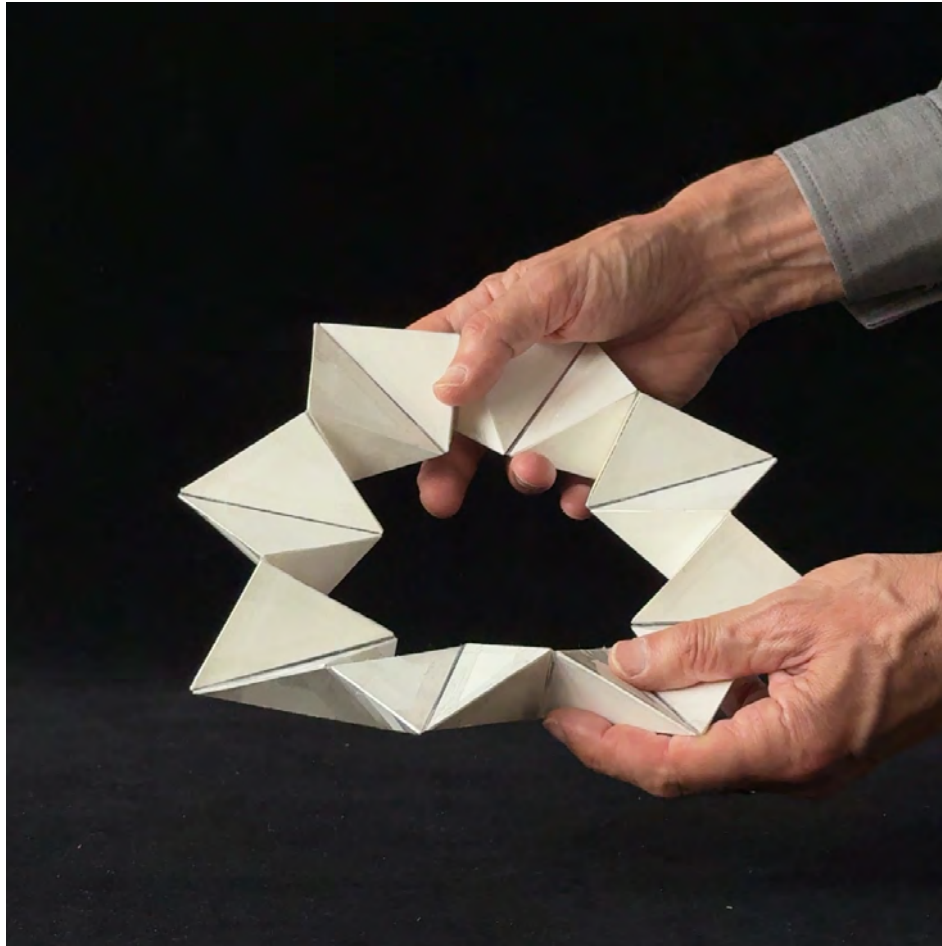
Strip: eight half triangles hinged together transform from a cubic shape to a regular tetrahedron.



SCARPA

OCTAHEDRAL CHAIN, 1978

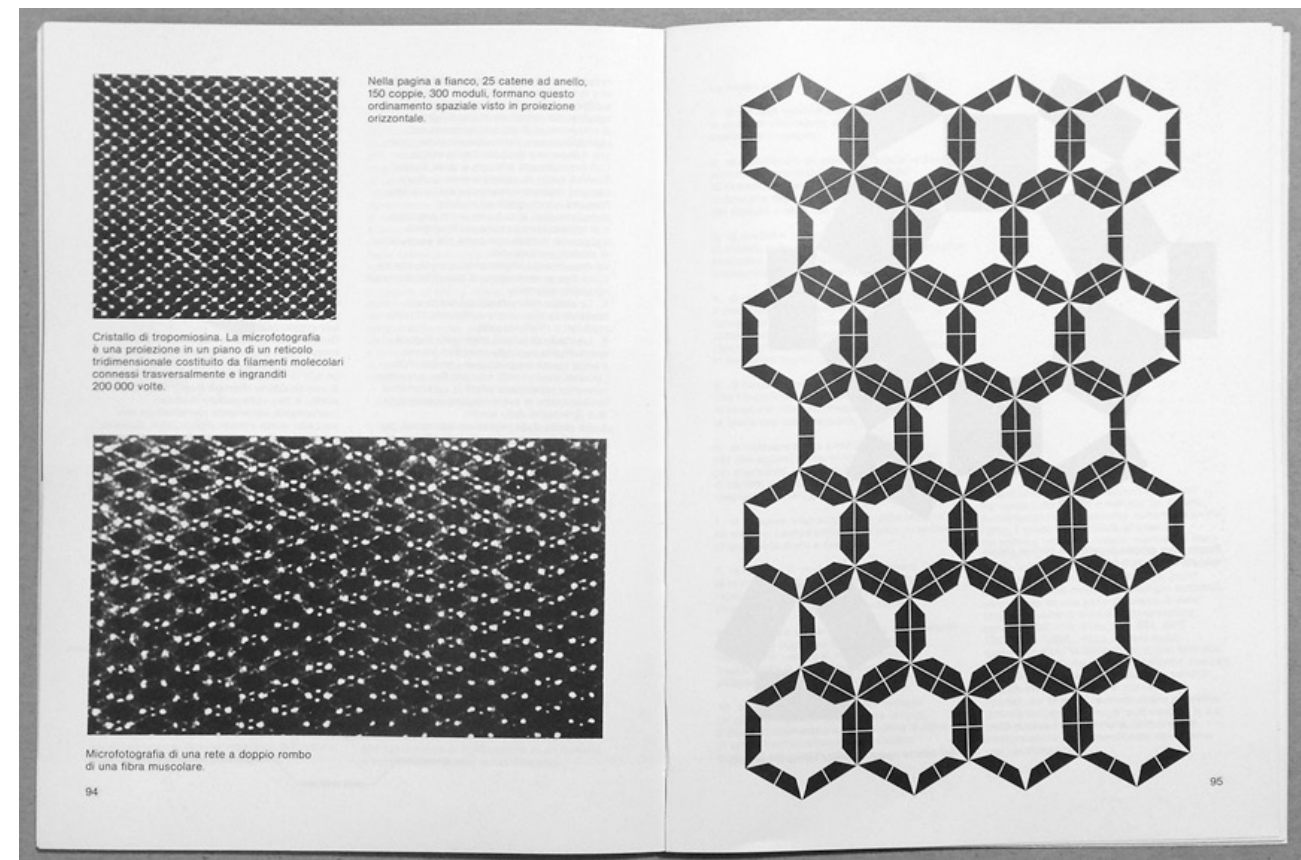
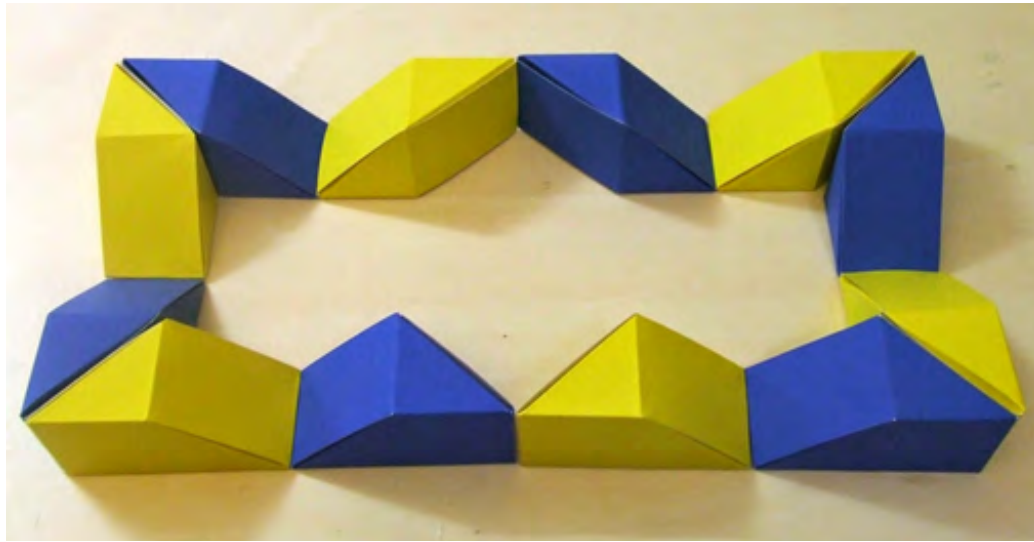
Chain: the same eight half triangles used in the tetrahedral pod, but with different hinge connecting, fold back into a regular octahedron.



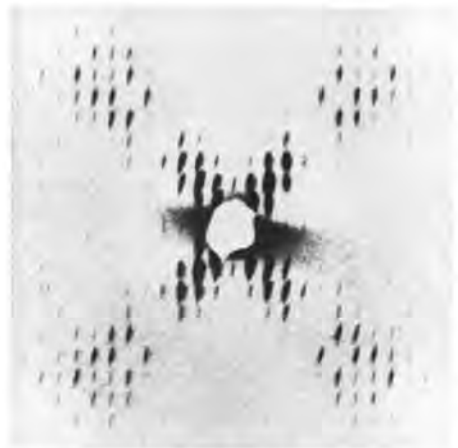
Replica by P.Trogu, 2025.

SCARPA

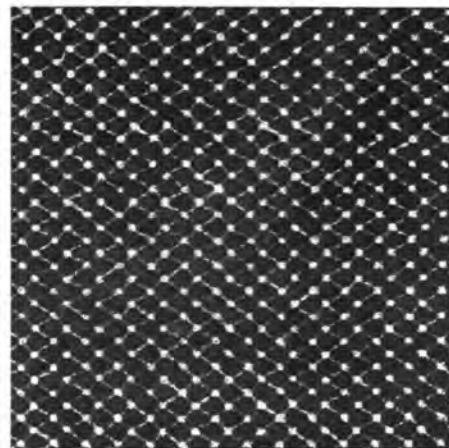
TRANSFORMABLE FABRICS, 1978



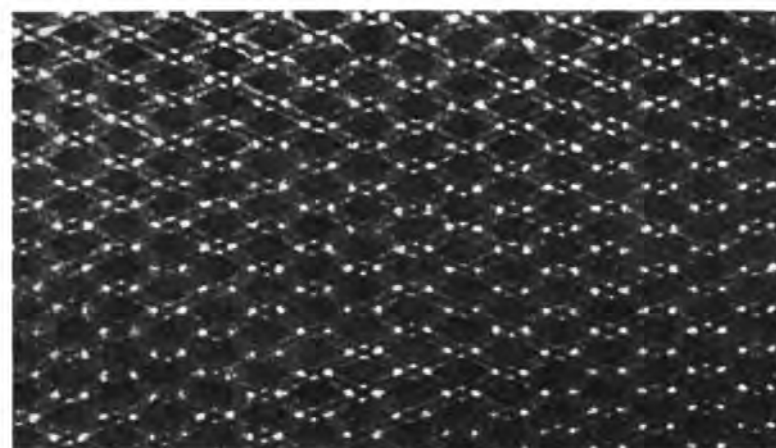
G. Scarpa, *Models of Rotational Geometry*, 1978



X-RAY PATTERN AND ELECTRON MICROGRAPH of tropomyosin crystals were interpreted together to decipher the structure and interactions of the molecule. The X-ray-diffraction pattern (left) could not be readily interpreted by itself but could be understood with the aid of an electron micrograph (right) of a negatively stained tropomyosin crystal. The micrograph is a projection in two



dimensions of a three-dimensional lattice of cross-connected molecular strands enlarged 200,000 diameters. The strands are wavy (resembling a sine wave, the projection of a helix), so that their mesh forms kite-shaped regions. The repeat along a strand (a long arm plus a short arm) is about 400 angstroms. In parts of the micrograph one can see that strands are made up of two filaments.



DOUBLE-DIAMOND MESH is produced when the *TnT* subunit of troponin is crystallized with tropomyosin. The period along the strands is still 400 angstroms but the crossovers are separated to produce a mesh of large and small diamonds. Tropomyosin molecules cross at or near position of *TnT* (bright nodes), which apparently generates new cross-connections.

Carolyn Cohen, The Protein Switch of Muscle Contraction.
Scientific American 233, no. 5 (1975): pp 42, 44

“An experiment which is currently under way has for its aim the construction of **tranformable fabrics** with the following goals, in the order:

1. The study of more appropriate materials for the construction of a relevant number of modular units and their respective connections.

2. The study of **electronic tessellations** spatially arranged in a binary order, with which we can **magnetize the modules**. All the tranformable models constructed so far present in fact the fundamental characteristic of having the connections (hinges) in two dimensions in space.

3. The study of the interactions of the modules, through **mathematical models**, to be fed to the **computer**, in such a way that it will be possible to **rapidly evaluate various solutions** and thus choose those that better adapt to the specific goals.

4. The study of diagrams to illustrate the order of each modular unit rotation in such a way that the set of specific series of rotations, and therefore the precise combinations of modules, can be visualized as shrinkings, stretchings, curlings, vibrations, etc. In this sense, the **electronic paths** in the tilings of modular connections contribute to structure, in a given model, the forms designated by the selected linguistic terms.

5. The study of how to interact with the articulated models through the use of **electronic remote controls**.”

Scarpa, G., *Models of rotational geometry*, 1978, p. 93.

TWO

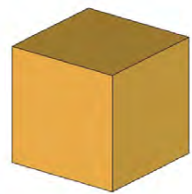
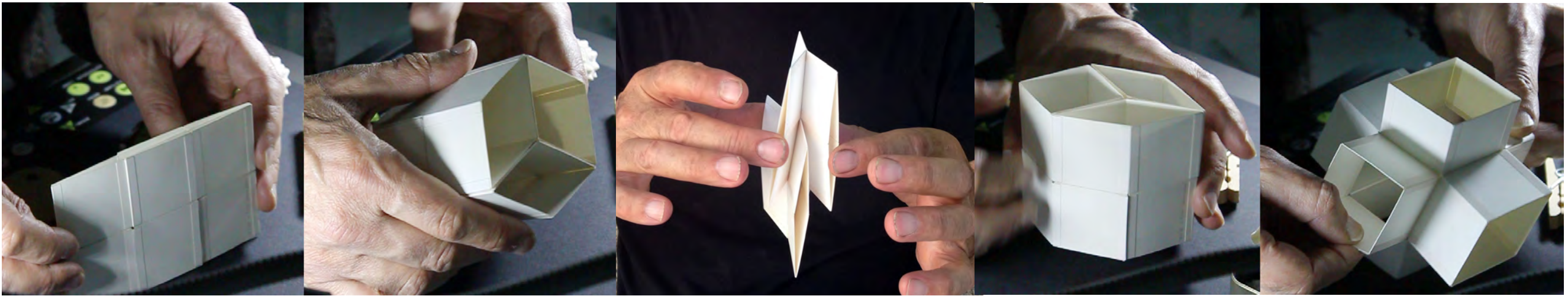
TRANSFORMABLE SHAPES:

“FIGURE TRASFORMABILI”

1996

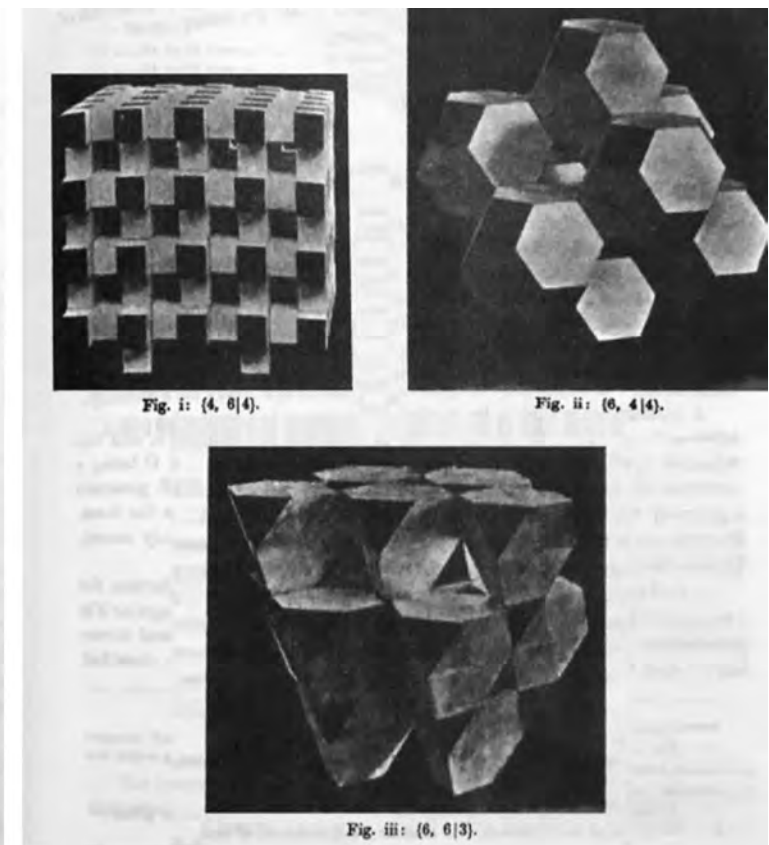
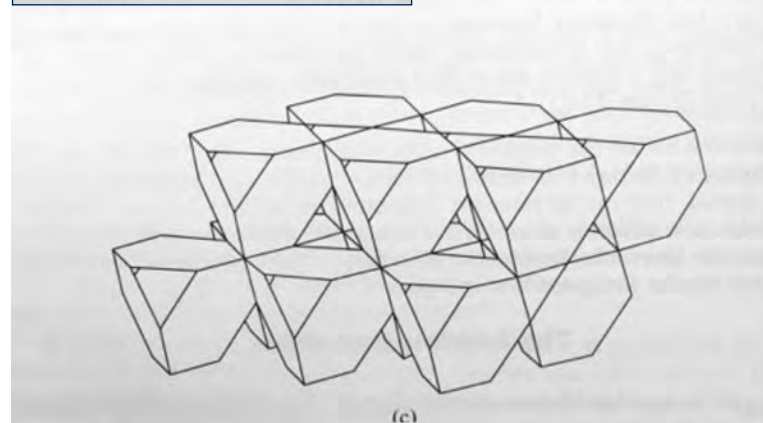
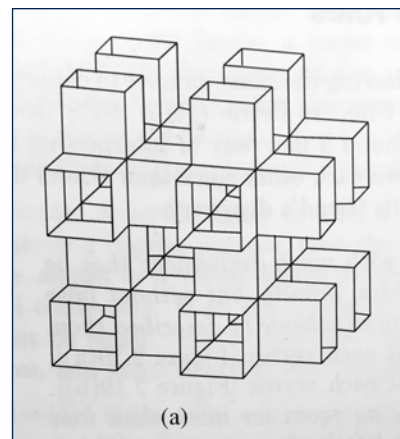
“I hope you like the transformable shape you will find in the package. But it was something else that I wanted to send you, a paper object that I built in three different versions but which still has more than one problem to be resolved.”

July 28, 1996



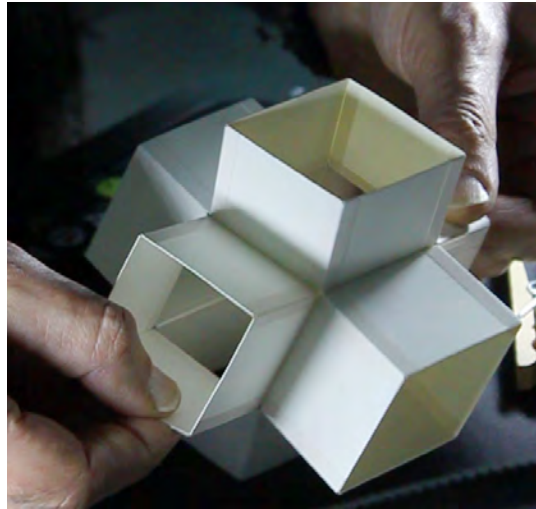
J. F. PETRIE REGULAR HONEYCOMB 1926

P. Cromwell, Polyhedra,
Cambridge University Press, 1997. p.79

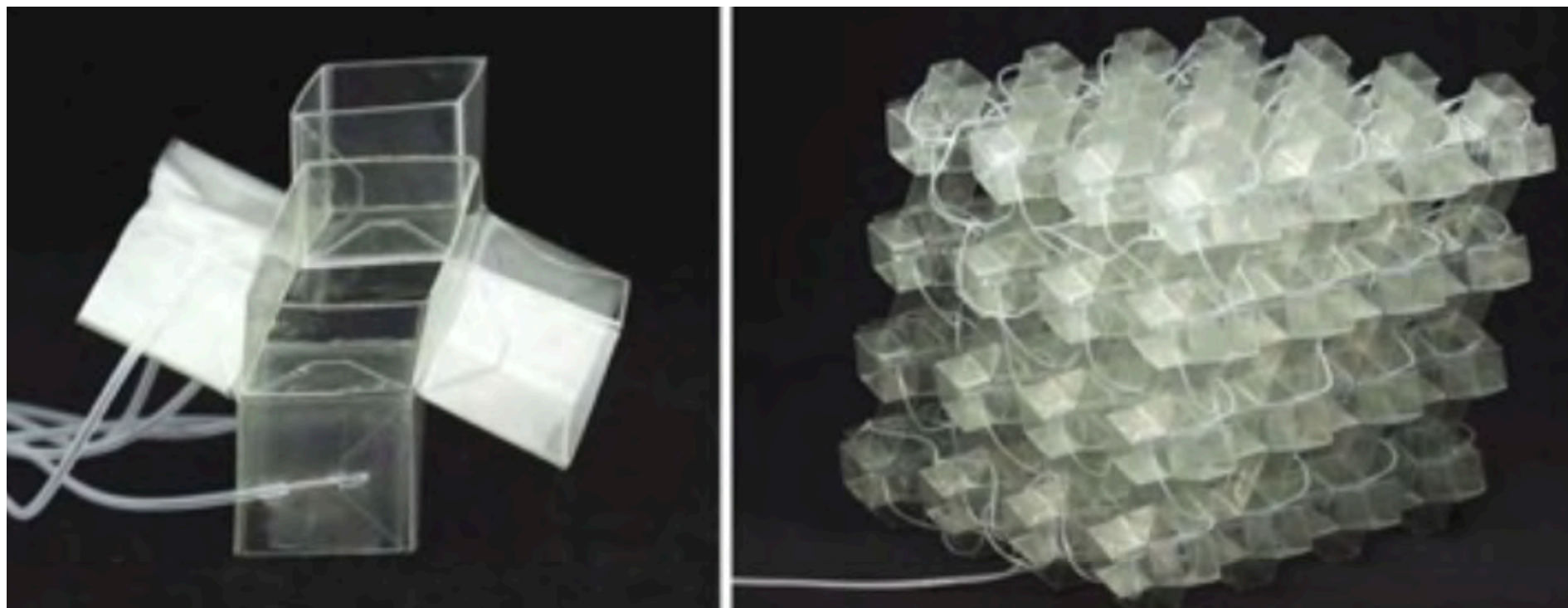


H.S.M. Coxeter, Regular Skew Polyhedra in Three and Four Dimensions, and Their Topological Analogues, *Proc. London Math. Soc.* (series 2) 43 (1937) pp33-34

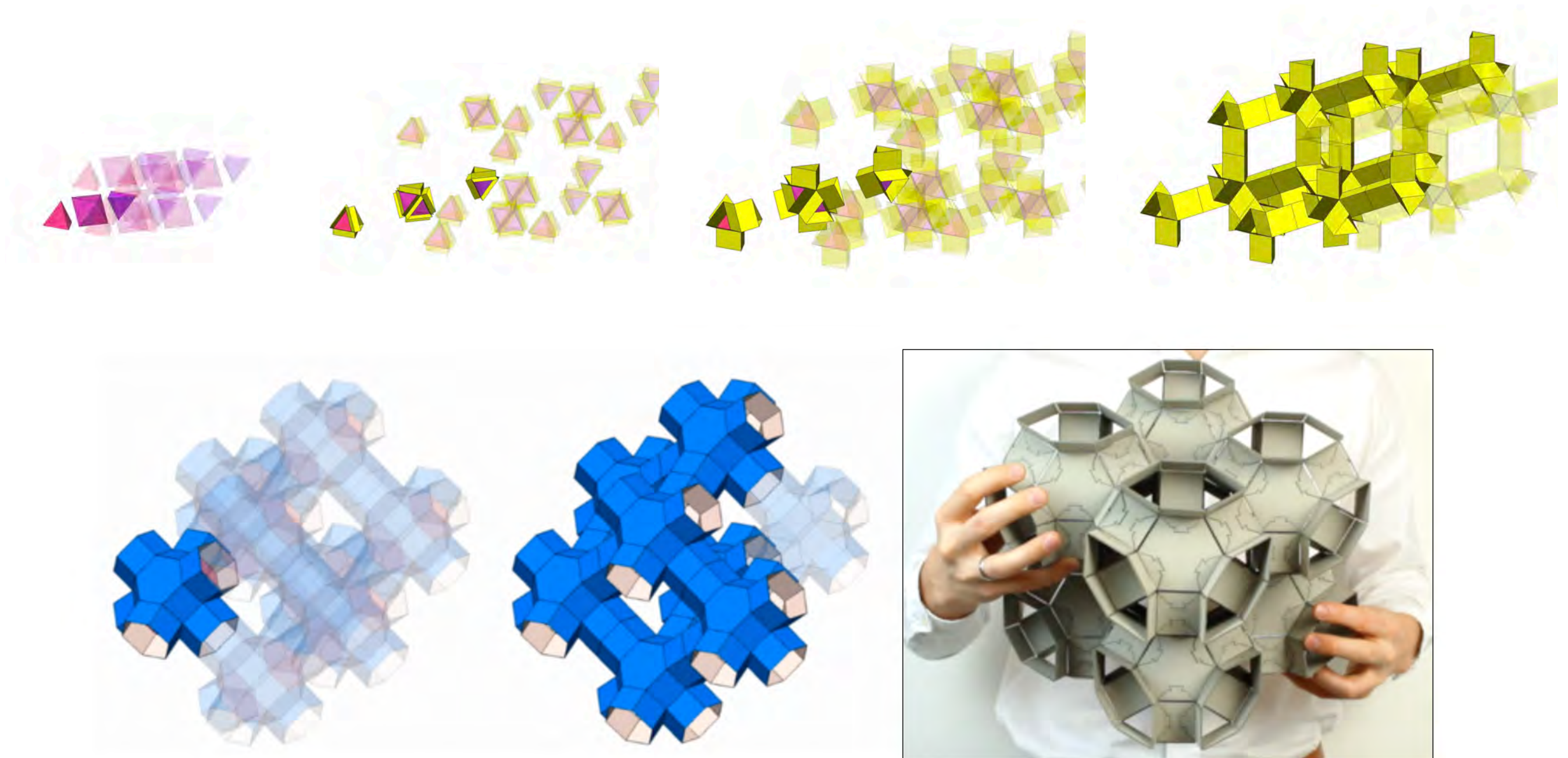
SCARPA, 1996



OVERVELDE ET AL, 2016

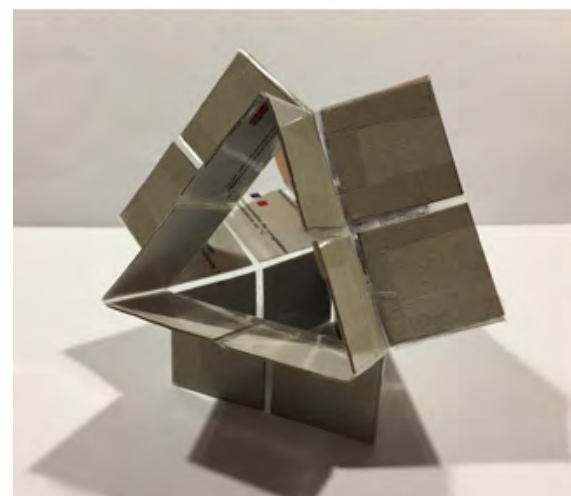
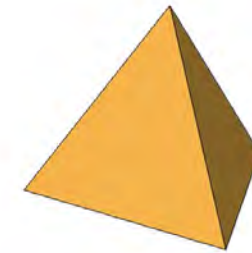
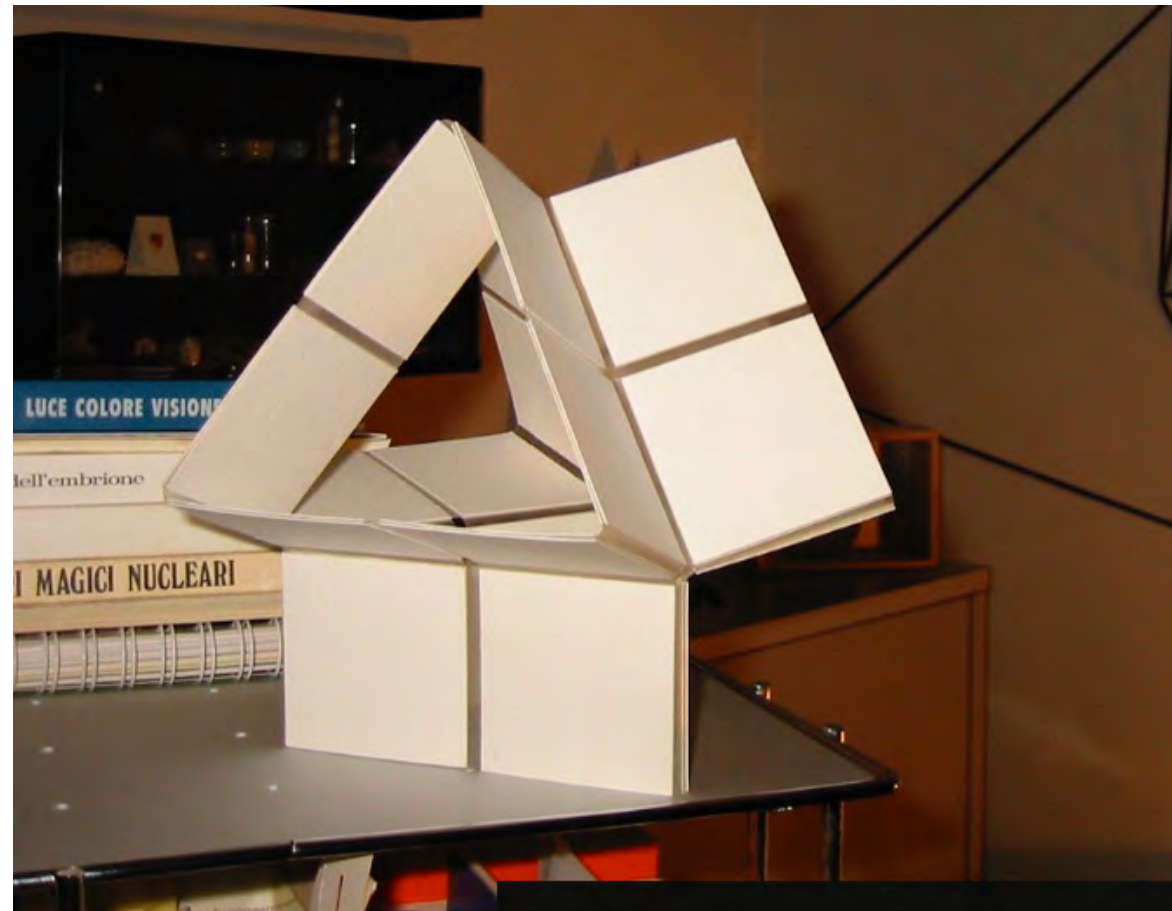


Overvelde, J.T. B. et al, A three-dimensional actuated origami-inspired transformable metamaterial with multiple degrees of freedom.
Nat. Commun. 7, 10929 (2016)



Overvelde, J., Weaver, J., Hoberman, C. et al.
Rational design of reconfigurable prismatic architected materials.
Nature 541, 347–352 (2017).

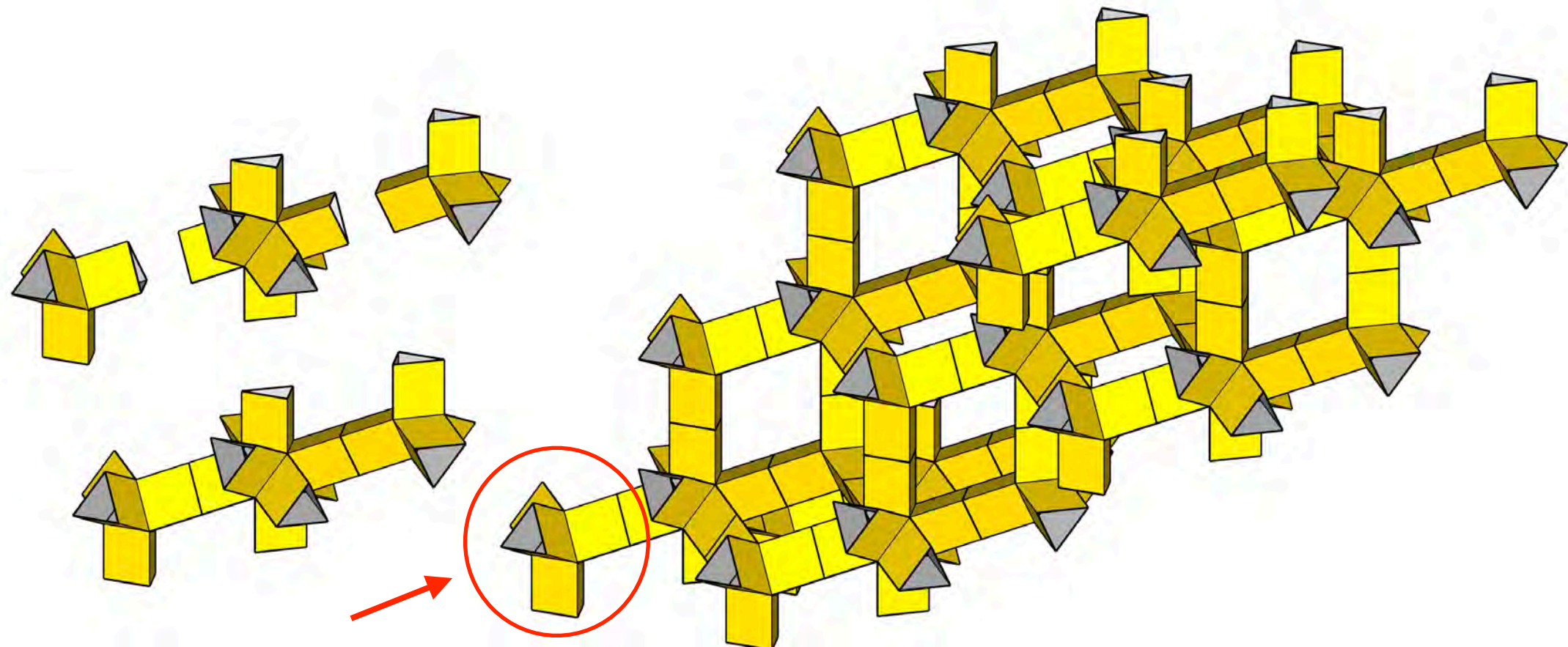
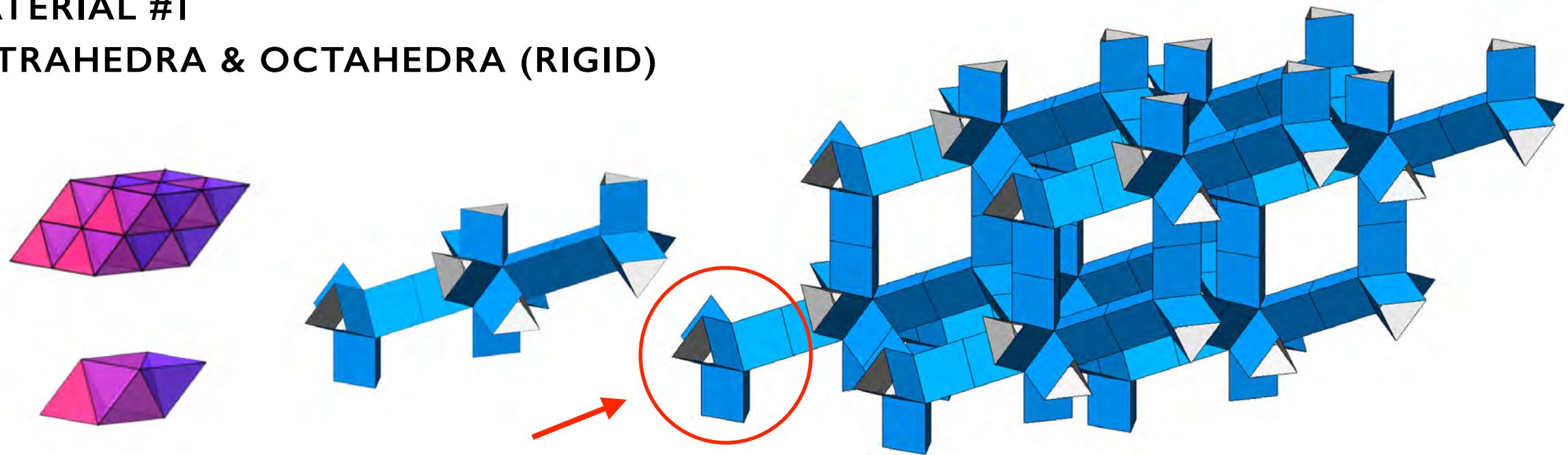
G. SCARPA – SPLIT EXTRUSION TETRAHEDRON – 1996



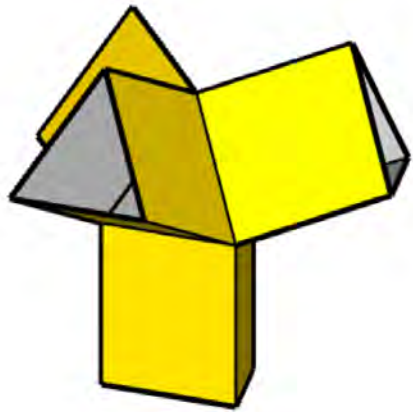
First replica by P.Trogu, 2017

FLAT-FOLDABLE AUXETIC METAMATERIALS (PROCESS)

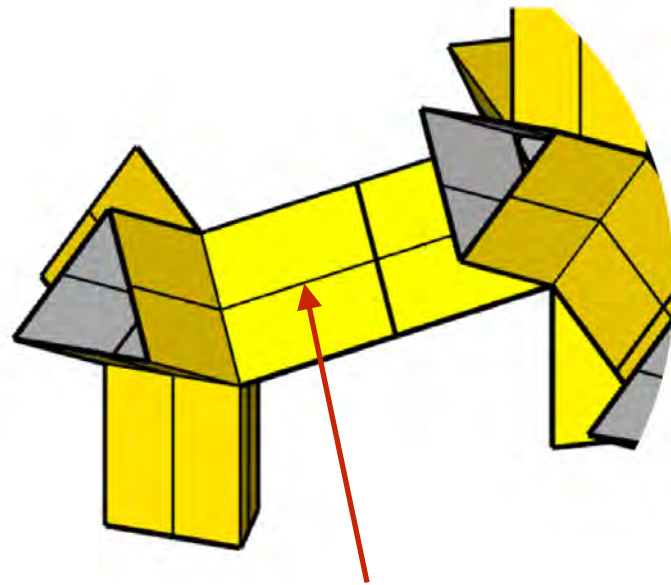
MATERIAL #1
TETRAHEDRA & OCTAHEDRA (RIGID)



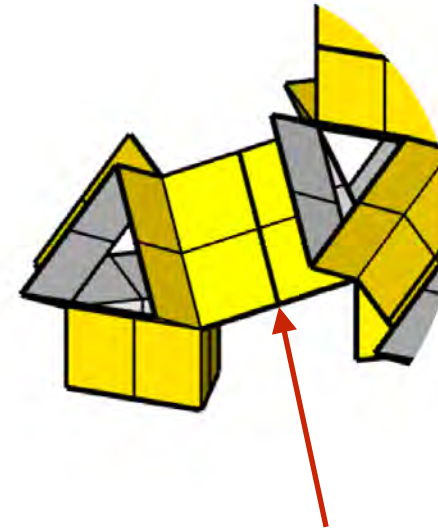
MATERIAL #1
TETRAHEDRA & OCTAHEDRA (FLAT-FOLDABLE)



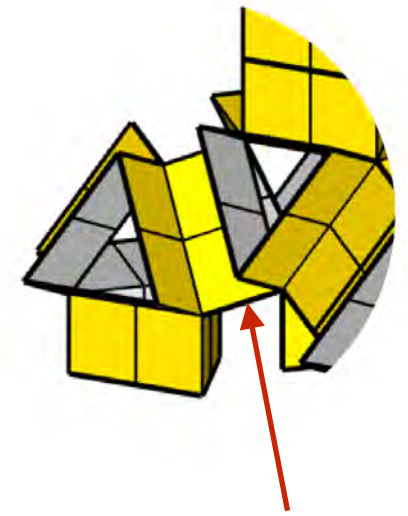
START



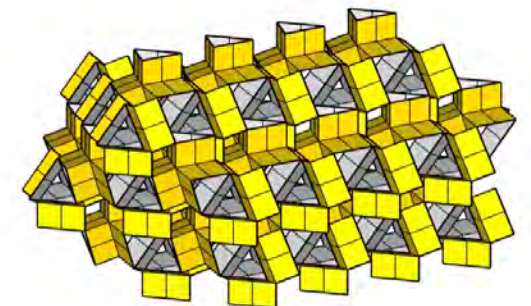
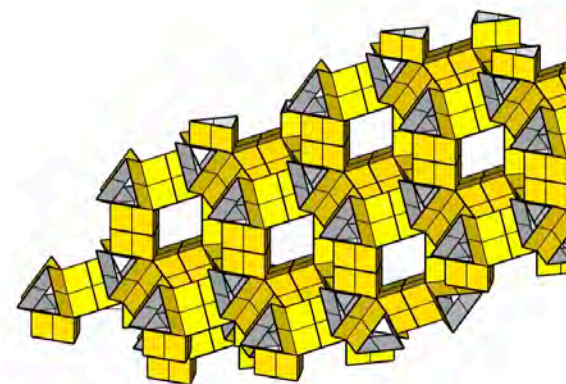
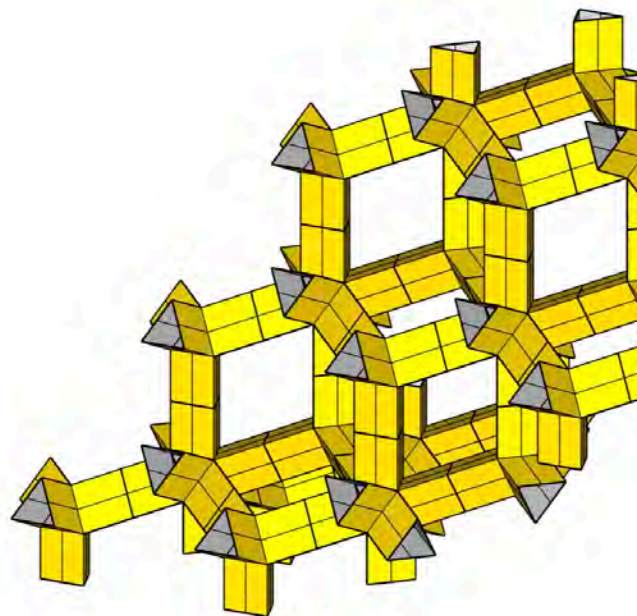
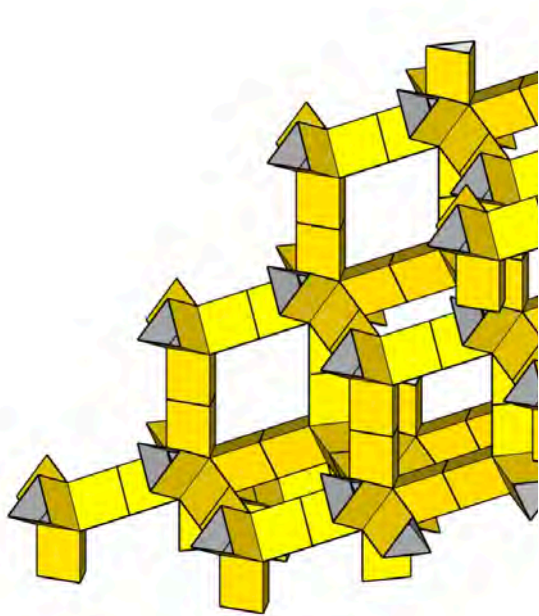
**STEP 1: BISECT
EXTRUDED PRISM WALLS**



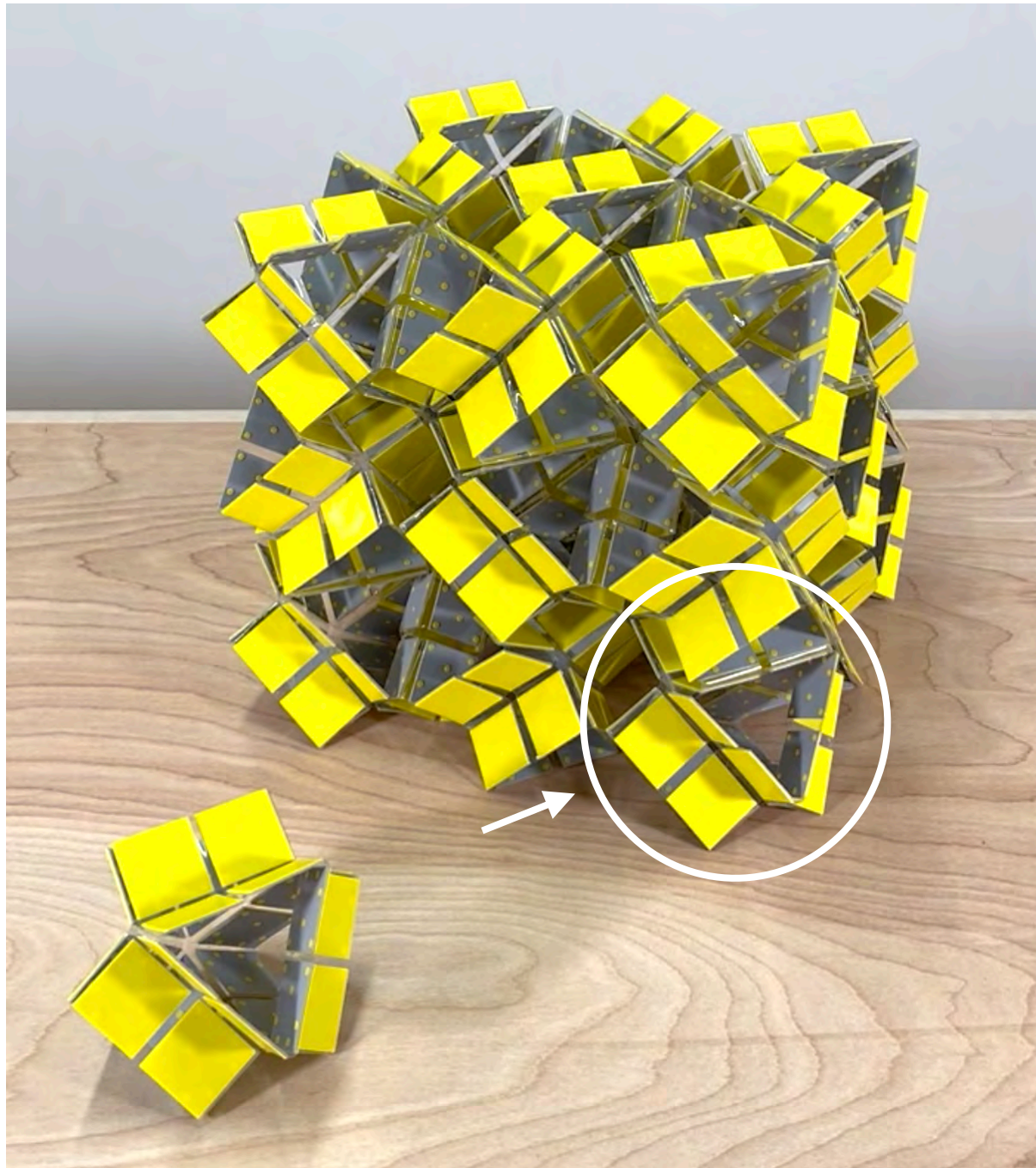
**STEP 2: HALVE THE
EXTRUSION LENGTH**



**STEP 3: "PUSH-FIT"
THE EXTRUDED PRISMS**



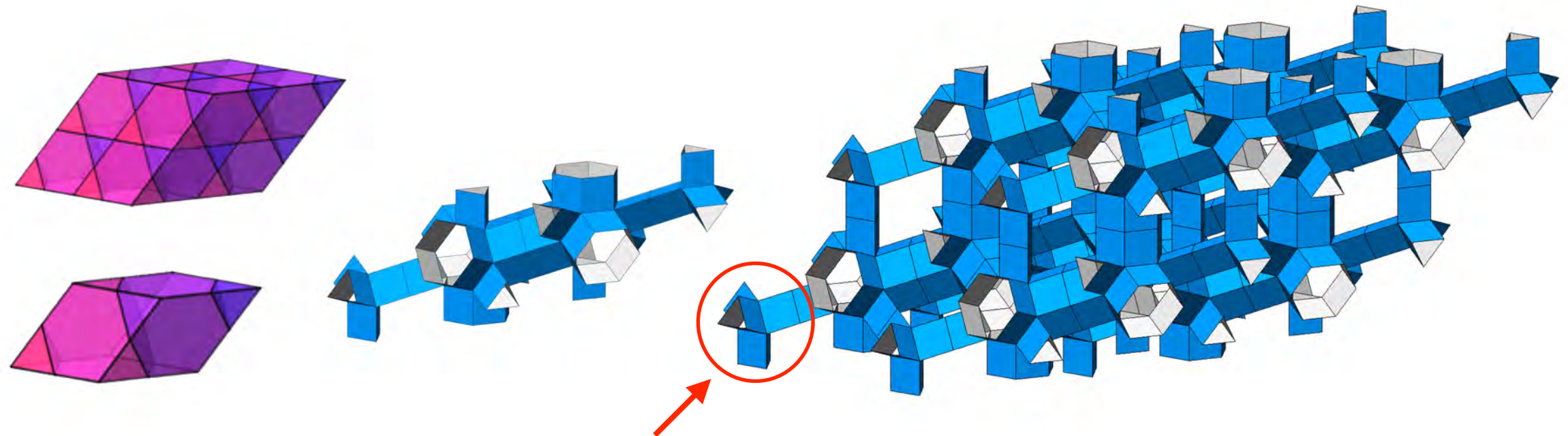
MATERIAL #1
TETRAHEDRA & OCTAHEDRA (FLAT-FOLDABLE)



(Model fabrication:
E. Montano, J. Minnick,
D. Munechica, J. Cuellar,
P.Trogu, 2023)

MATERIAL #6

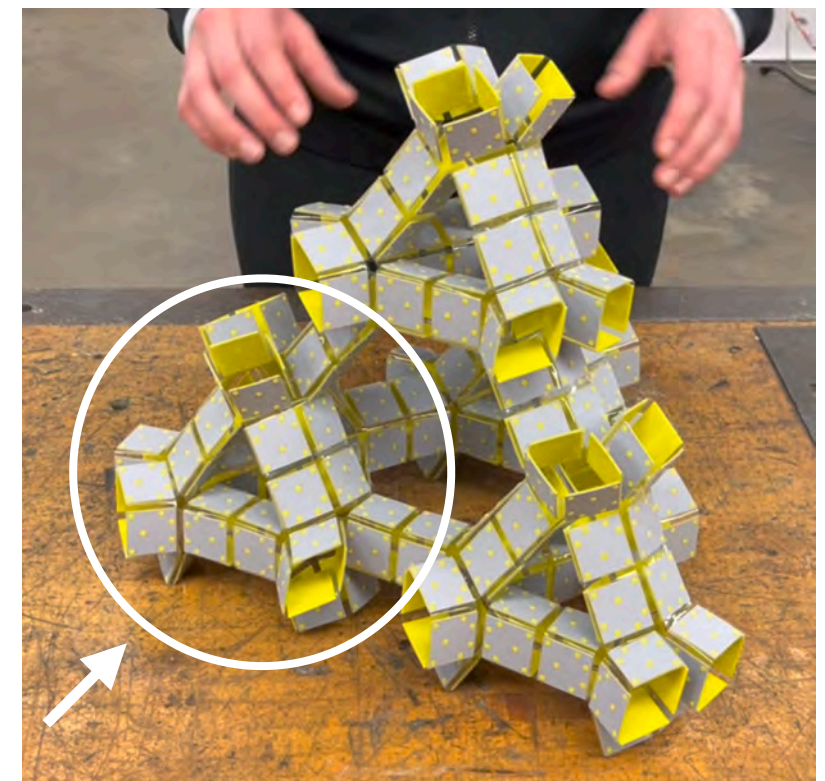
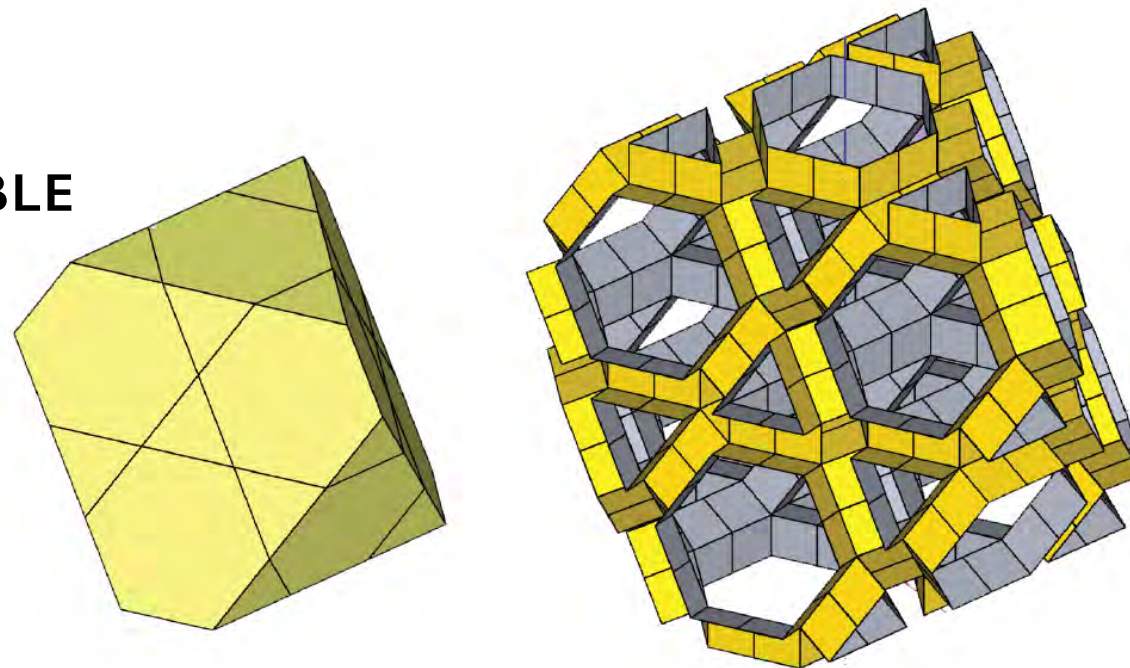
TETRAHEDRA & TRUNCATED TETRAHEDRA (RIGID)



TROGU, 2023

MATERIAL #6

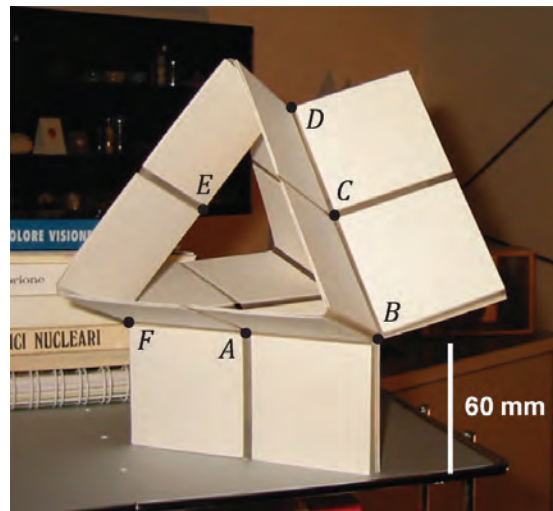
FLAT-FOLDABLE



Model fabrication: E. Montano, J. Minnick, D. Munechica, J. Cuellar, P.Trogu, 2023

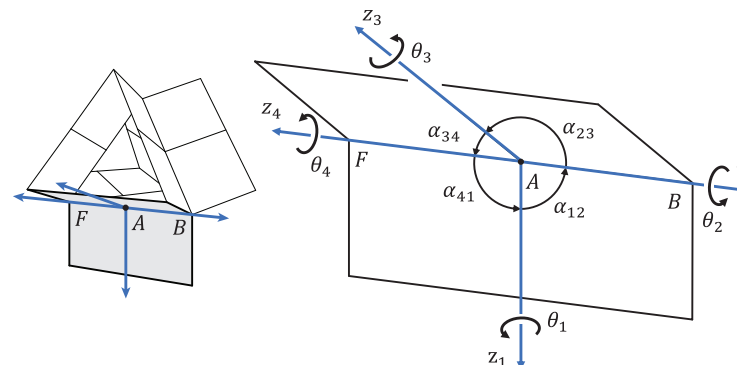
EXTRUDED
TETRAHEDRON:
FROM
NON RIGIDLY FOLDABLE
TO RIGIDLY FOLDABLE

Scarpa's transformable model (1996)

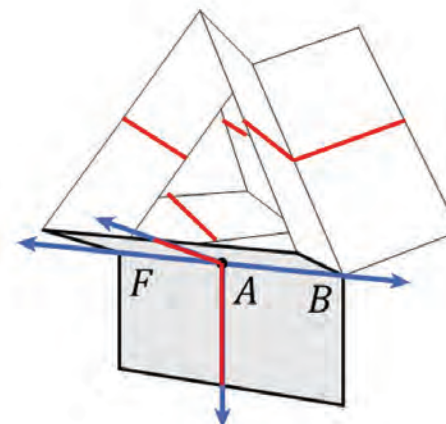


It is flat-foldable

Rigid foldability analysis



D-H notation of the four-crease vertex A .



inactive creases

It is not rigidly foldable

Conditions:

$$\alpha_{12} = \alpha_{23} = \alpha_{34} = \alpha_{41} = \frac{\pi}{2}$$

Closure equation (D-H):

$$Q_{21}Q_{32} = Q_{41}Q_{34}$$

where

$$Q_{(i+1)i} = \begin{bmatrix} \cos \theta_i & -\cos \alpha_{i(i+1)} \sin \theta_i & \sin \alpha_{i(i+1)} \sin \theta_i \\ \sin \theta_i & \cos \alpha_{i(i+1)} \cos \theta_i & -\sin \alpha_{i(i+1)} \cos \theta_i \\ 0 & \sin \alpha_{i(i+1)} & \cos \alpha_{i(i+1)} \end{bmatrix}$$

$$Q_{i(i+1)} = \begin{bmatrix} \cos \theta_i & \sin \theta_i & 0 \\ -\cos \alpha_{i(i+1)} \sin \theta_i & \cos \alpha_{i(i+1)} \cos \theta_i & \sin \alpha_{i(i+1)} \\ \sin \alpha_{i(i+1)} \sin \theta_i & -\sin \alpha_{i(i+1)} \cos \theta_i & \cos \alpha_{i(i+1)} \end{bmatrix}$$

Solution:

$$\theta_1 = \theta_3 = 0, \theta_2 = \theta_4;$$

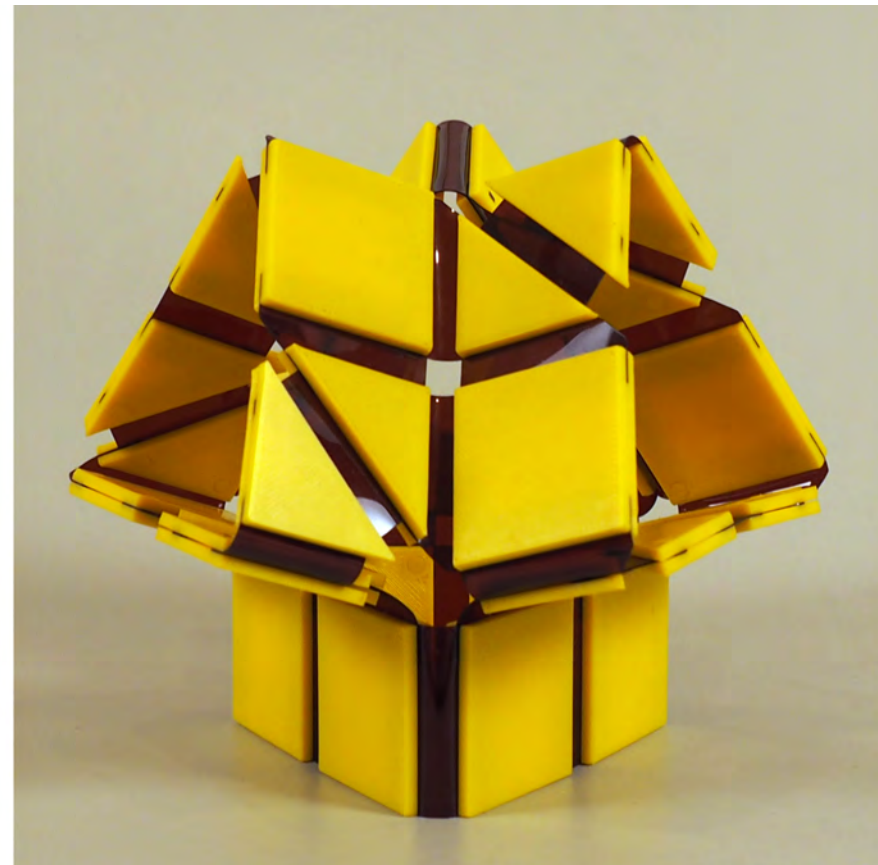
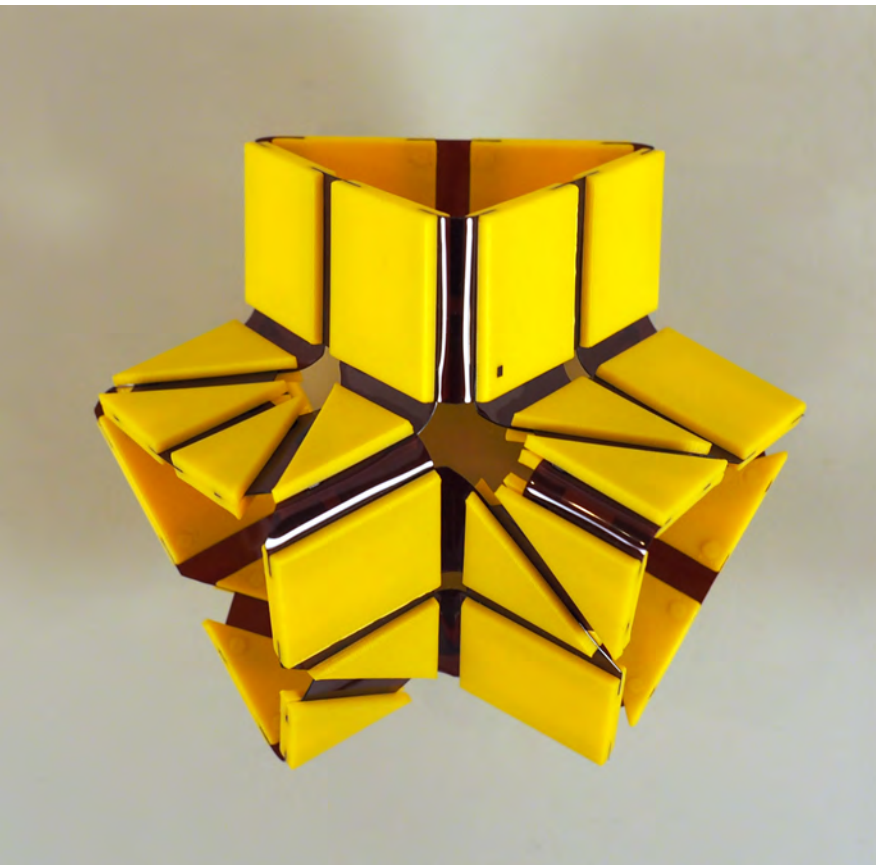
$$\text{or } \theta_2 = \theta_4 = 0, \theta_1 = \theta_3.$$

SCARPA'S ORIGINAL SHAPE: NON-RIGIDLY FOLDABLE

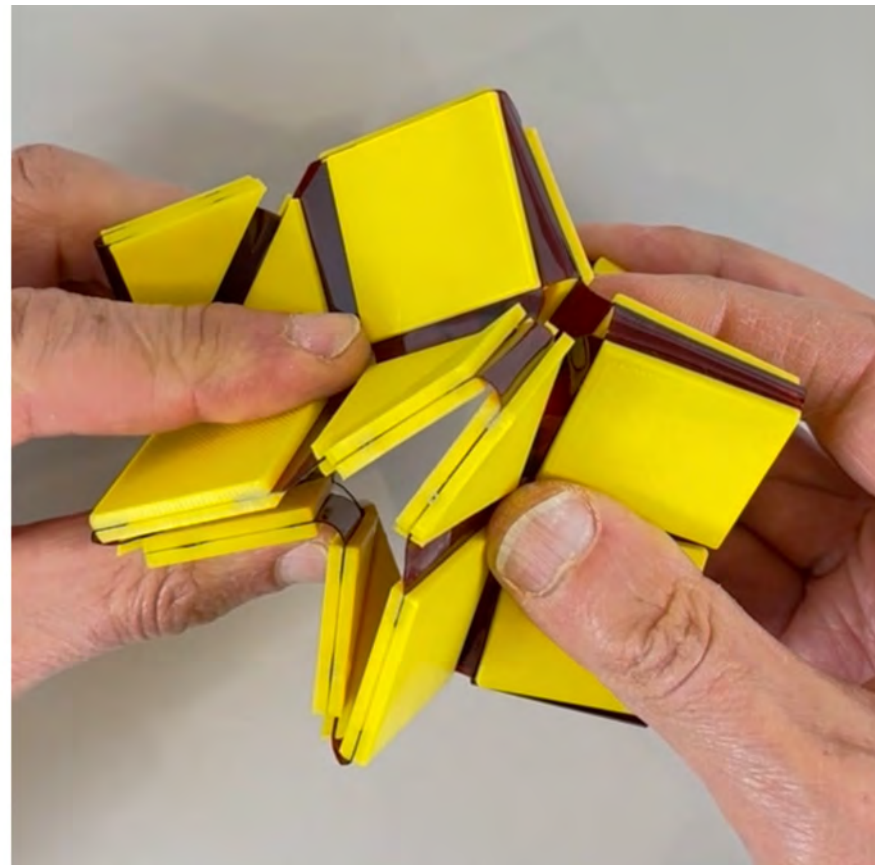
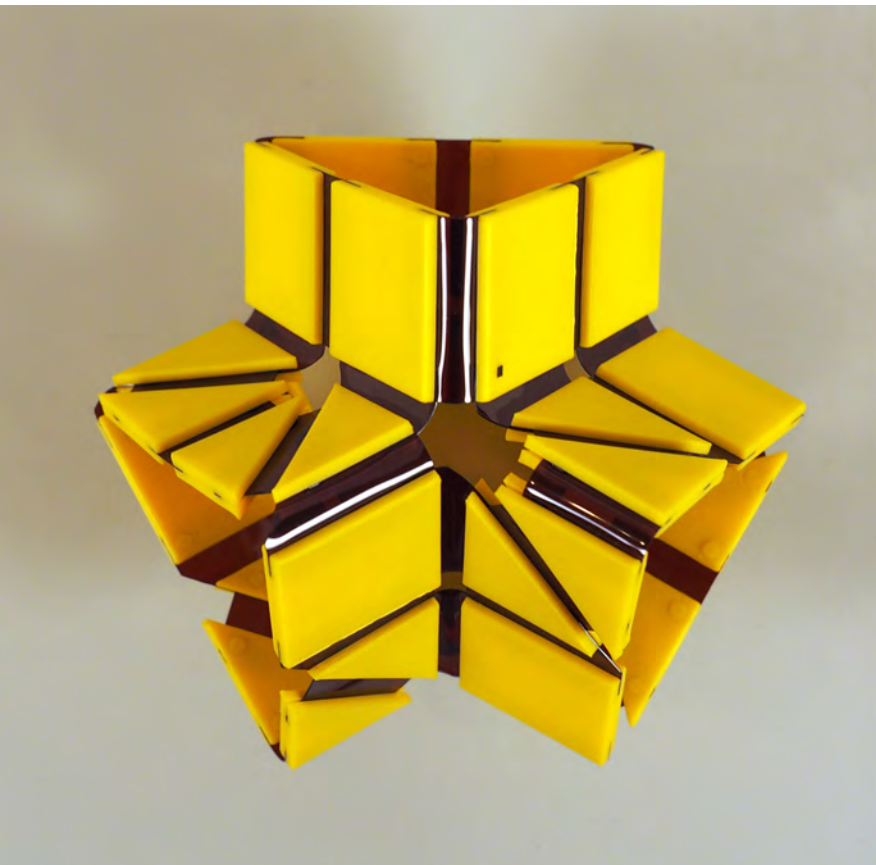


Model fabrication: H. Feng, W. Shi, P. Trogu, E. Montano,
J. Minnick, G. Montalvo, T. Casanova, 2023

MODIFIED SHAPE: RIGIDLY FOLDABLE WITH ADDITIONAL CREASES



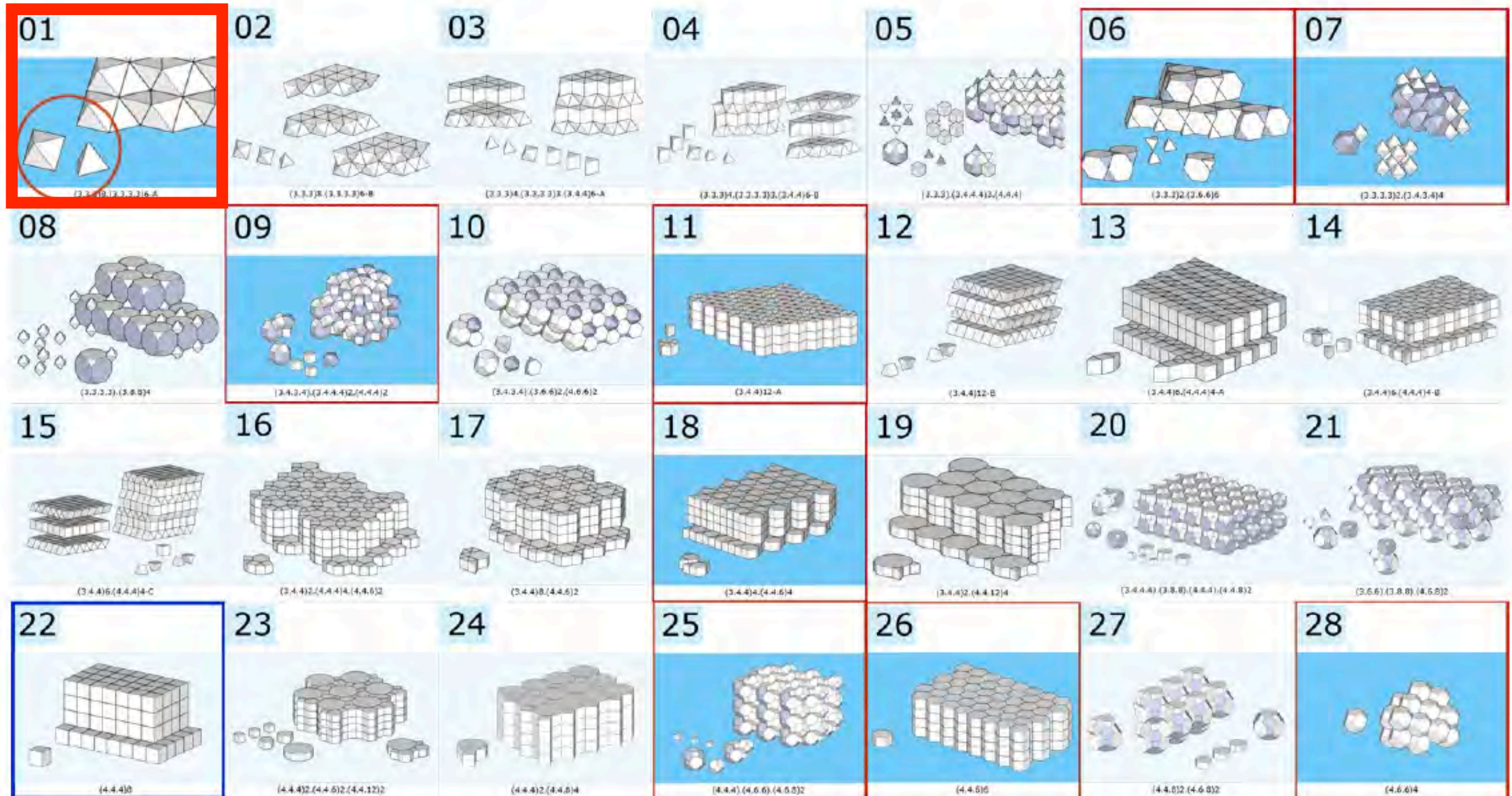
MODIFIED SHAPE: RIGIDLY FOLDABLE WITH ADDITIONAL CREASES



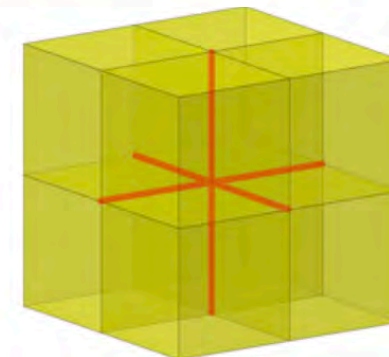
MATERIAL #1

**HOW DOES THE ORIGINAL
SHAPE FOLD?**

UNIFORM TILINGS OF 3-SPACE*

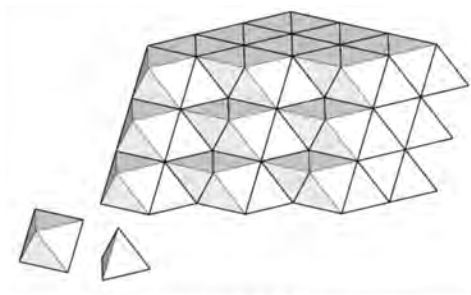


*Grünbaum, 1994
“Vertex neighborhoods”
are all the same.



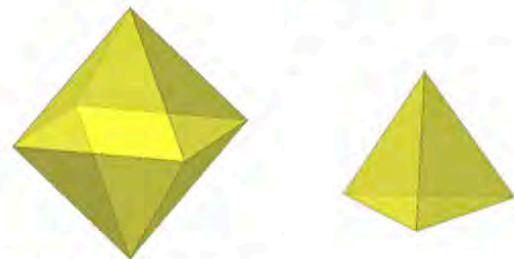
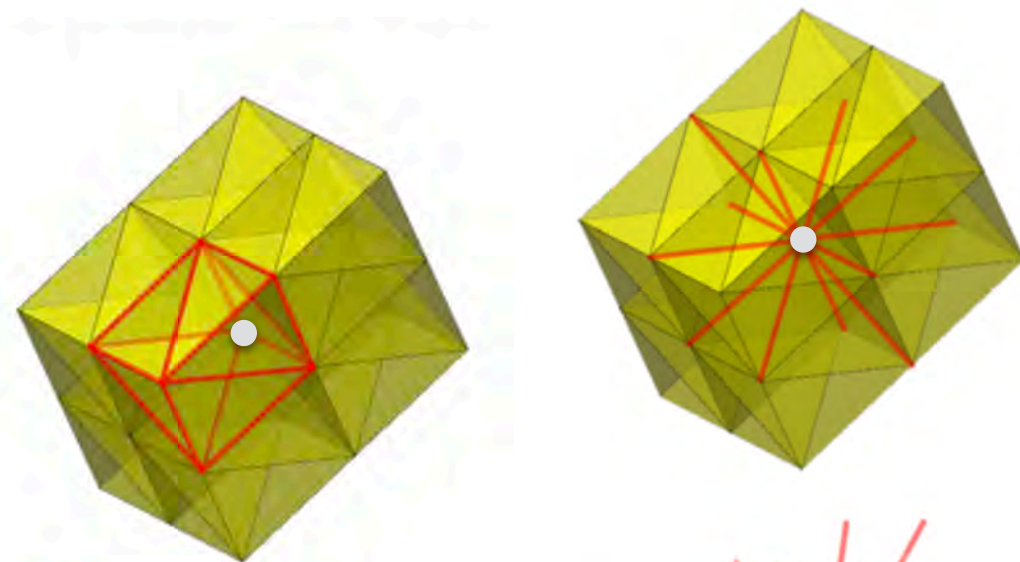
Vertex neighborhood
in tiling #22 (cubes)

Uniform tiling #1

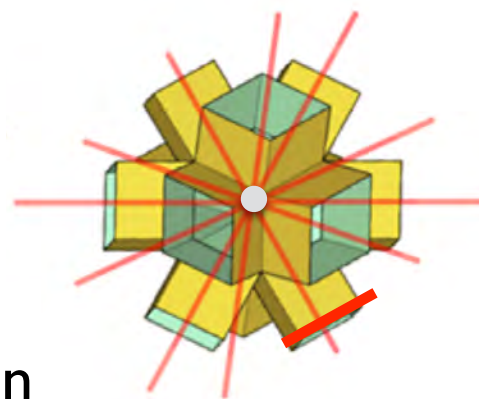


VERTEX NEIGHBORHOOD

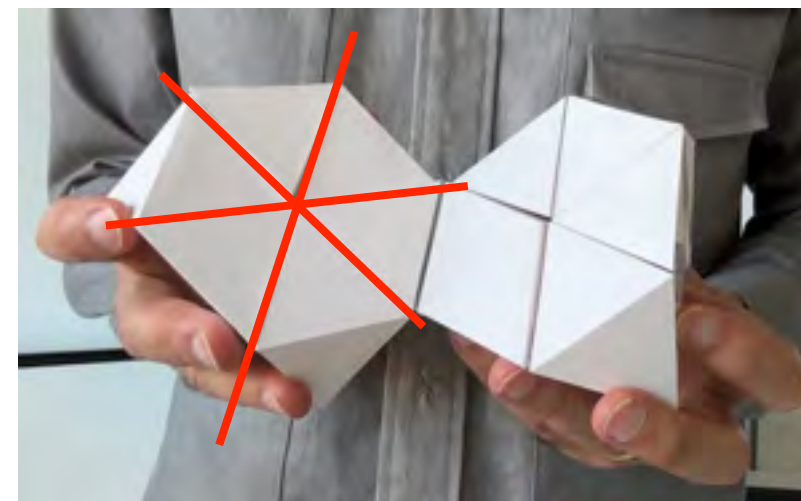
Eight tetrahedra and six tetrahedra meet at a vertex.



Octahedron Tetrahedron



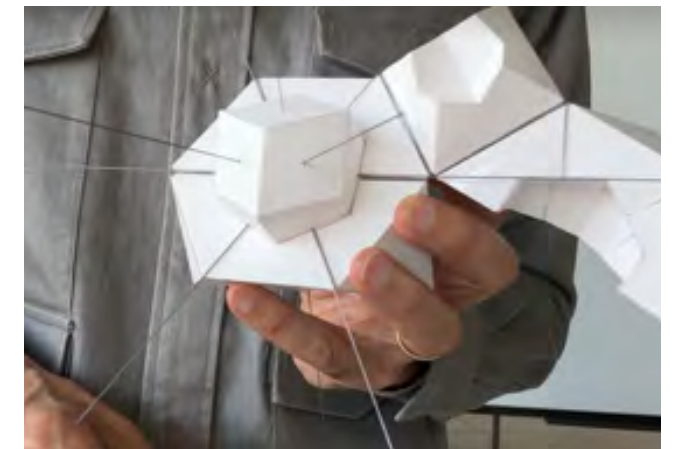
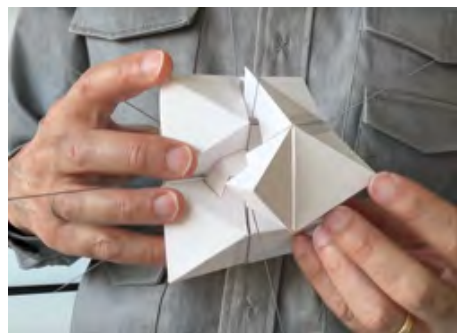
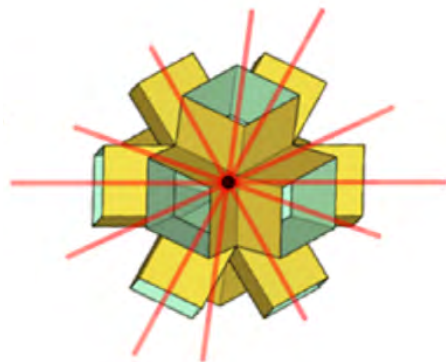
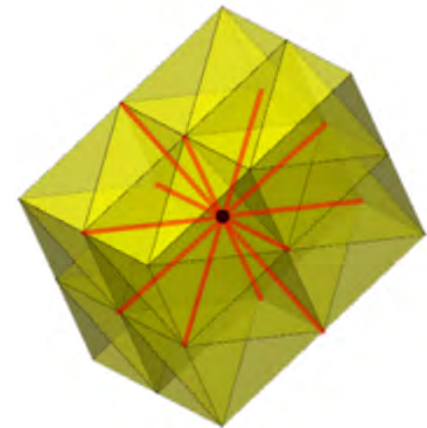
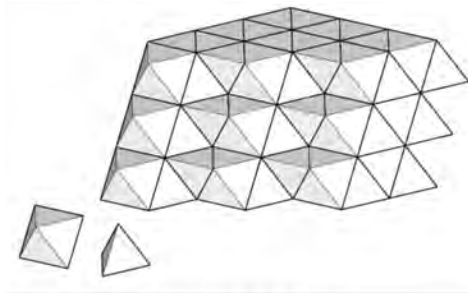
Extruded
rhombic
dodecahedron
(twelve prisms)



Common edges
form a six-axis star.



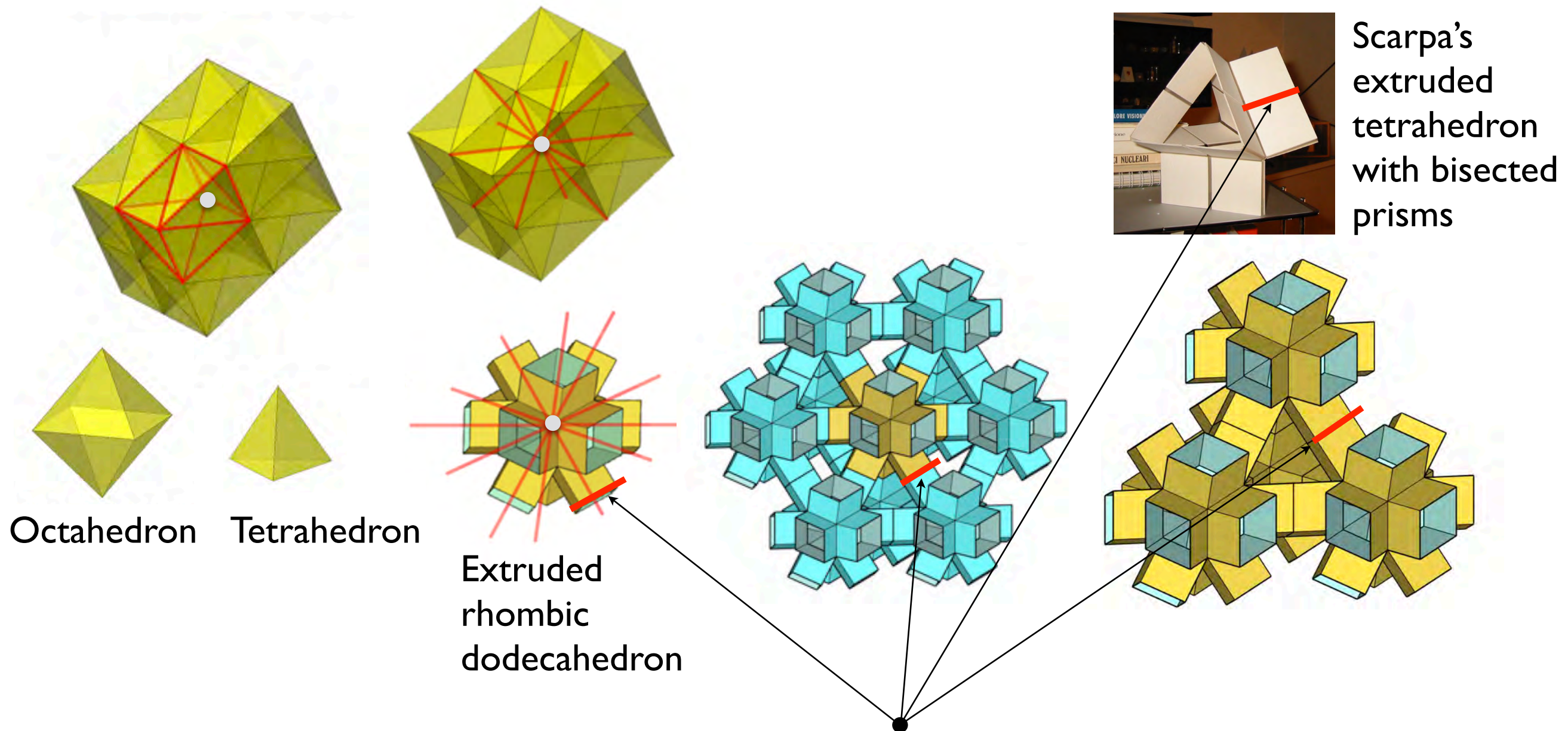
Uniform tiling #1



BYPRODUCT POLYHEDRA

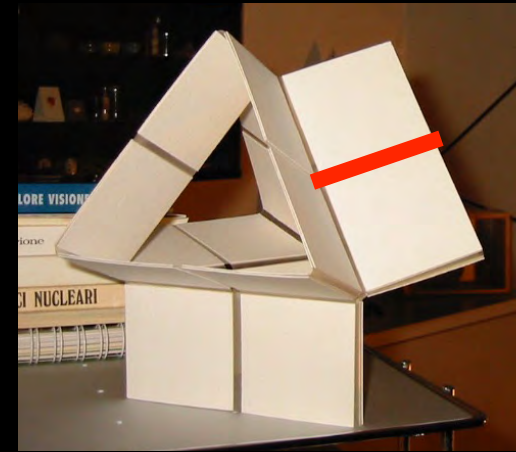
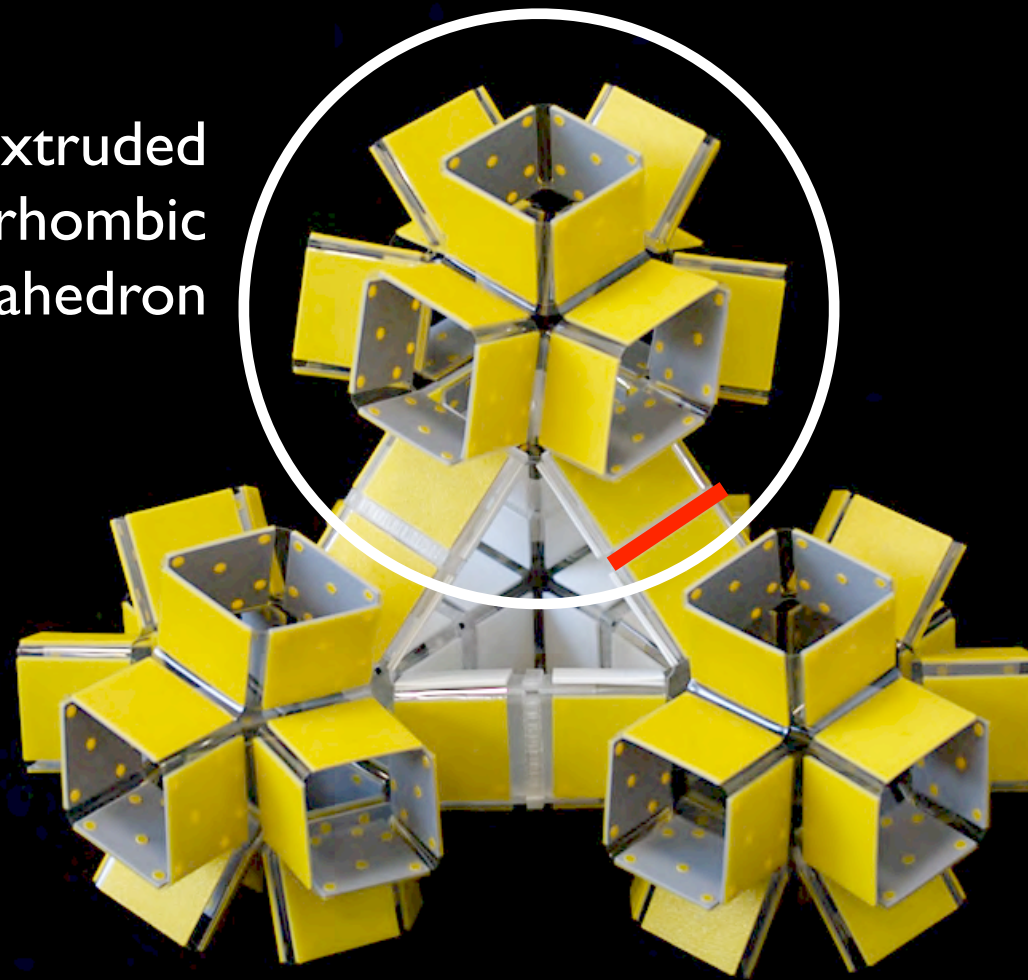
A way to predict what “byproduct polyhedra” will be generated after the base polyhedra are extruded, is to consider the dual honeycomb of the original honeycomb. Lines connecting the centers of adjacent tetrahedra and octahedra are the edges of a rhombic dodecahedron.

After extruding the faces of the tetrahedra and octahedra in the base tiling of material #1, rhombic dodecahedra or “byproduct polyhedra” – form at the location of the original vertex neighborhoods.



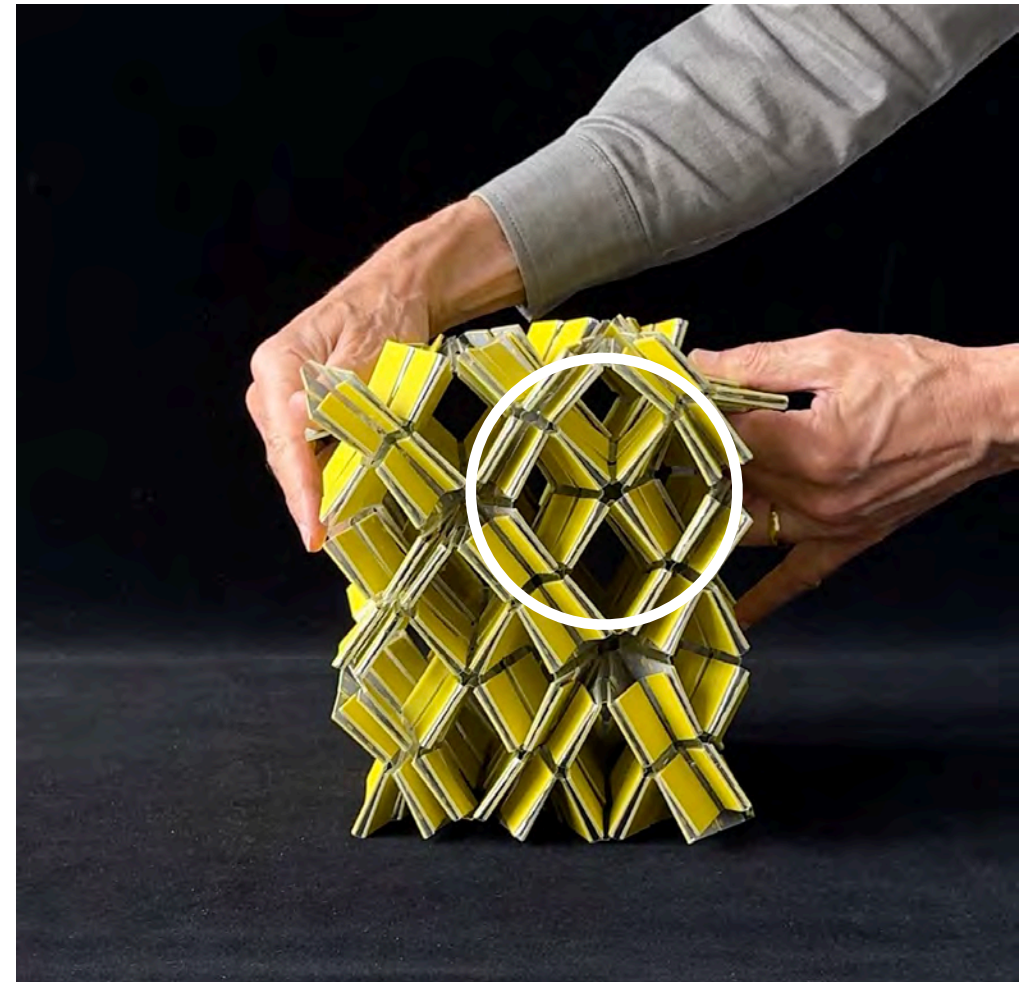
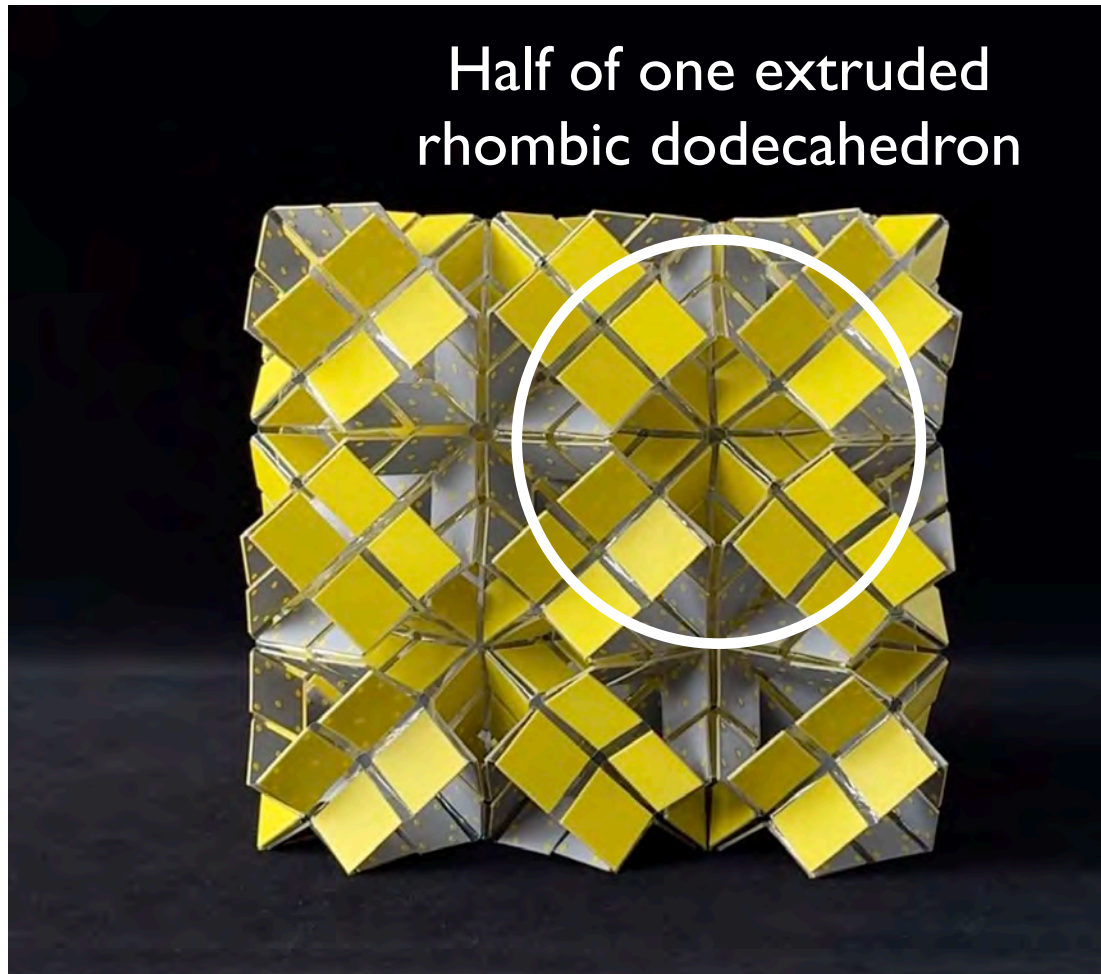
The ends of the non-split prisms in the rhombic dodecahedra correspond to the bisections in Scarpa's original tetrahedron

Extruded
rhombic
dodecahedron



3x3x3 TETRAHEDRA MATERIAL

Half of one extruded
rhombic dodecahedron

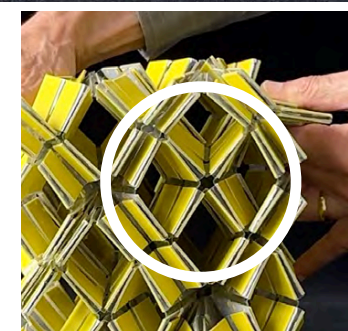
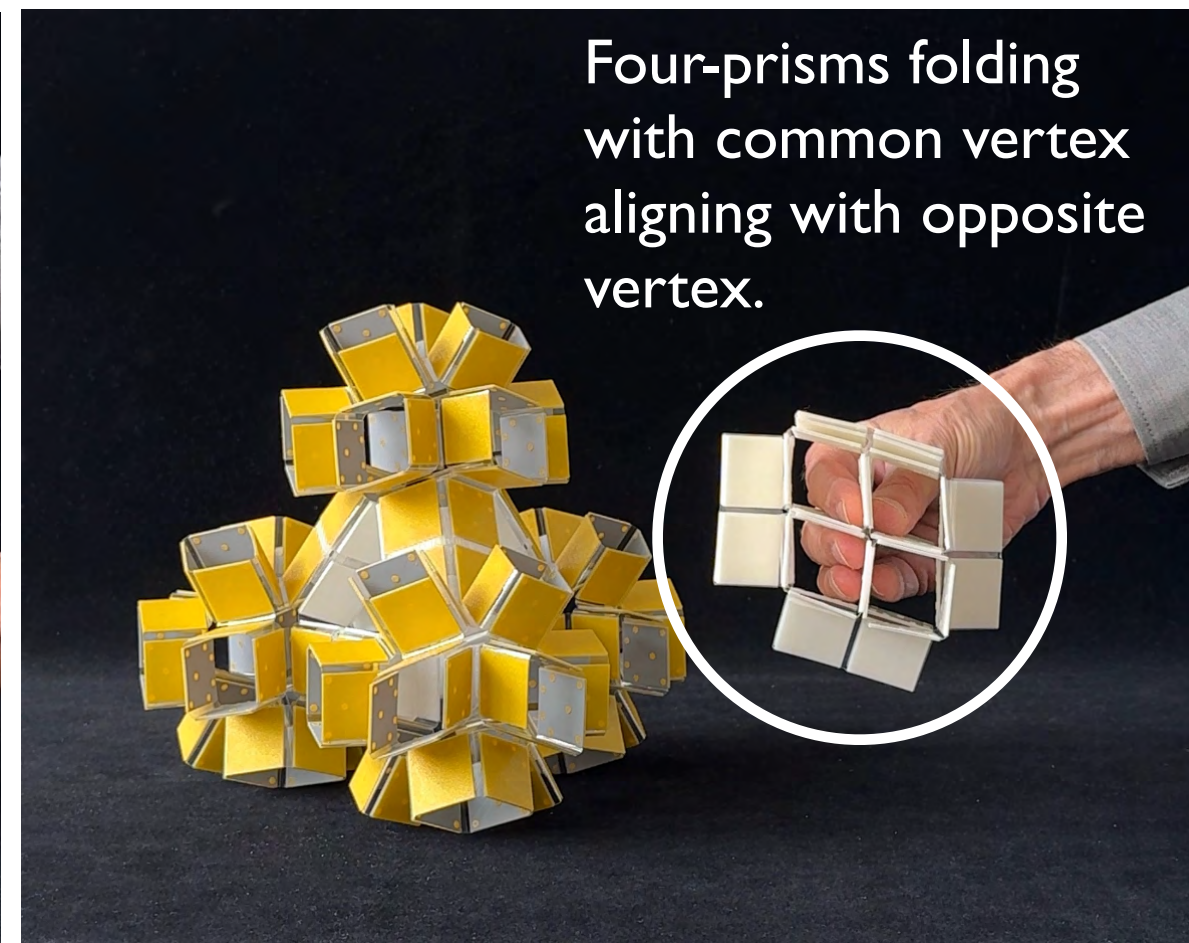


Four “channels”* are seen
forming at a four-crease
vertex of the rhombic
dodecahedron during folding.

*(B. Kresling)



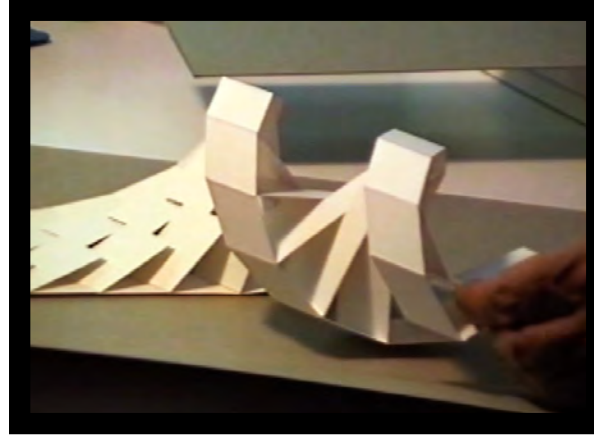
Four-crease vertex
with four prisms in
the rhombic
dodecahedron.



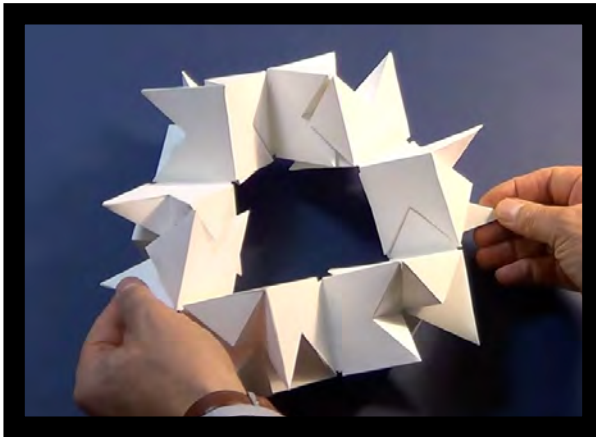
VIDEOS



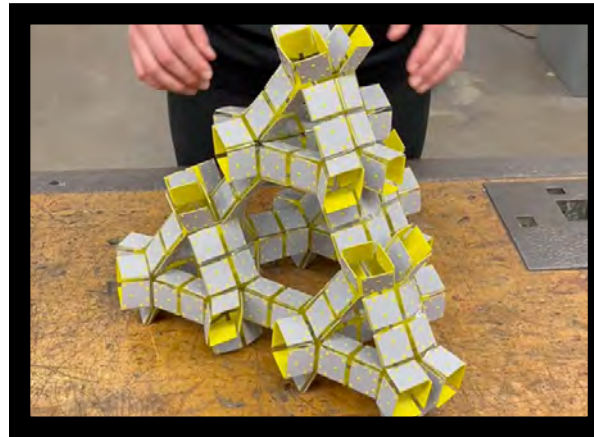
[Scarpa: Aristotle's Lantern](#)



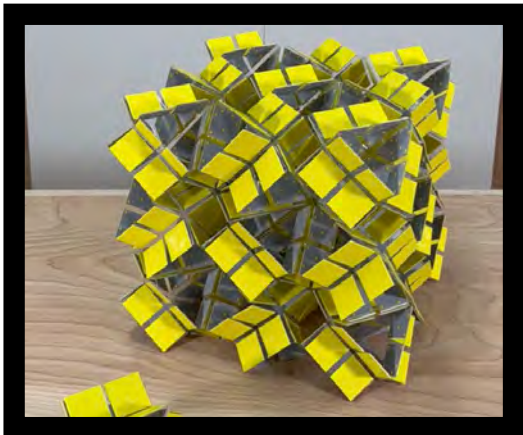
[Scarpa: DNA Model](#)



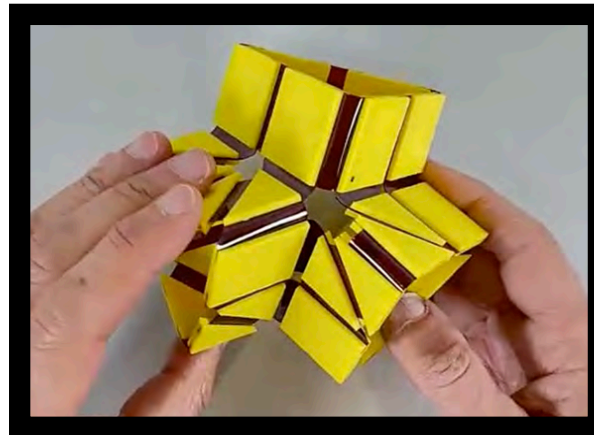
[Scarpa: Hexahedral Chain](#)



[Trogu: Material #6](#)



[Trogu: Material #1](#)



[Feng, Shi, Trogu, & Dai: Auxetic Metamaterial](#)

Giorgio Scarpa
Italian designer, bionics and topology researcher, teacher, and artist.


Profile and videos by **Pino Trogu**, San Francisco State University [trogu at sfsu dot edu]

The short videos below refer to the topics of Scarpa's two books. The first is a bionic study of the mouth apparatus of the sea urchin, also known as Aristotle's Lantern, after the first detailed study of it by the Greek philosopher. Recently new prototypes of a biopsy harvester and a ground sampler were inspired by Scarpa's model of the urchin. This new instrumentation is described in an article published in 2016 by the journal Leonardo (MIT). Click links below to download those articles. The PDFs of the bionics books are at right. The English is an unpublished draft translation; the Italian is the original text and images.

The second video shows one of the many modular chains described in the rotational geometry book, which focuses on rotational movement as a basic form generating process. Scarpa dissects the five Platonic solids and other solids into chains of hinged triangular pyramids that fold back into their enclosure cells. The PDFs of the geometry books are at right. The English is an unpublished draft translation; the Italian is the original text and images.

Both bionics and geometry books were published as part of a now out-of-print series called Design Notebooks, edited by the late Italian designer Bruno Munari. The covers of the books in that series are shown below. The other videos show more topological and bionic studies by Scarpa, including DNA models and studies of muscle cells.

This page was last updated on Sunday Feb. 6, 2022.
On July 29, 2021, the website was moved from <http://online.sfsu.edu/trogu/scarpa/> to <https://res.trogu.com/scarpa/>




Bionic Model of Aristotle's Lantern
Video length: 1:12 | Video: Pino Trogu, 1994.

Interviews


Leonardo Book Club: Live discussion with Pino Trogu, author, "Giorgio Scarpa's Model of a Sea Urchin Inspires New Instrumentation"
Length: 58:30 | April 24, 2019.

Articles

Pino Trogu
Giorgio Scarpa's Model of a Sea Urchin Inspires New Instrumentation,
Leonardo Journal, 52.2, 2019.
Free article download from MIT Press website:
[doi:10.1162/LEON_a_01384](https://doi.org/10.1162/LEON_a_01384).



Download PDF of complete Bionic Models book.
Unpublished English translation of Italian Edition: Modelli di Bionica, 1985.
Translated by Pino Trogu. 120 pages. File size: 38MB.



Scarica PDF completo del libro Modelli di Bionica Zanichelli, Bologna, 1985. 120 pagine. File size: 50MB.

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Giorgio Scarpa

Giorgio Scarpa (Brisghella 1938, Castel Bolognese 2012) frequenta l'Istituto d'Arte di Faenza pensando di diventare pittore e ceramista, ma nel 1962 ottiene la cattedra di Disegno Architettonico e Geometria Descrittiva all'Istituto d'Arte di Oristano sorta in quell'anno. Accetta e la sua vita prenderà una direzione di studi che lo accompagnerà per sempre. Negli anni '60 farà parte del Gruppo V di Rimini, diretto da Pino Parini, che collabora con il Centro di Cibernetica di Milano diretto da Silvia Ceccato. In seguito a questa fondamentale esperienza, comincia a studiare le figure topologiche e realizza le prime figure trasformabili. Nel '71 Bruno Munari vede una sua opera alla Galleria Sincron di Brescia e decide di scrivergli; nasce così una amicizia duratura che vedrà molti dei modelli progettati da Scarpa nei testi pubblicati da Munari. In seguito, ispirato da alcuni disegni di Paul Klee, inizierà lo studio sulla sezione del cubo creando catene esodriche trasformabili. Si applicherà allo studio della bionica realizzando un modello inerente il riccio di mare che ispirerà, tra l'altro, uno strumento medico. Da queste esperienze



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