LEARNING FROM NATURE: THE ECHINOID STRATEGY TO DESIGN A LIGHTWEIGHT AND RESISTANT SHELL STRUCTURE

BIOMIMETIC RESEARCH ON THE MECHANICAL DESIGN OF THE ECHINOID TEST AIMED TO CREATE NEW BIOINSPIRED LIGHTWEIGHT SHELL STRUCTURE

Interdisciplinary team: engineers, biologists, designers

Francesco MARMO[a], Valentina PERRICONE*[b], Gabriele PONTILLO[b], Carla LANGELLA[c], Luciano ROSATI[a]

[a] *Dept. of Structures for Engineering and Architecture, University of Naples Federico II, Napoli, Italy*
[b] *Dept. of Engineering, University of Campania Luigi Vanvitelli, Aversa, Italy*
[c] *Dept. of Architecture and Industrial Design, University of Campania Luigi Vanvitelli, Aversa, Italy*

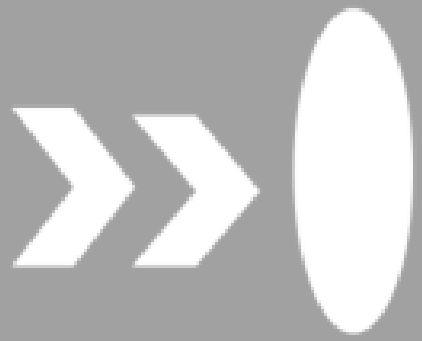
Università degli Studi di Napoli Federico II

Università degli Studi della Campania *Luigi Vanvitelli*

THE BIOMIMETIC PROCESS

BIOLOGICAL MODEL

ABSTRACTION



TRANSFER

APPLICATION

METHOD AND TOOLS

- Visual survey (macro and microscale)
- Photogrammetry
- 3D Modelling
- Three-point bending test
- FEM
- Abstraction of the design principle
- 3D modelling of the bioinspired shell

1.
VISUAL SURVEY

Visual survey

MACRO

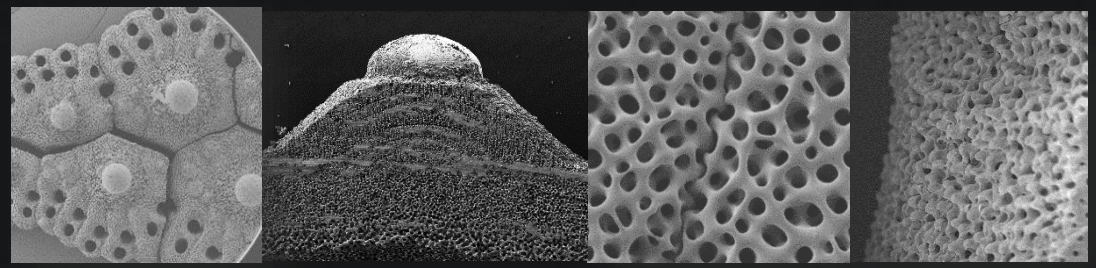
MICRO

cm

µm

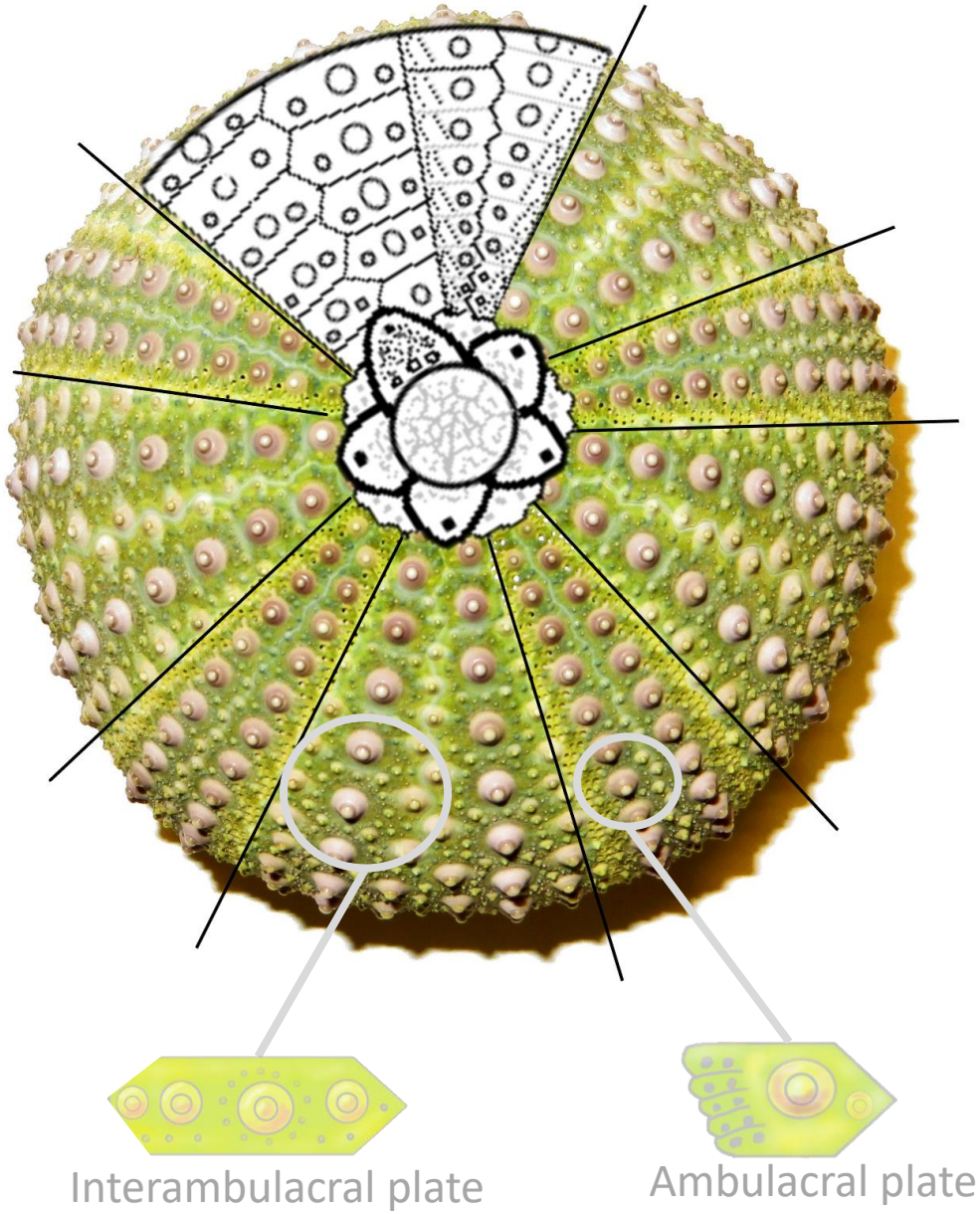
Ambulacral

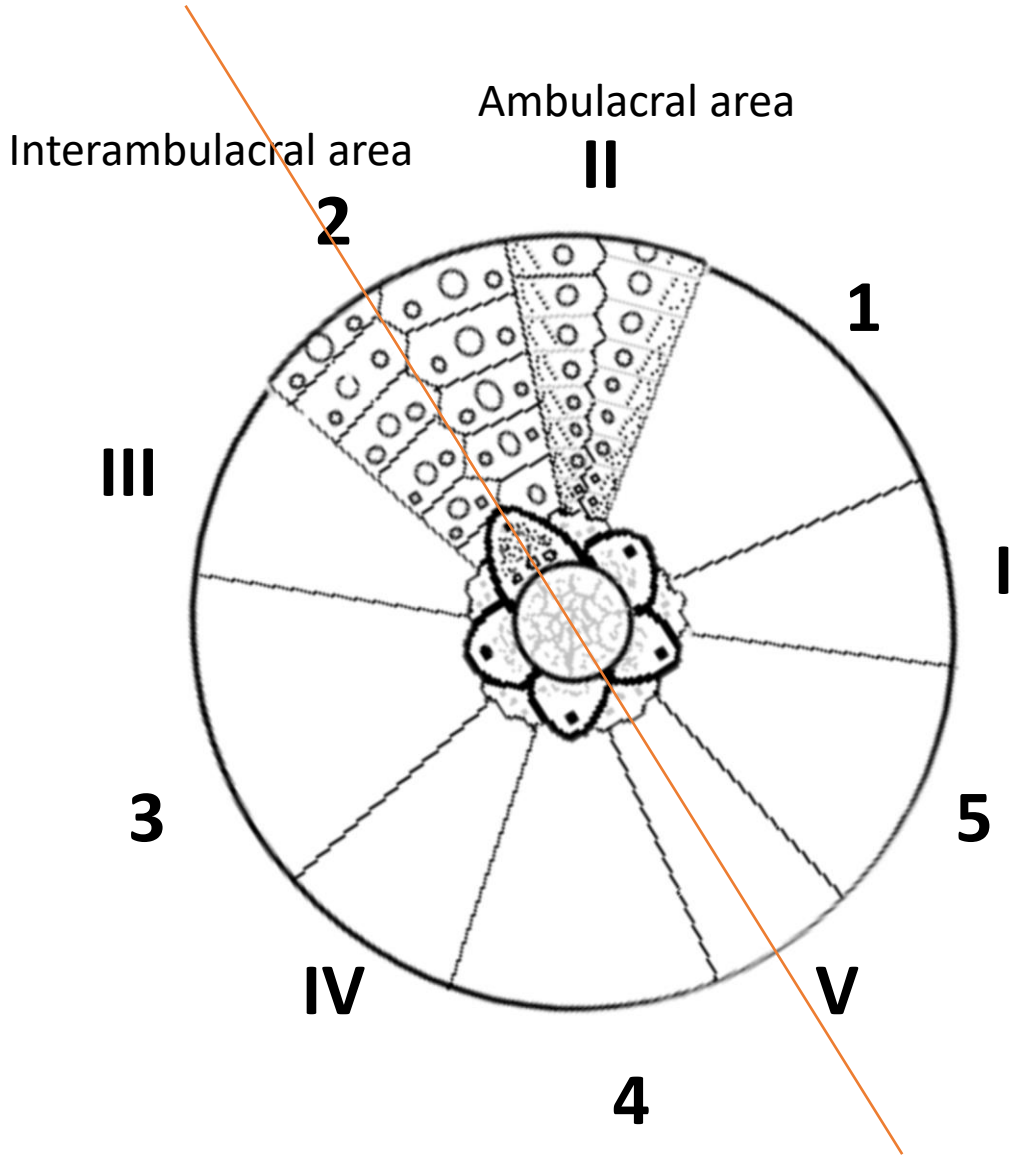
Interambulacral



Visual survey

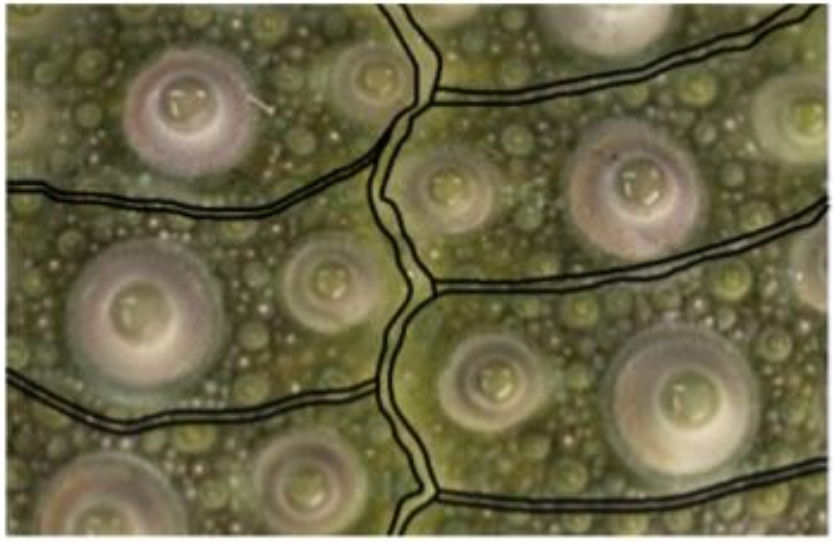
MACROSCALE





Visual survey

MICROSCALE

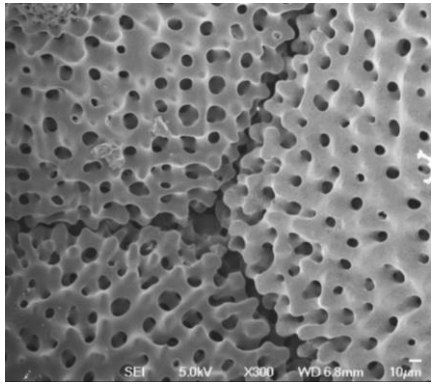


Interambulacral area

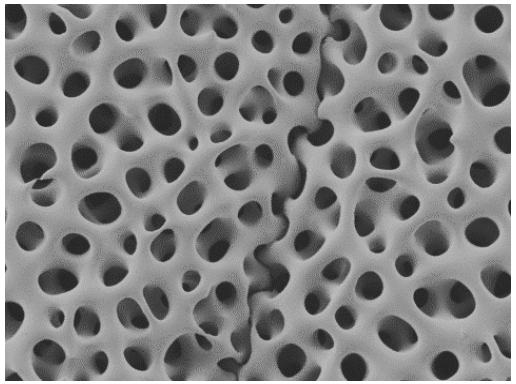
Interambulacral plate

Vertical section of the plate

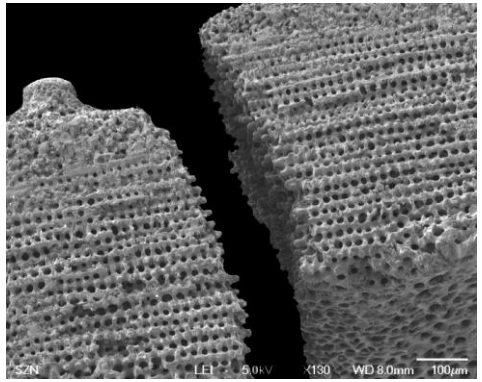
Thrivalent vertex (Y)



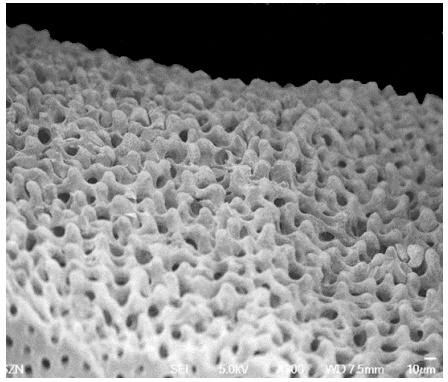
Interlocking

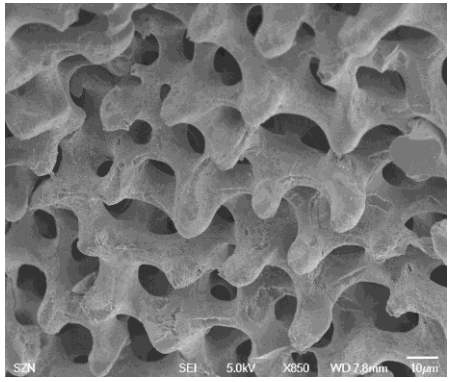


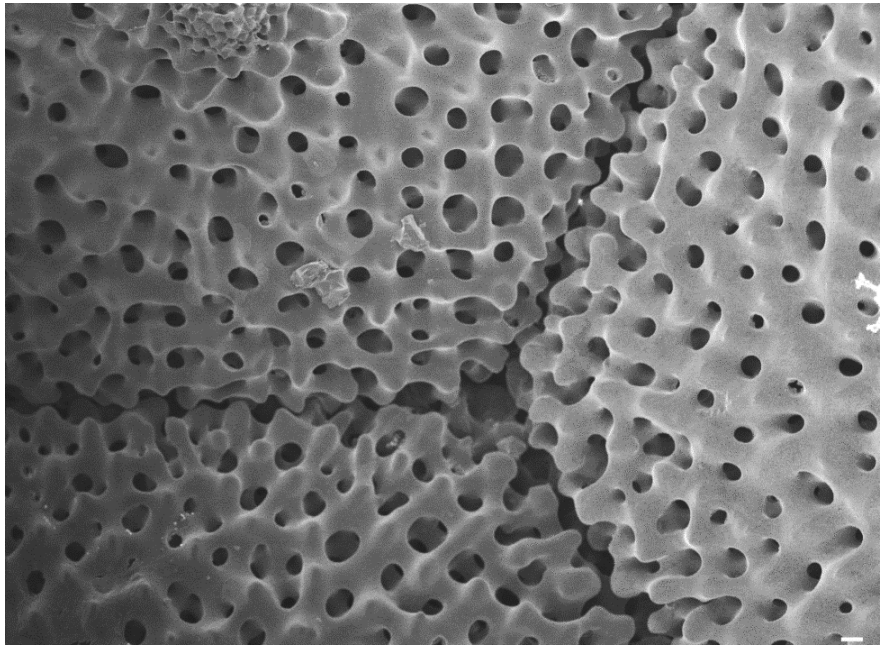
Suture

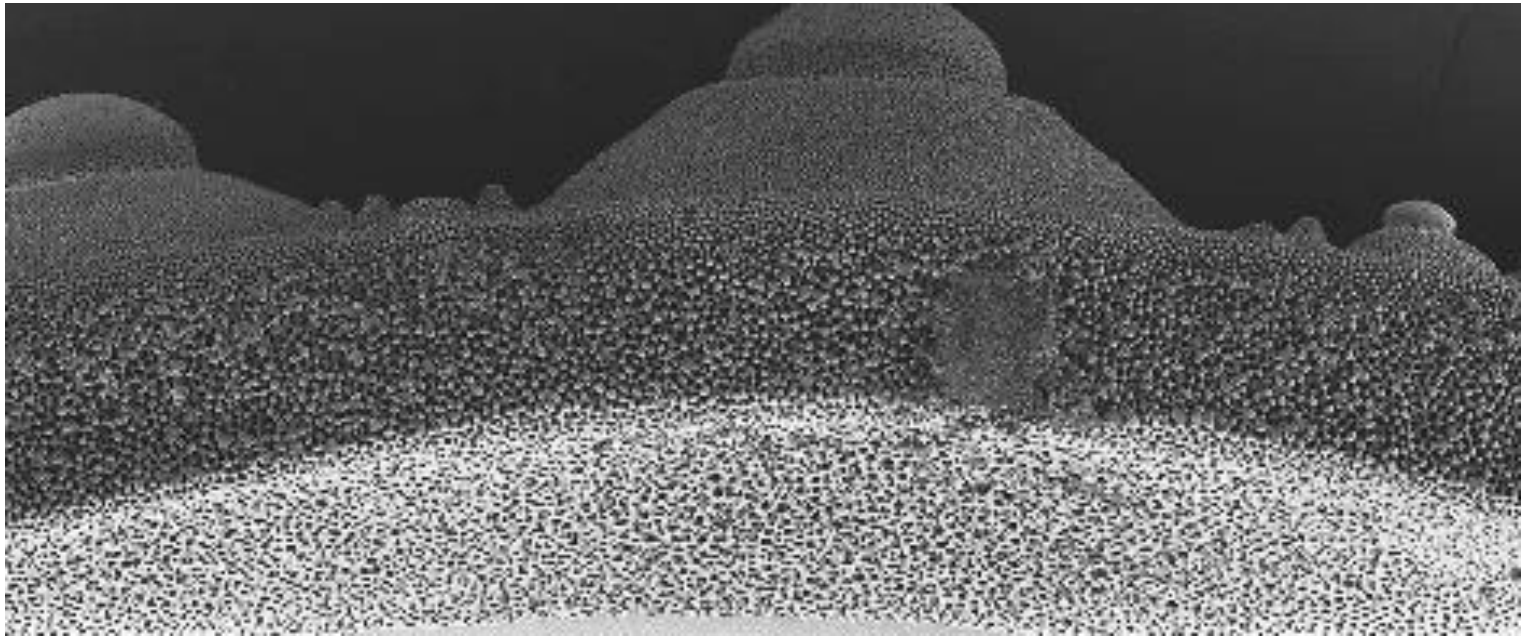


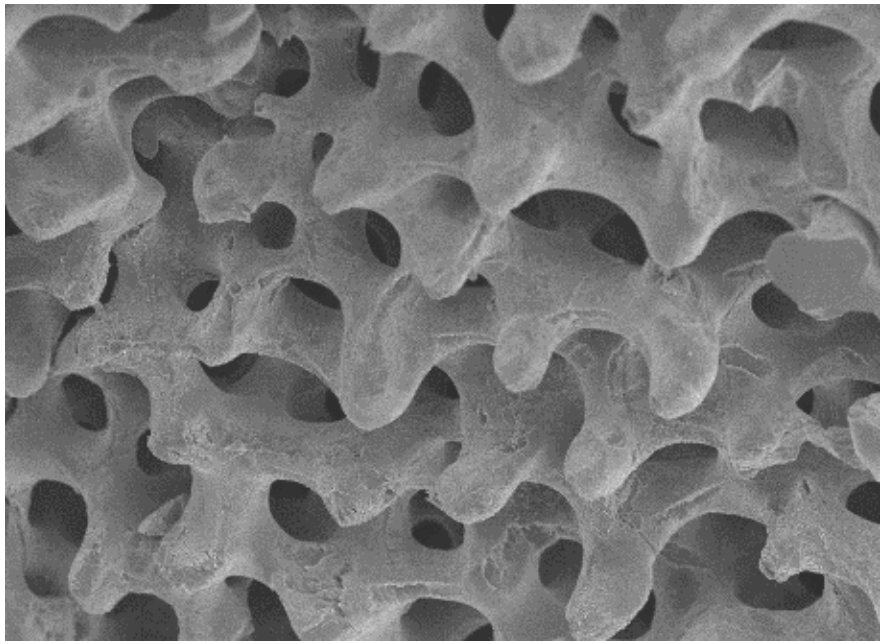
Finger joints











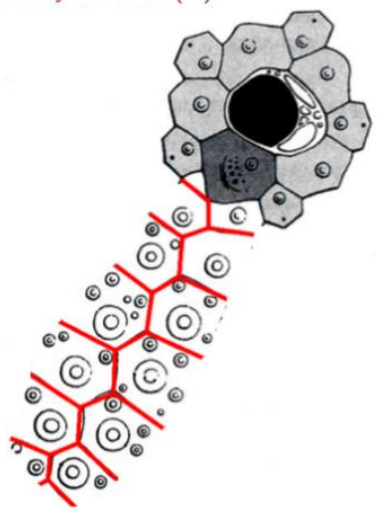
THE FUNCTIONAL FEATURES THAT CONTRIBUTE TO THE STABILITY OF THE ECHINOID STRUCTURE AND INFLUENCE ITS MECHANICAL BEHAVIOUR ARE:

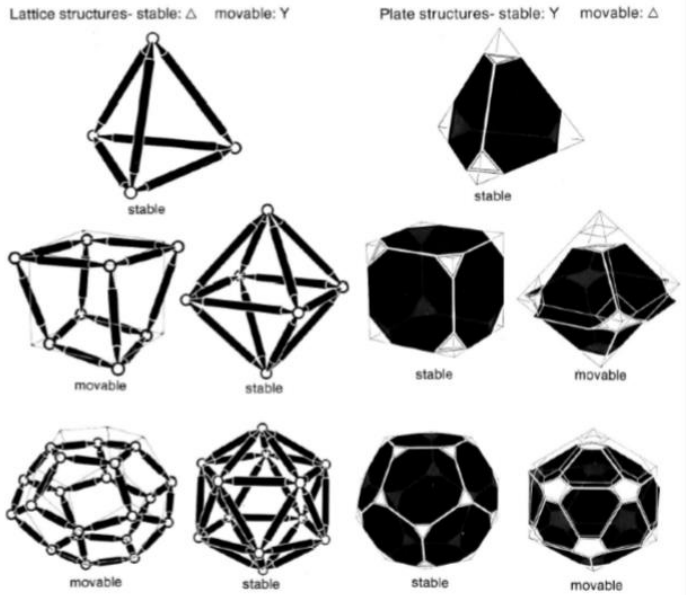
1. ARRANGEMENT 2. PLATE CURVATURE 3. SUTURES

1. ARRANGEMENT: trivalent vertex (Y)

The plate-lattice dualism

3–way vertices (Y)

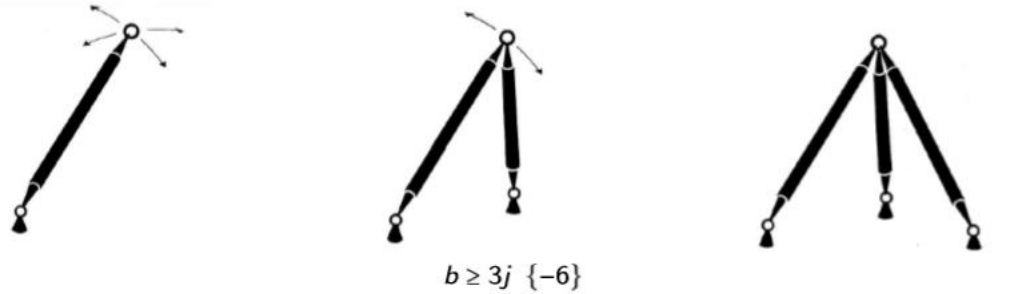




Wester - Structural order in space (1984)

The plate-lattice dualism

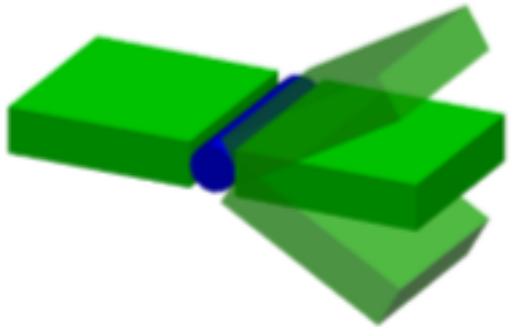
Euler's geometrical theorem for polyhedra: $f + v = e + 2$



$b \geq 3j \ \{-6\}$

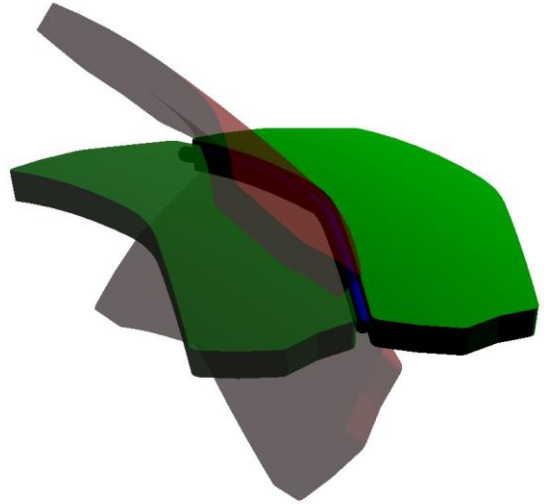
$\ell \geq 3p \ \{-6\}$

2. PLATE CURVATURE

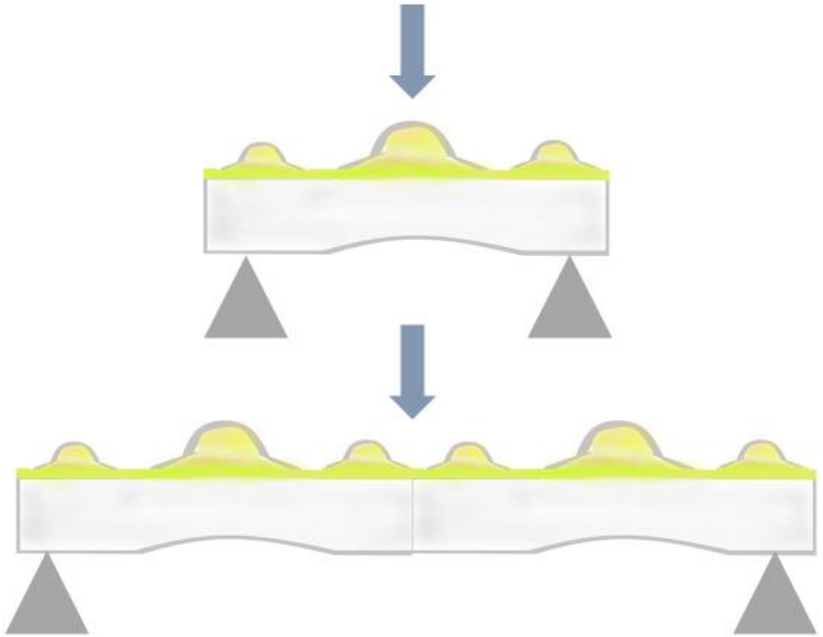


CURVED EDGES

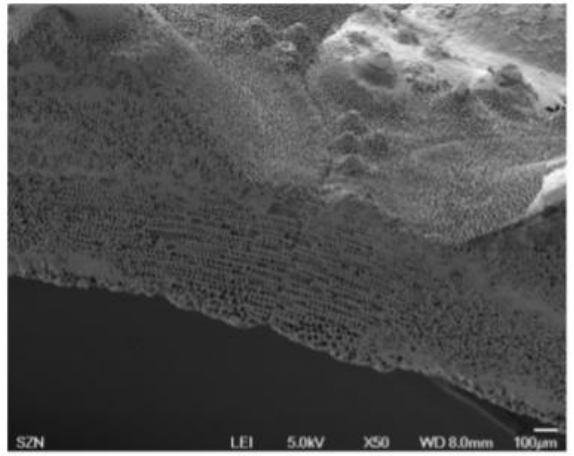
Curved hinges avoid mechanisms even with just one line of support per plate, yet being locally movable

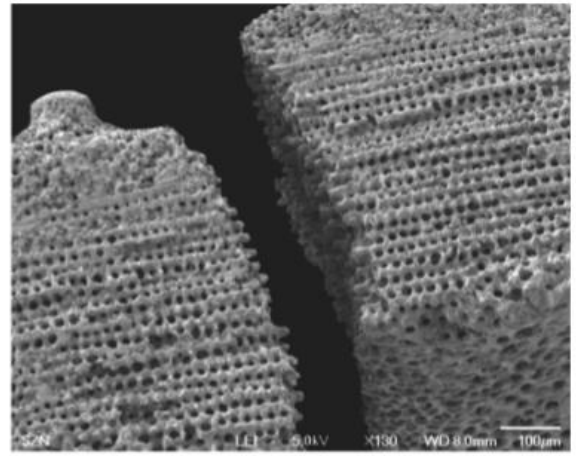


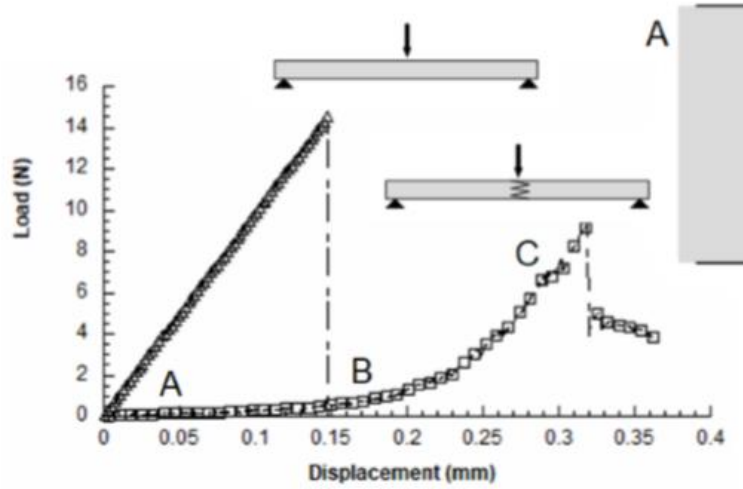
3. SUTURES

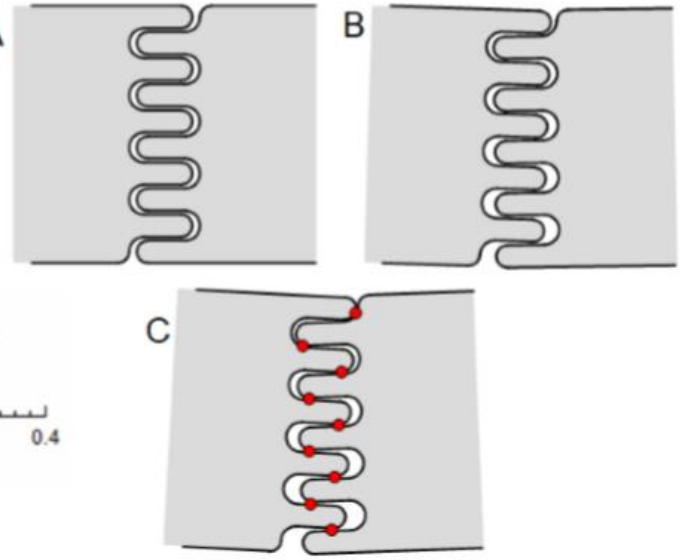


Interlocking micro-structure and colloidal filaments that make sutures flexible–rigid

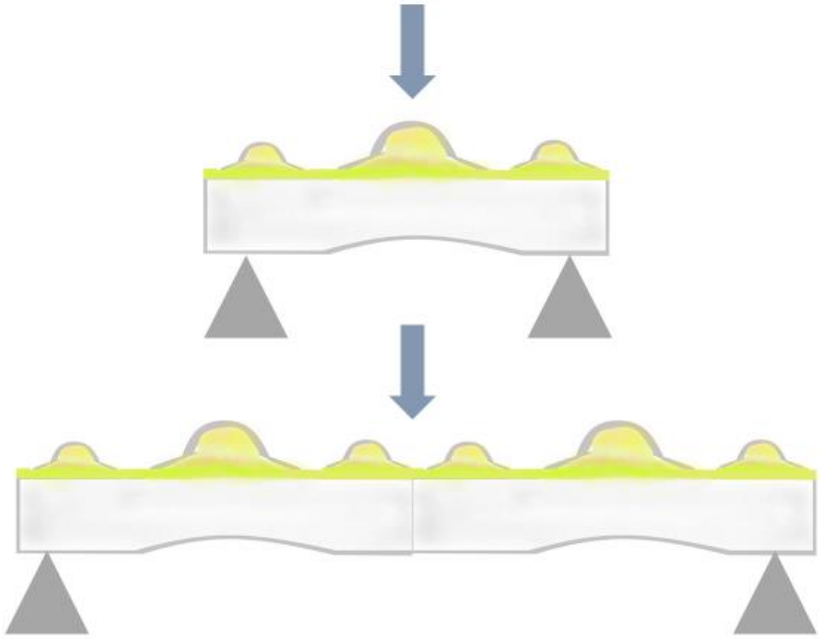






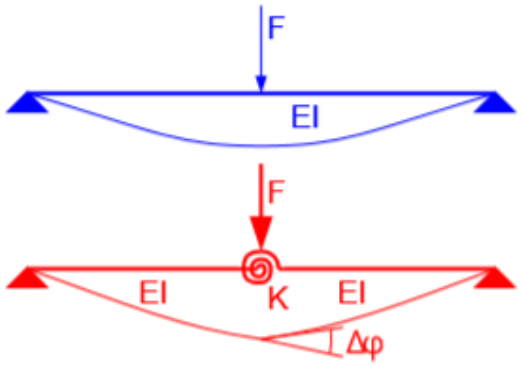


3. SUTURES



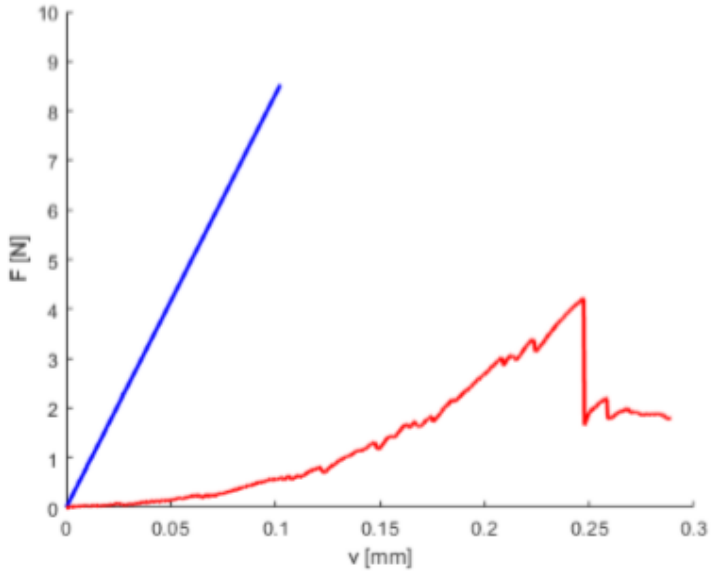
Flexible–rigid sutures

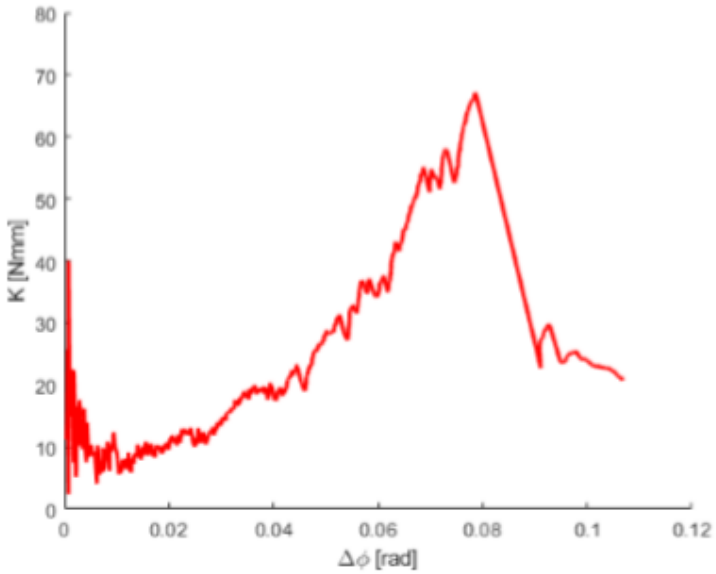
An easy way to model the nonlinear behaviour of sutures



$$v = \frac{F\ell^3}{48EI} \qquad E = \frac{F\ell^3}{48Iv}$$

$$v = \frac{F\ell^3}{48EI} + \frac{F\ell^2}{16K} \qquad K = \frac{F\ell^2}{16\left(v - \frac{F\ell^3}{48EI}\right)}$$



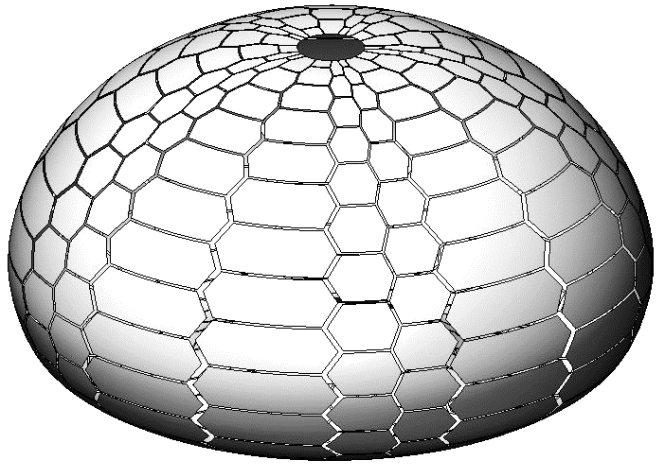


2.

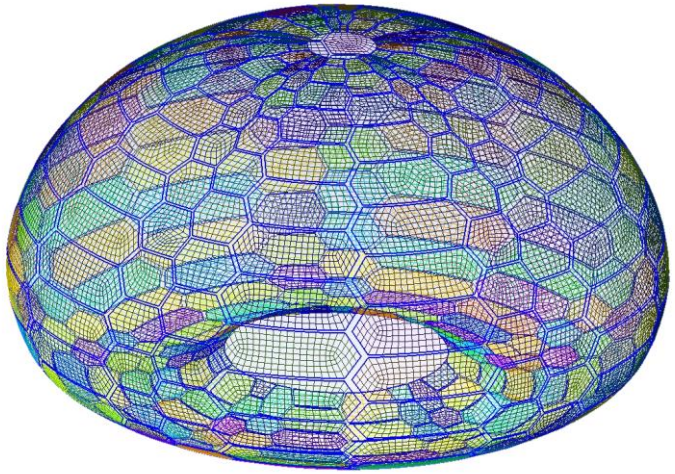
RECONSTRUCTION AND ANALYSIS OF THE ECHINOID TEST

P.lividus sample

Photogrammetry

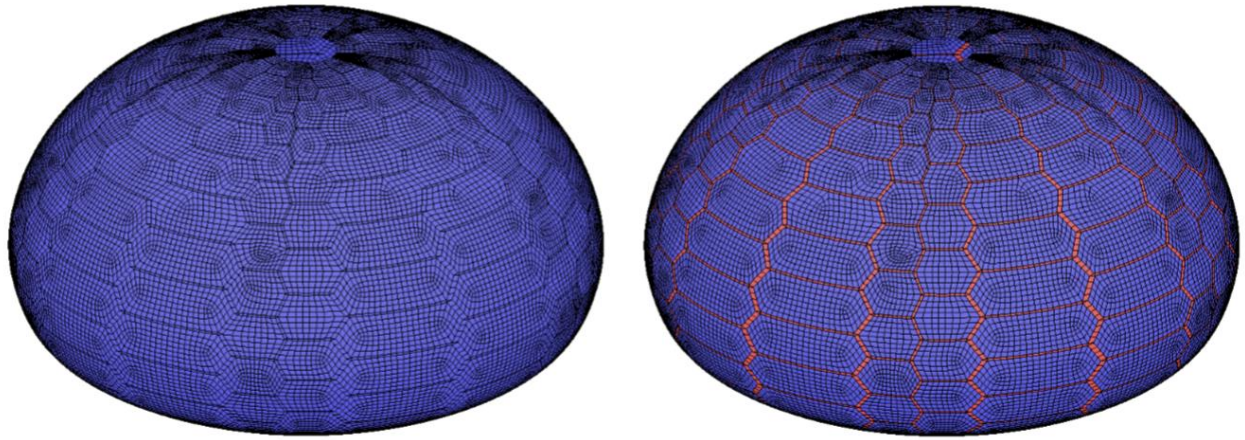


3D model

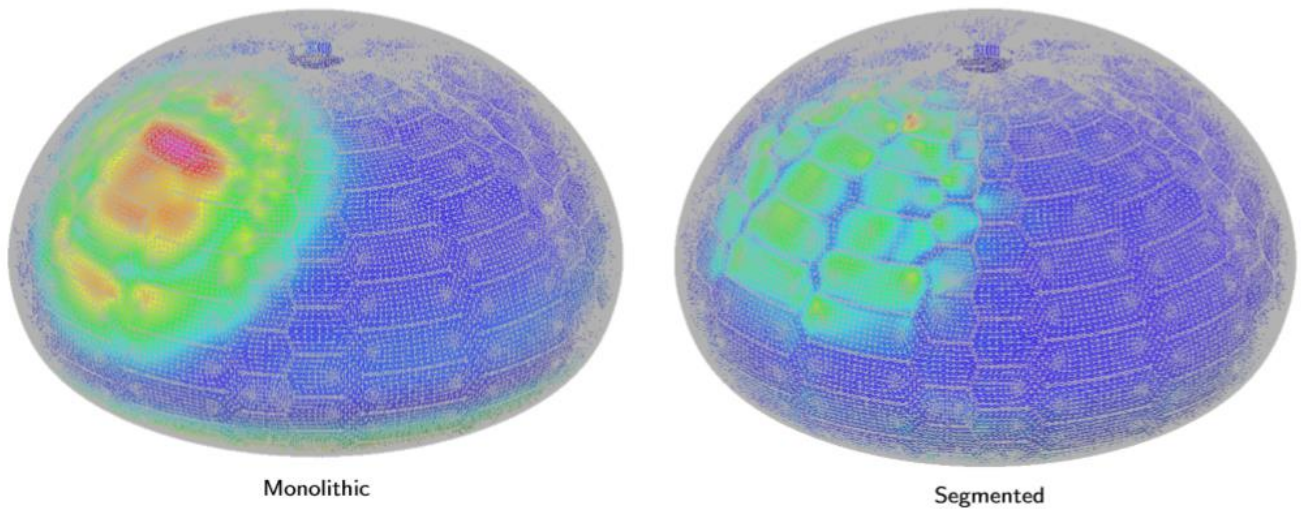


3D mesh for FEM

Monolithic and segmented FEM models



Maximum bending principal component



Monolithic

Segmented

WHAT HAVE WE LEARNED FROM ECHINOIDS' TEST?

Global mechanisms are avoided by:

- Trivalent vertex
- curved edges
- interlocking at large rotations

Identified biological principle:
flexible sutures reduce bending actions

WHAT CAN BE USED IN SHELL STRUCTURES?

Global mechanisms/large displacements are controlled by:

- Trivalent vertex
- curved edges
- locking large rotations

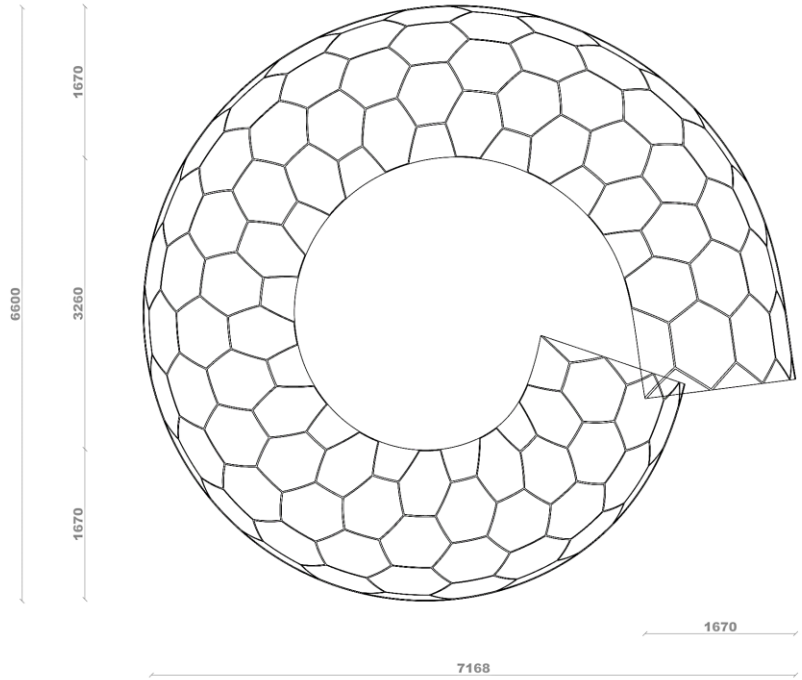
Abstraction of the biological principle:
segmentation + cylindrical hinges: produce significant reduction of bending actions in shells

3.

THE BIOINSPIRED SHELL

ABSTRACTION AND EMULATION

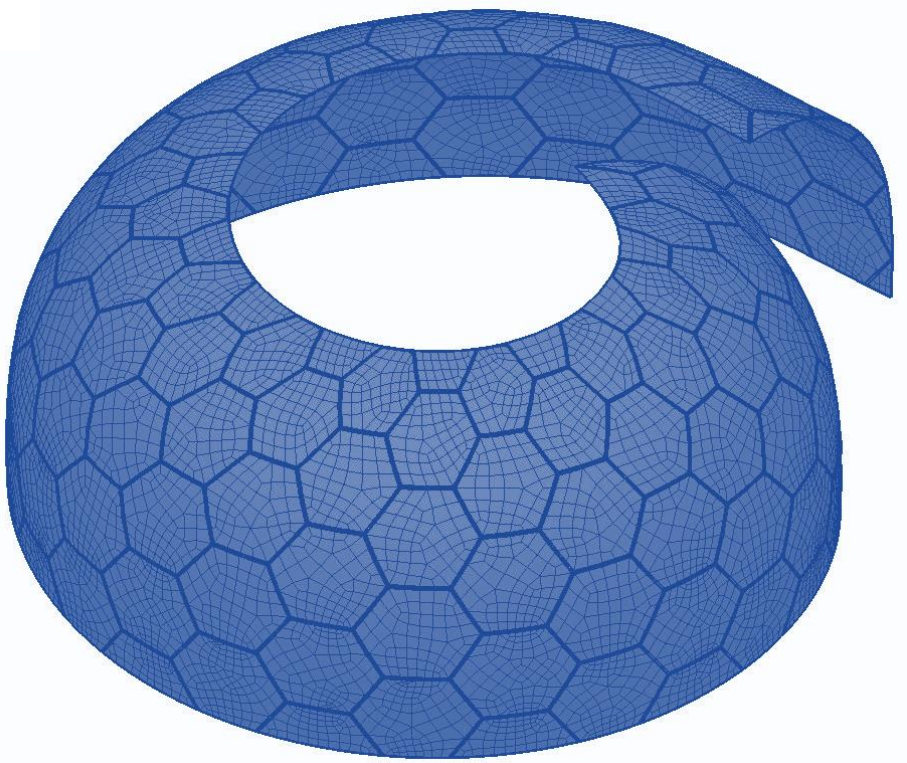
Discontinuous structure



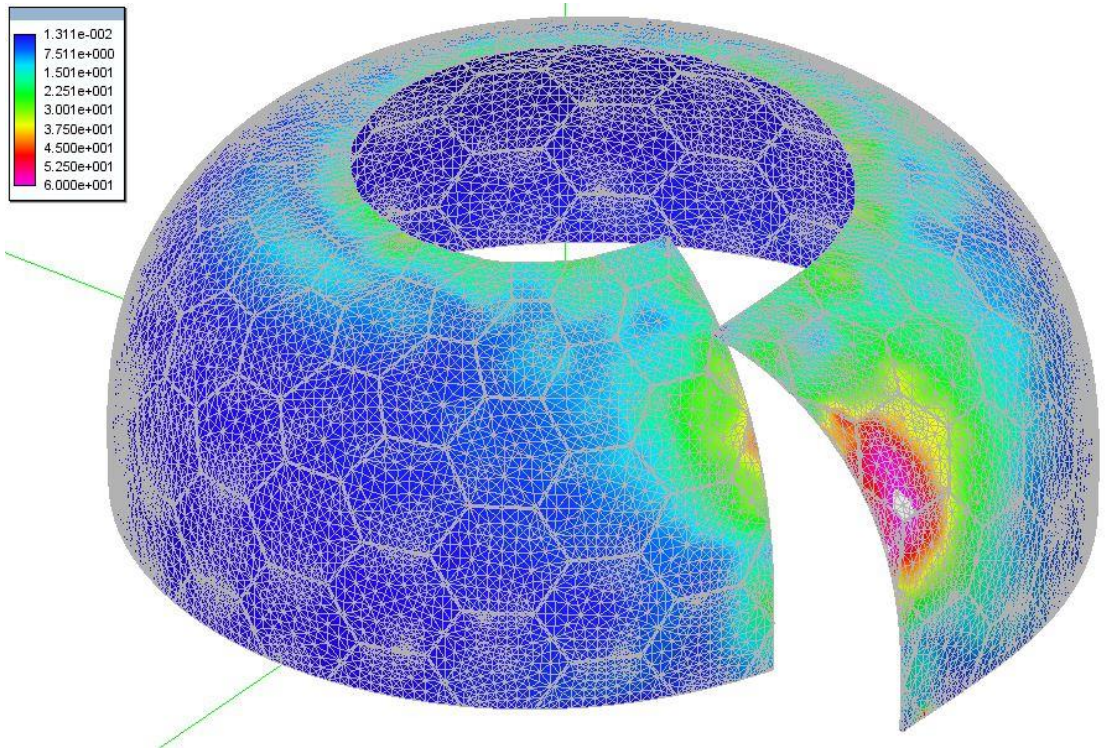
Hexahonal modules

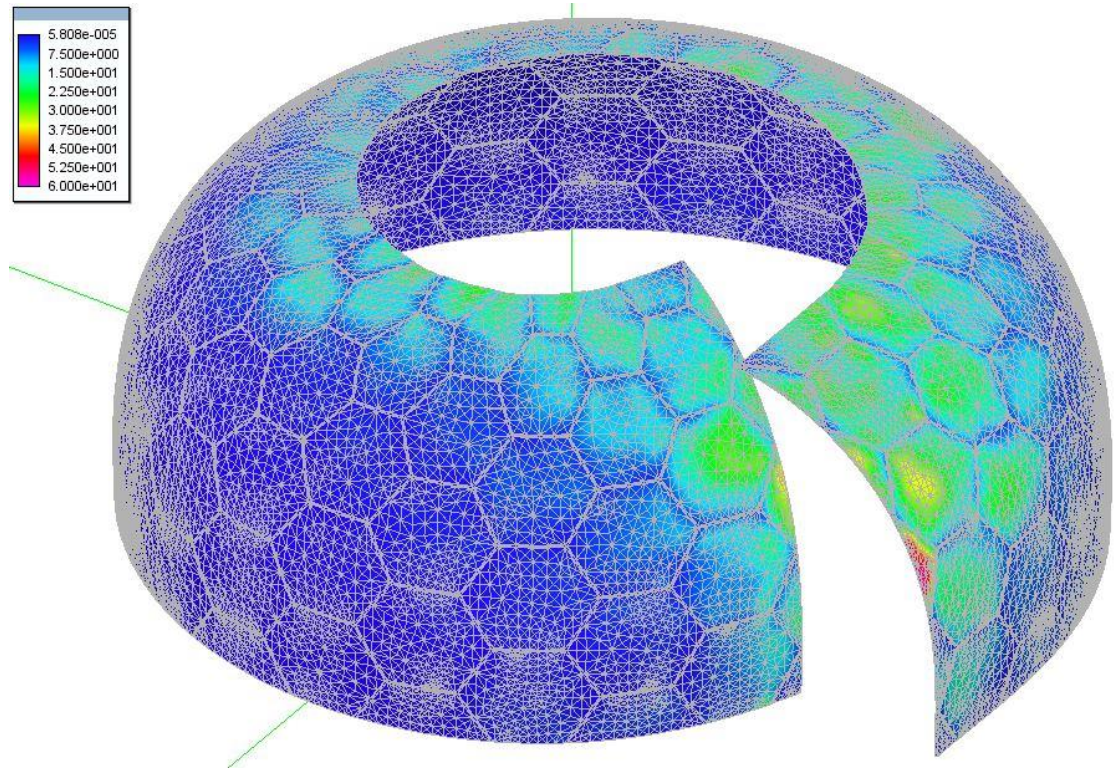
Thrivalent vertex (Y)

Curved edges



Flexible sutures


1.311e-002
7.511e+000
1.501e+001
2.251e+001
3.001e+001
3.750e+001
4.500e+001
5.250e+001
6.000e+001


5.808e-005
7.500e+000
1.500e+001
2.250e+001
3.000e+001
3.750e+001
4.500e+001
5.250e+001
6.000e+001

THE BIOINSPIRED SHELL STRUCTURE