# Materials strategies and systems for Soft Robotics

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- Materials Systems in Biology – Bio-inspiration
- Soft Robotics
- Materials Strategies
- Conclusions

# ***VIRTUALLY ALL MATERIAL SYSTEMS IN BIOLOGY ARE FIBRE-BASED***

**Cellulose (Elastic modulus 150 GPa)**

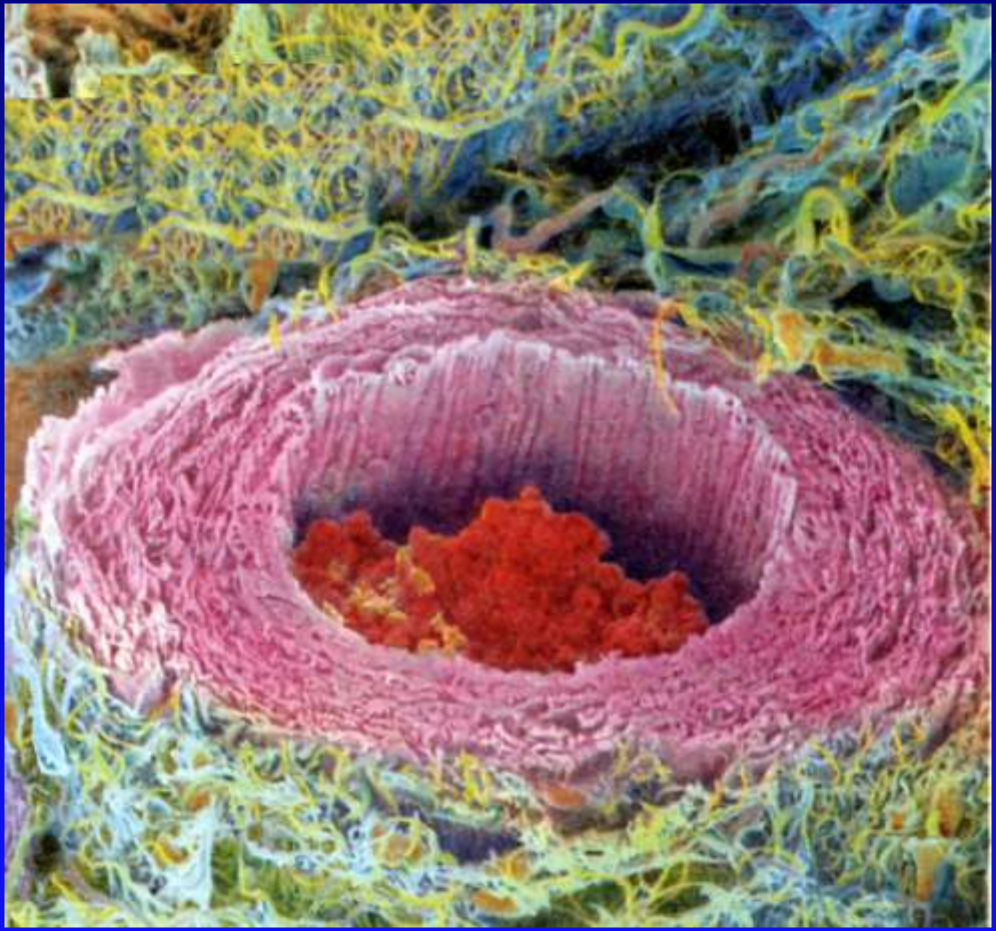
**Collagen (Elastic modulus 1-10 GPa)**

**Chitin (Elastic modulus 120 GPa)**

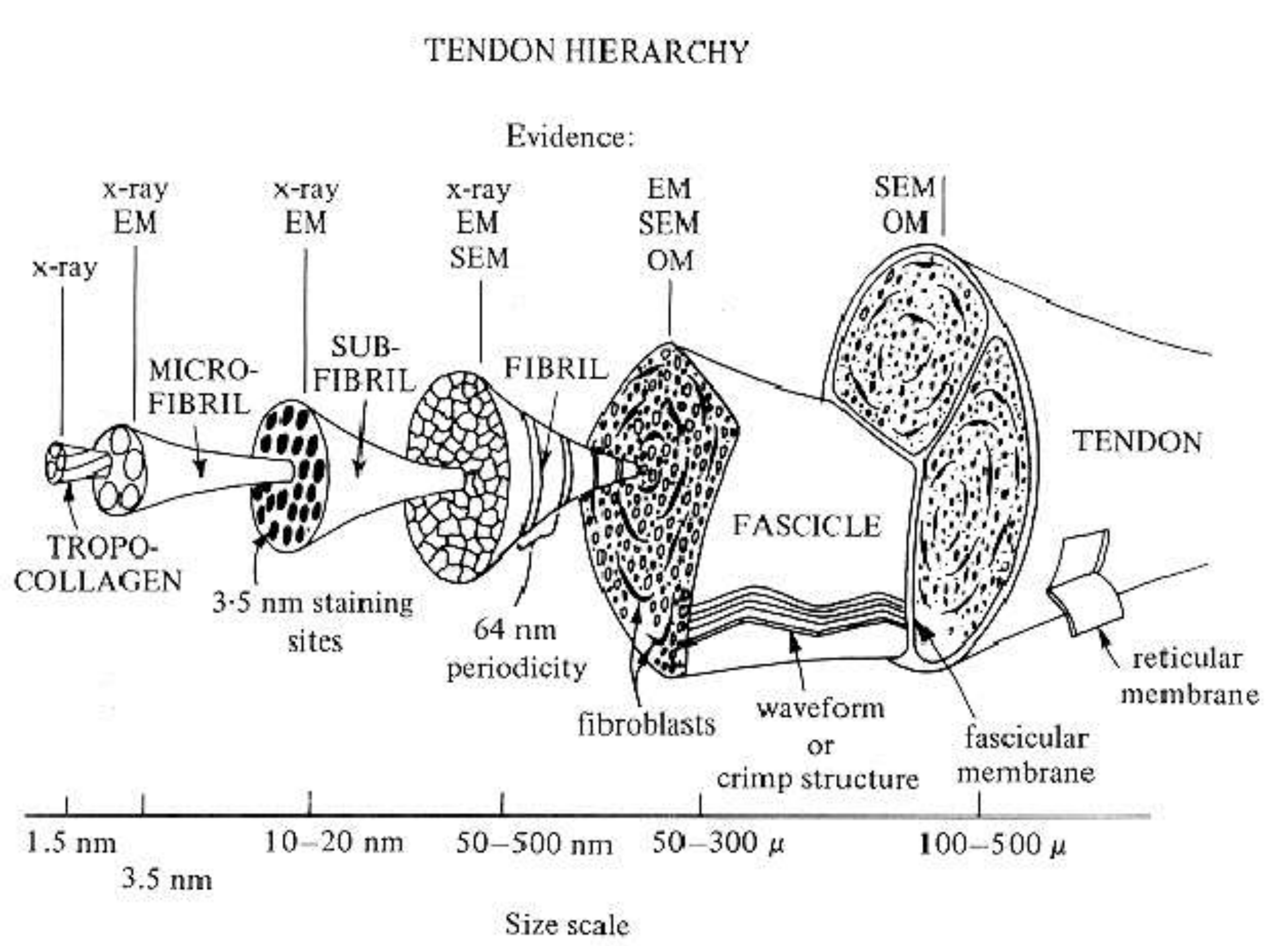
**"Softness" in biological structures is a key factor in interacting with "noisy" environments and in responding to external and internal forces**

**In some fibrous systems the modulus can by tailored using stiff ceramic materials: graded stiffness (tendon-bone attachment)**

**Fibres are not very good in compression: tensile pre-stressing via pressure or muscle actions (turgid plant cells) or "locking" via cross-linking (lignified plant cells)**



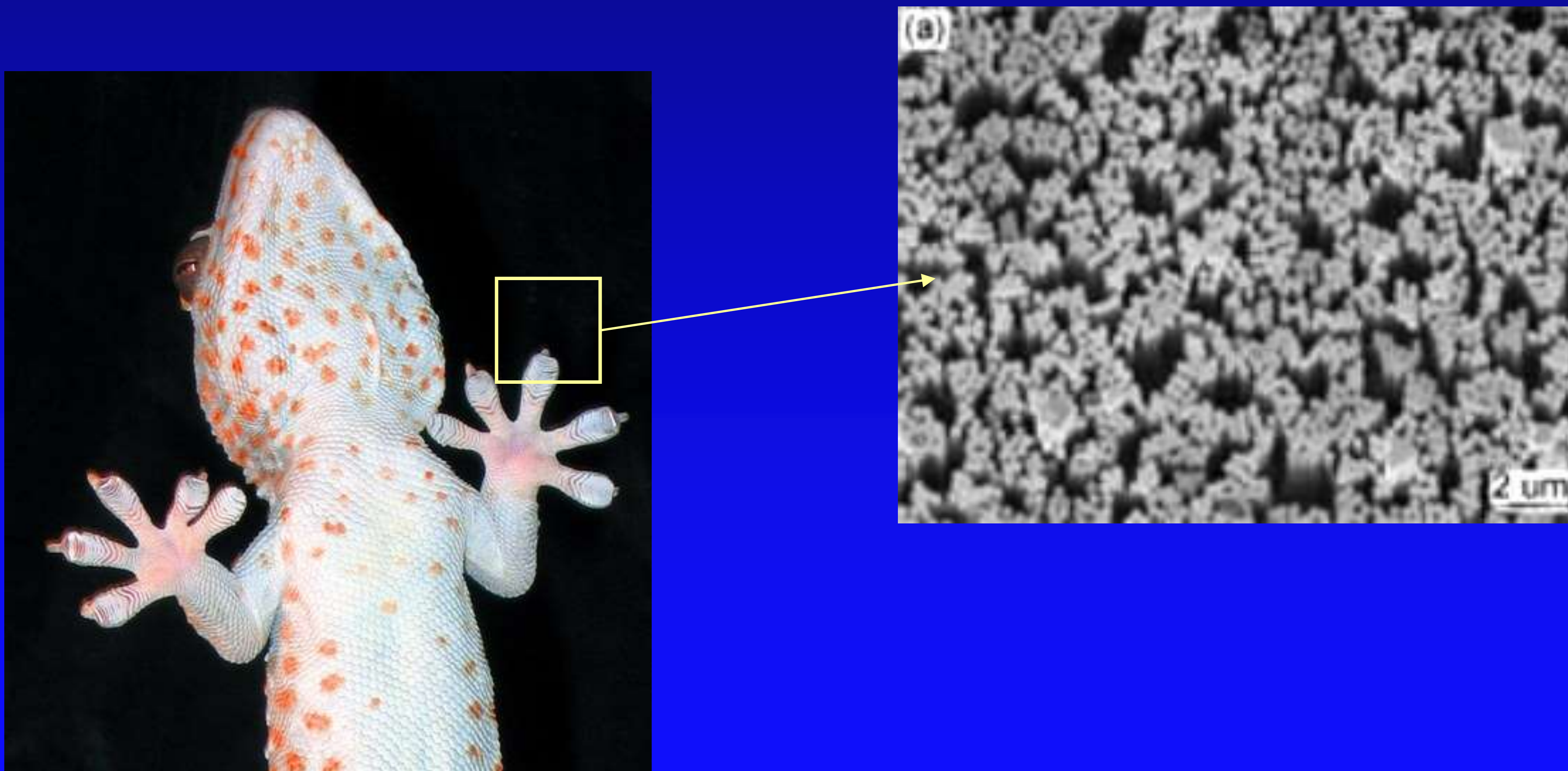
Collagen and elastin fibres in blood vessels



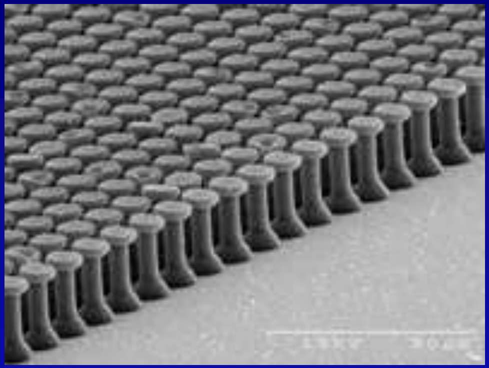

Tendon Hierarchy

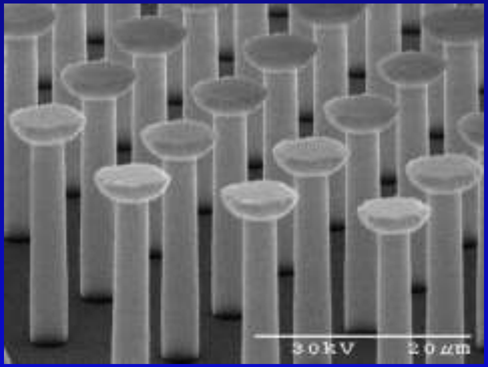
## Octopus arms - Hydrostats

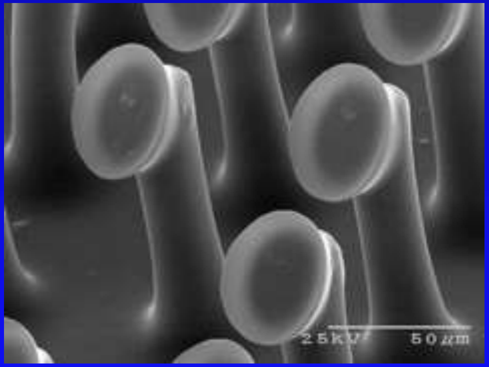
## Gecko's setae for adhesion

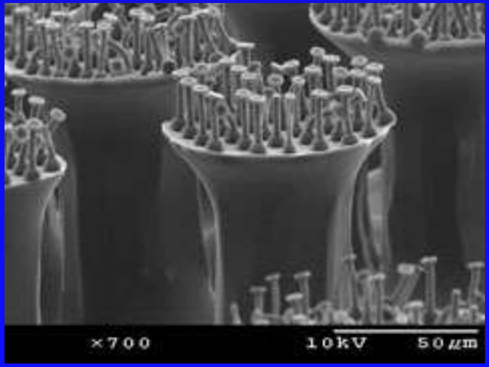


Same mechanism in insects and tree frogs (wet environment)





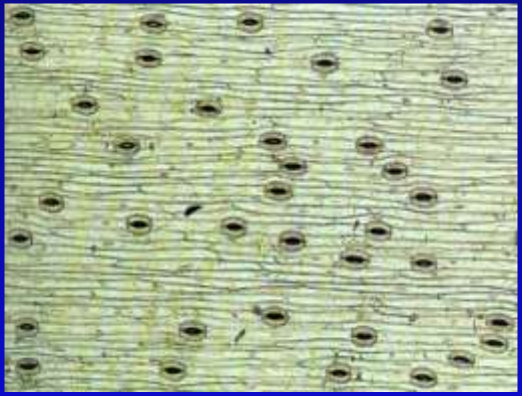




**Hierarchies of compliant elements inspired by gecko setae**

# “Soft” systems in plants using high modulus cellulose fibres

D. Attenborough (1995)

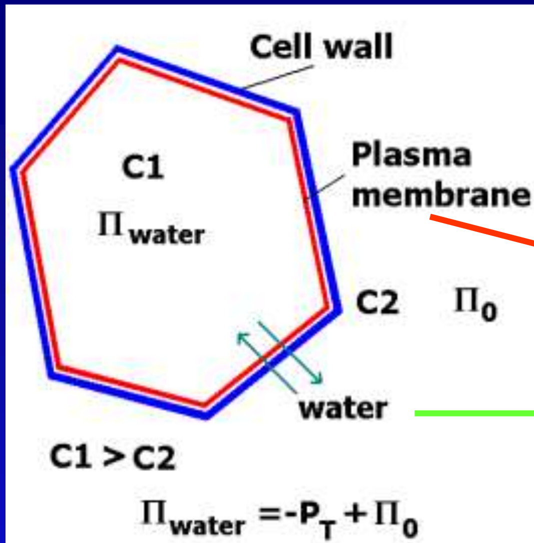


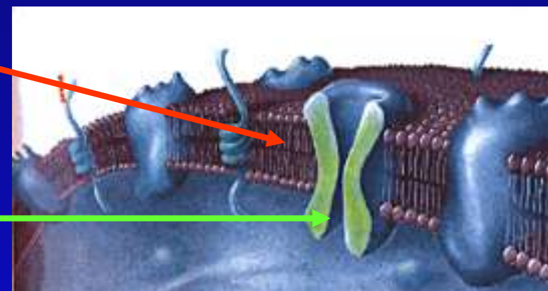
Opening and closing
of stomata on leaves
to control gas exchanges
in plant leaves

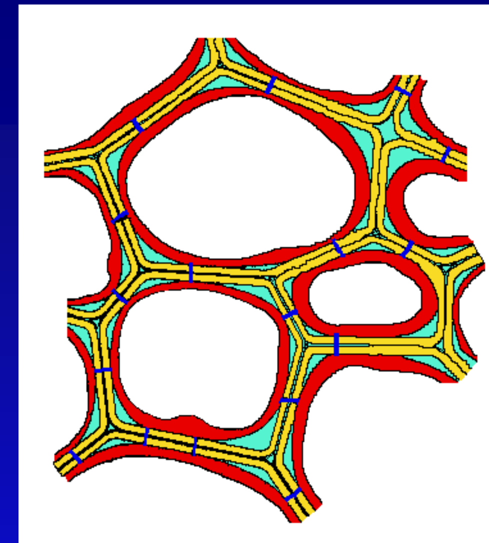
Leaf folding in Mimosa pudica (3 seconds)

Leaf deployment controlled by
turgor pressure and growth

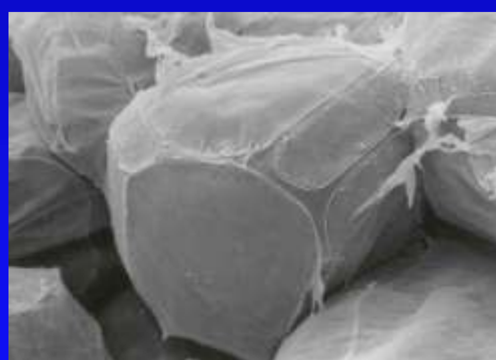
Venus fly-trap (Dionaea muscipula)
10 ms to trap the insect)

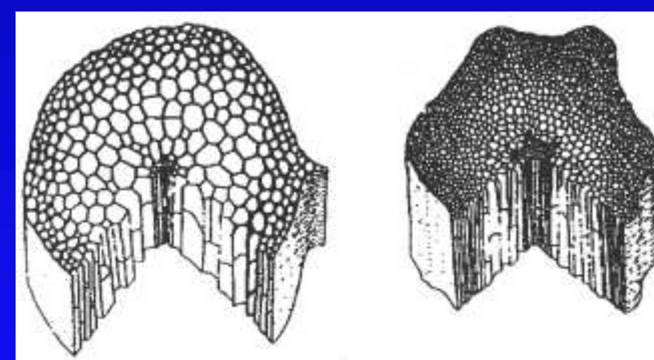




osmotic pressure mechanism





Every cell is essentially a micro-hydraulic actuator

***EXPANSION - CONTRACTION - ELONGATION***

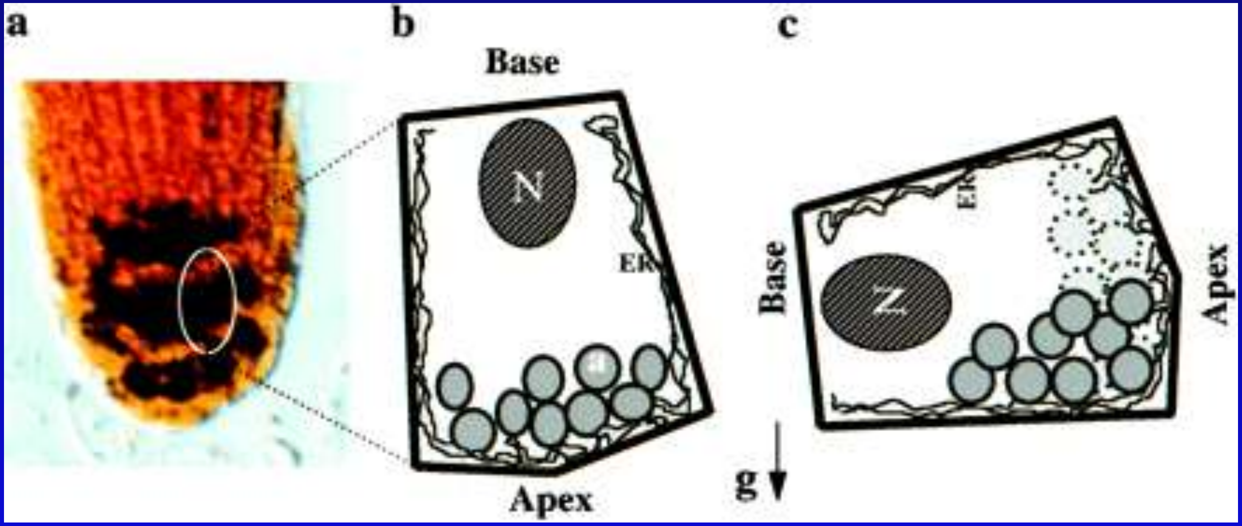
**The pressure $P_T$ which can be generated can be as high as 20 bar (10 times the pressure in a car tyre !!!!!**

## Modulation of fibre orientation

Trunk reorientation from tension wood
in hardwoods

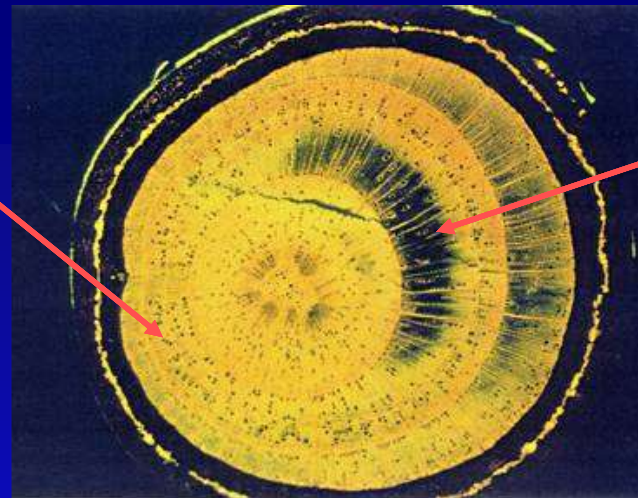
**Reaction wood is used by trees to modulate shape of trunk and branches (gravitropism / phototropism– reorientation of axes)**

## Statoliths in root cells

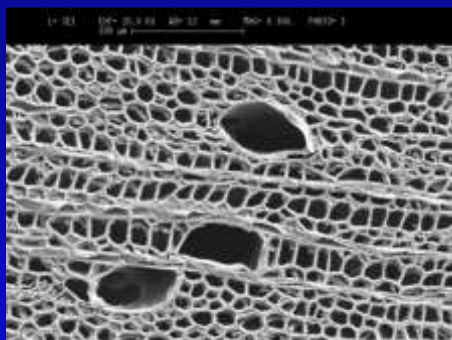


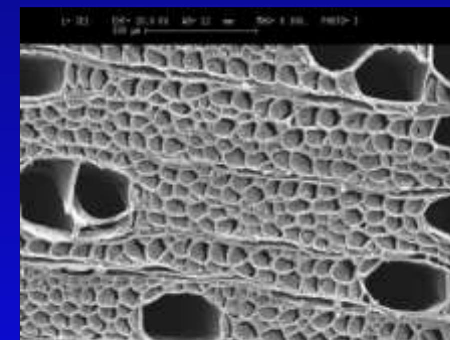

**Statoliths are a specialized sensory system in living cells involved in gravity perception by plants and most invertebrates**

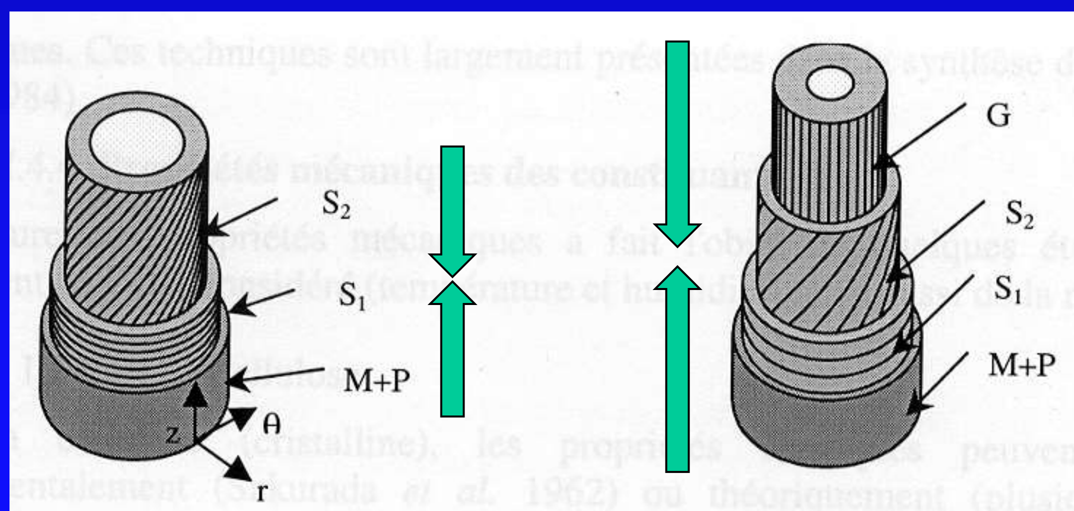
Normal wood



Tension wood



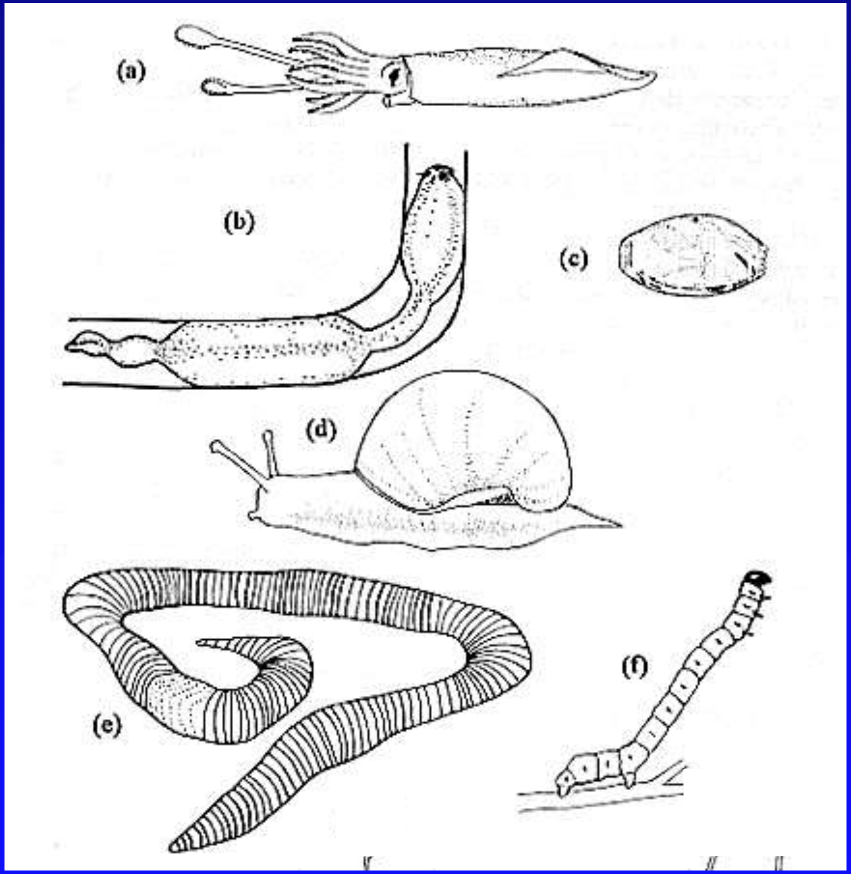


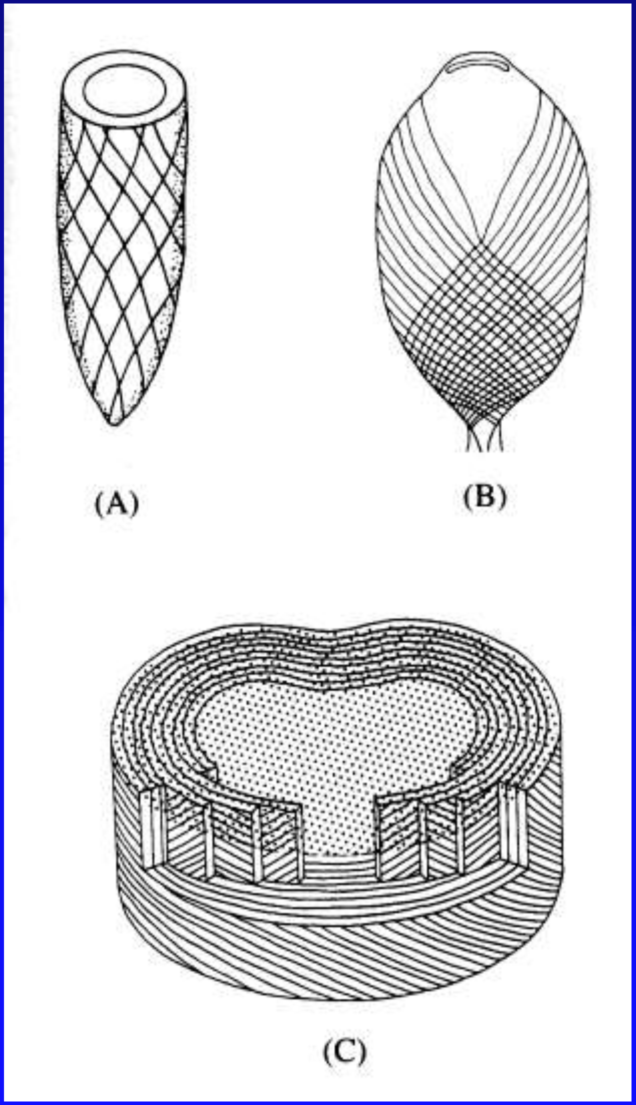


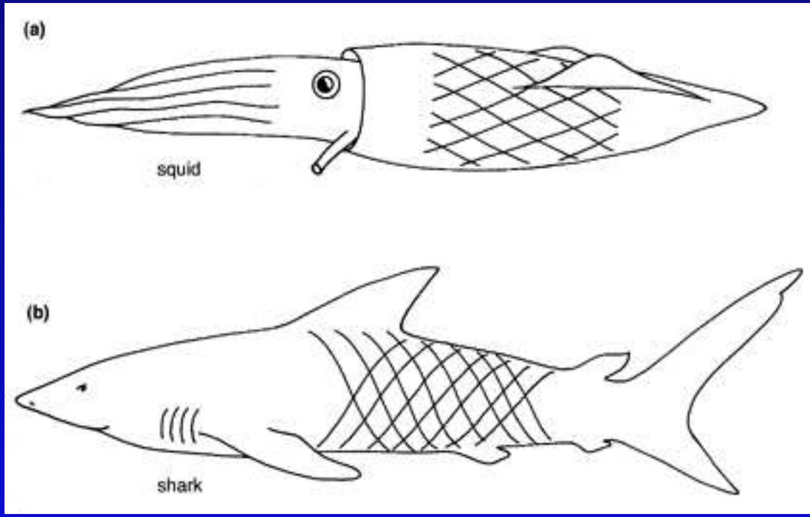

**Massive bending bimorph actuator**

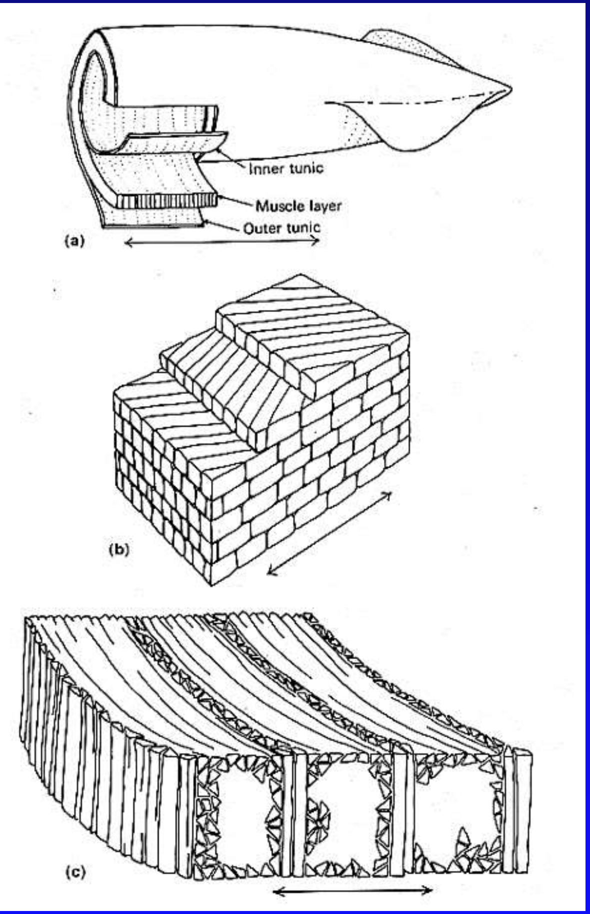
Coutand *et al., 2004* ; B. Clair (2001)

# Range of “soft” biological animal systems and typical fibrous architectures






Cross-helical arrangement of collagen fibres in tunicates (squids, etc.)

Internal liquid pressure generated by muscle action

Similar fibre arrangements are found in many animals with hydrostatic skeletons

# Deformability is achieved not by having intrinsically soft materials but by exploiting fibre architectures in 1D, 2D, 3D

Orientation
Hierarchies
Water
Interactions: fibre-fibre, fibre-matrix, fibre-fluids

***ALMOST INFINITE "DESIGN SPACE"***

***DIFFERENTIATION*** **AT THE “MATERIAL” LEVEL**

**(Anisotropy, Heterogeneity, Hierarchies)**

↓

***FUNCTIONAL*** **INTEGRATION AT THE STRUCTURE OR COMPONENT LEVEL**

# Soft Robotics:

**Deformable, compliant, low stiffness, ....**

System level
Component level
Material level

**Soft by nature or Soft by design**

## FIBRE SYSTEMS:

metallic (including SMA)

glass (including optical fibres)

piezoceramic

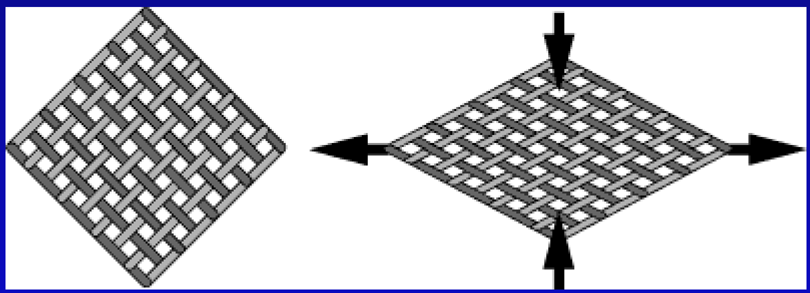
carbon (conductive)

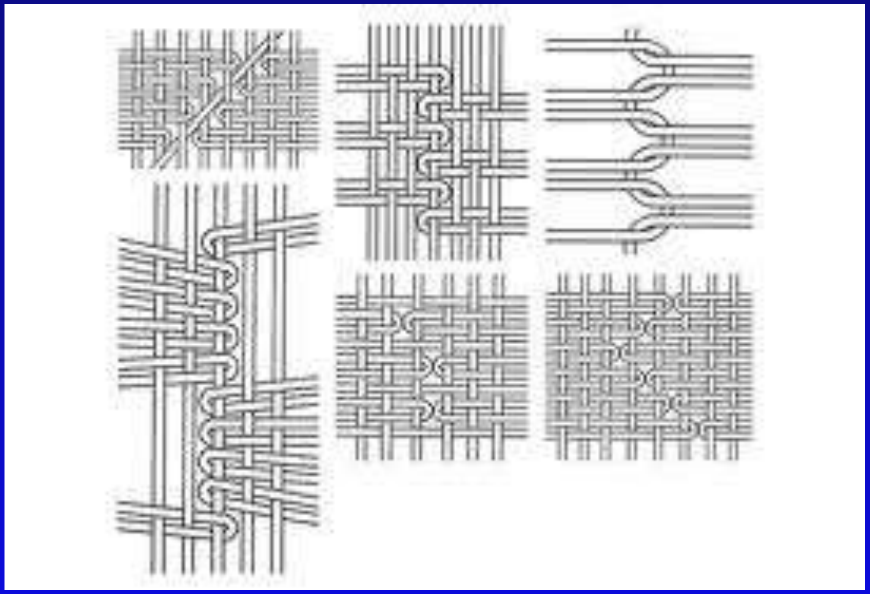
polymeric

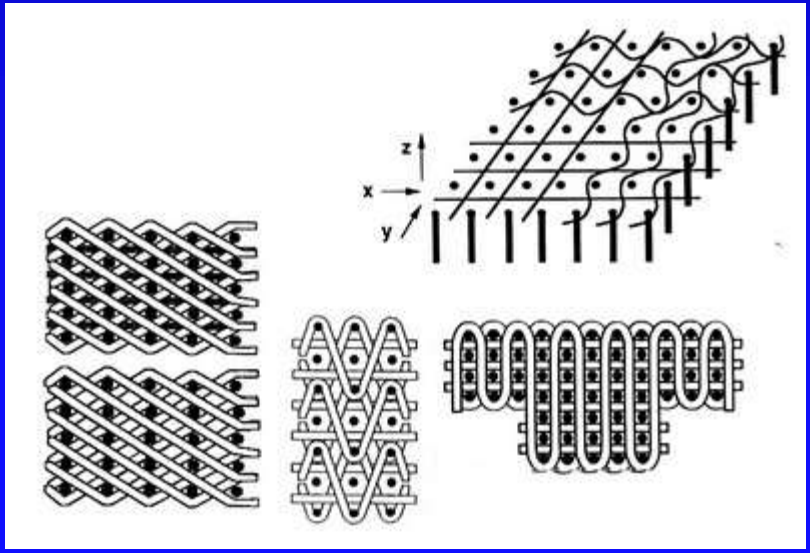
CNTs

**Textile technologies are particularly suited to manipulate fibres, create shapes, integrate functions**

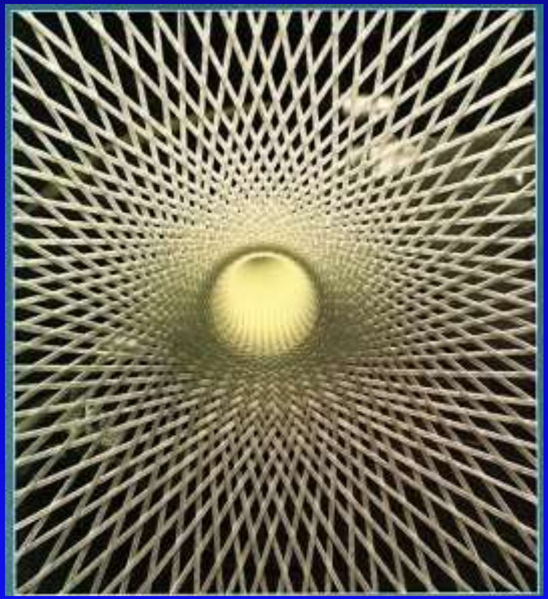
# Textile Technologies

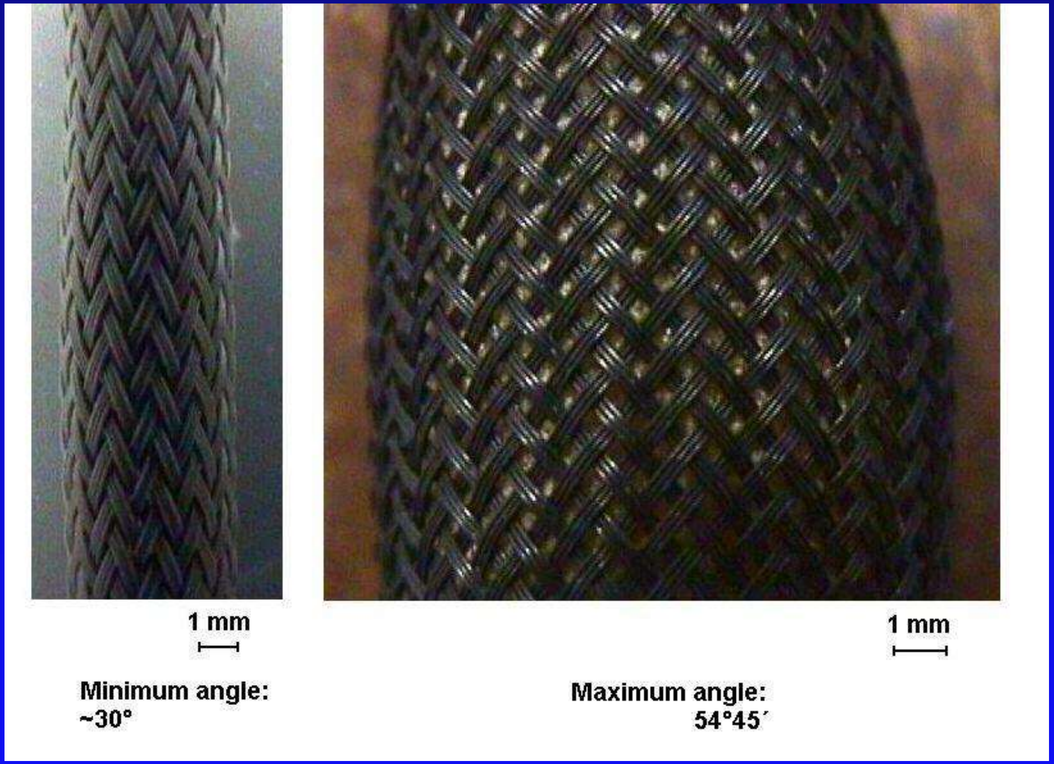







**Weaving**
**Knitting**
**Braiding**



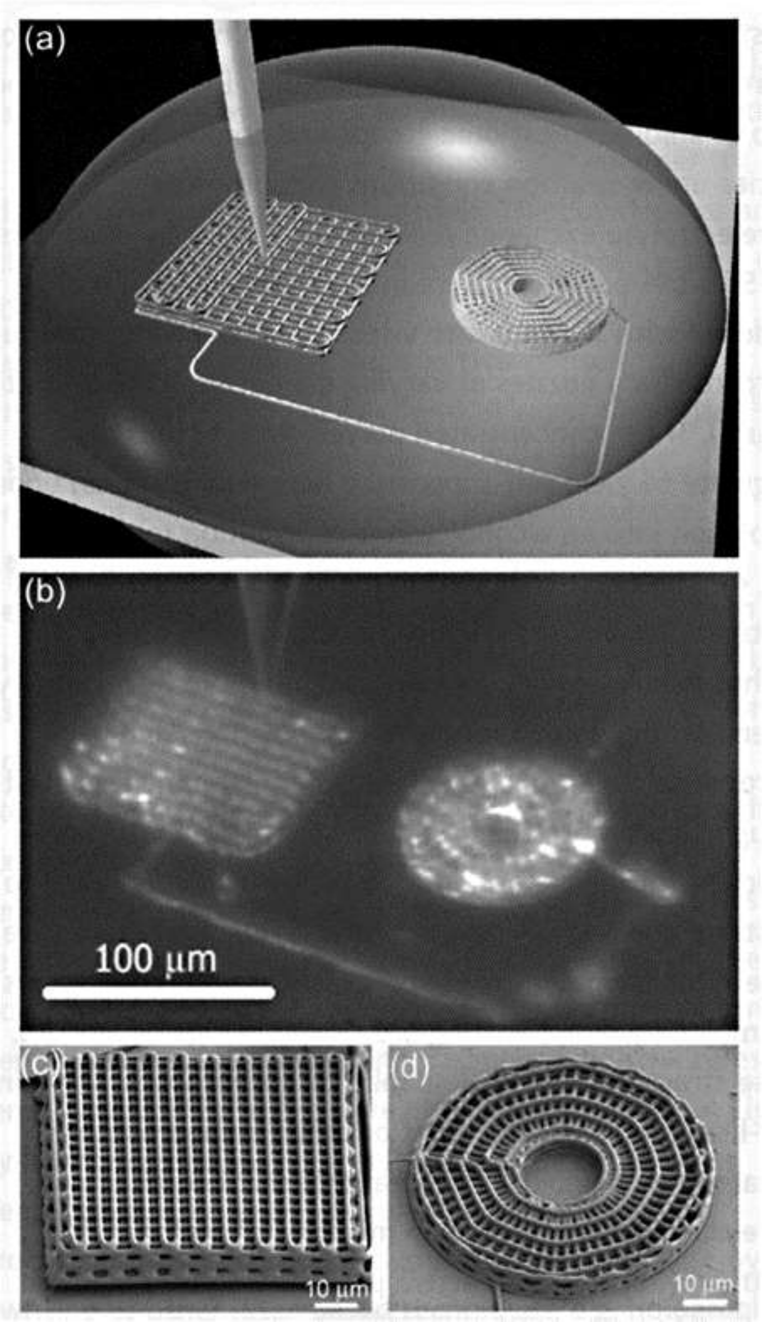



Fibre angle variation in braided tubular structures


KNITTED FABRICS FOR EFFICIENT, RELIABLE JOINTS

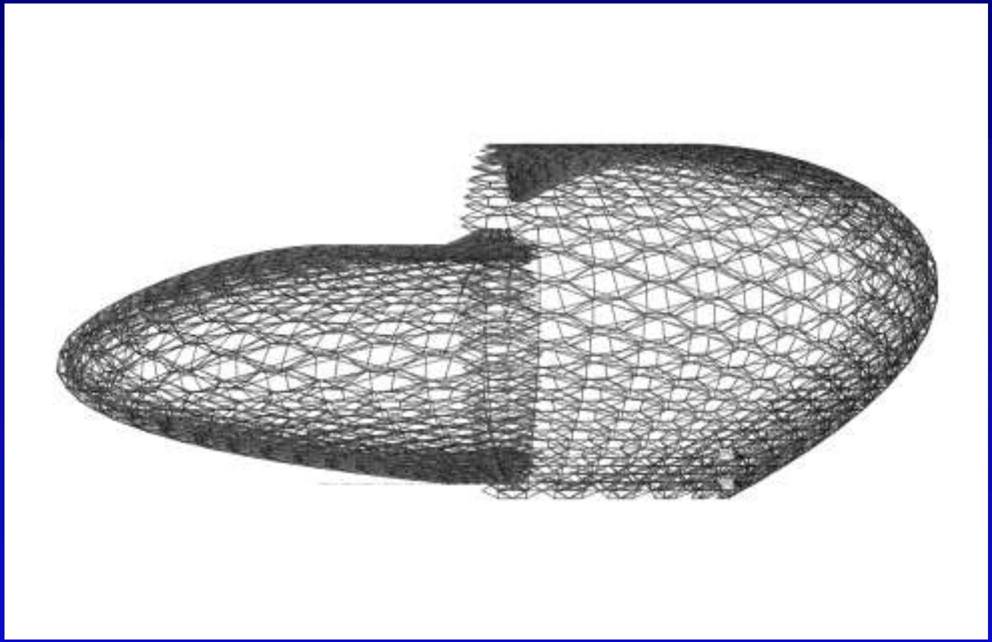
## FABRICATION

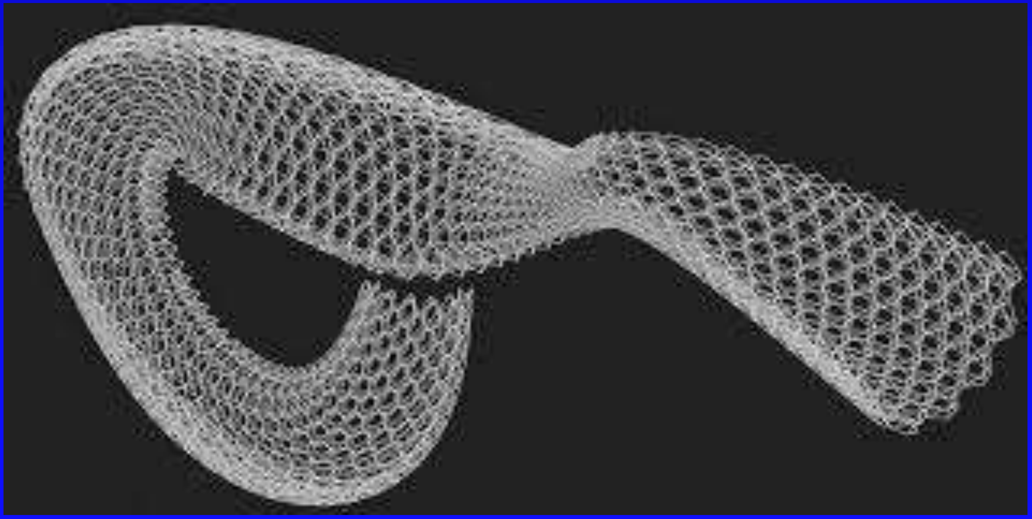
3D Printing
Additive fabrication




Nano-extrusion of 3D structures using gel-type carriers (nozzle) immersed in coagulation medium (drop) on glass substrate

Fibre systems are being incorporated in the process





# Pressure-Strain (Deformation) vs Fibre Angle

## Low compliance system

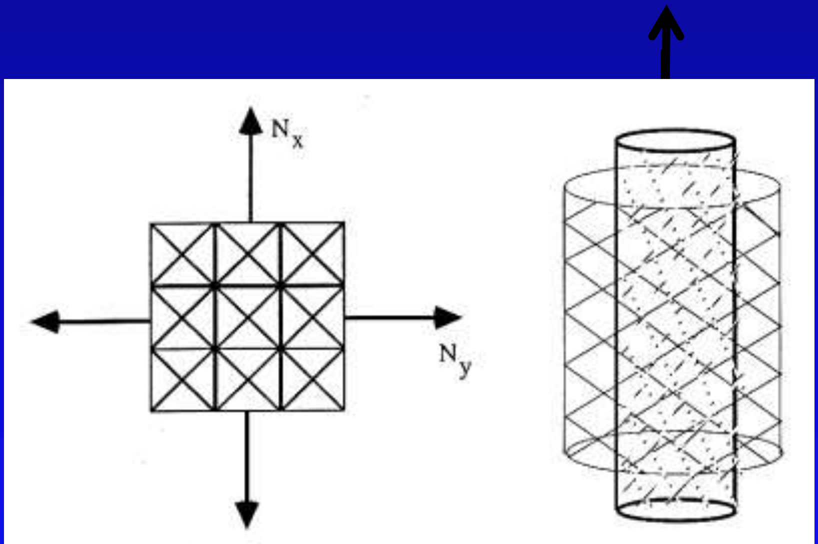



Figure 1a. Composite laminate structure under in-plane biaxial loading

Figure 1b. Deformation of cylindrical tube under pressure

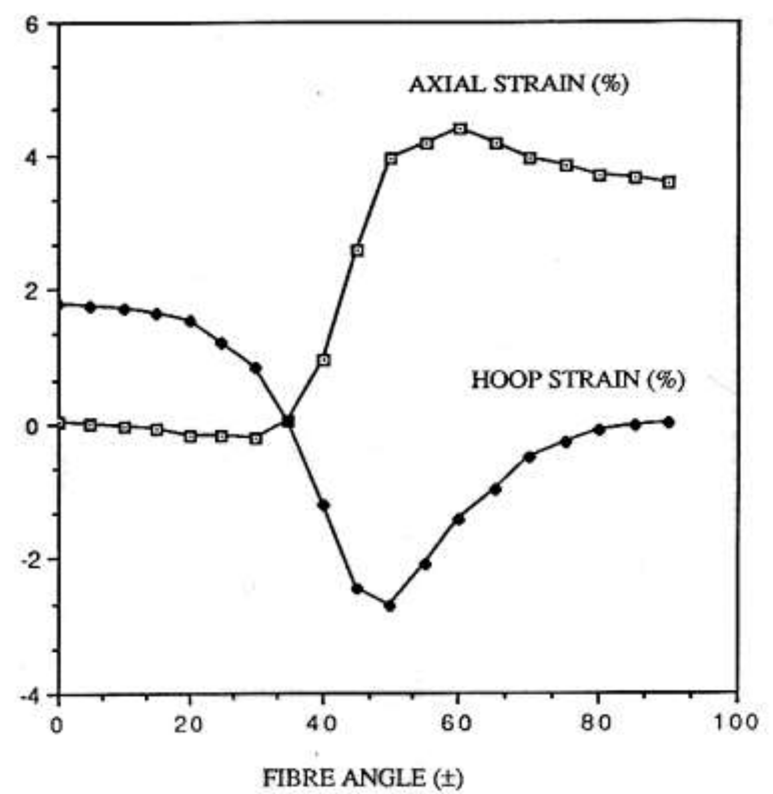
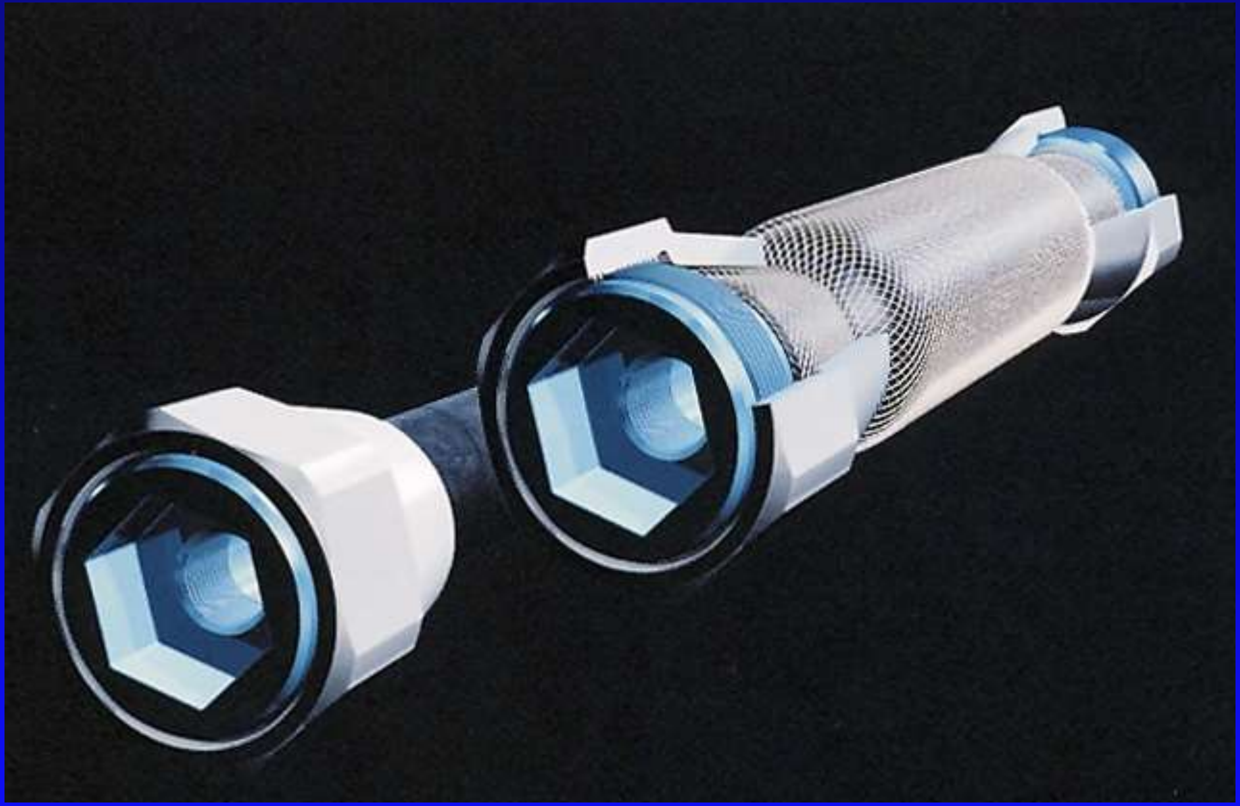
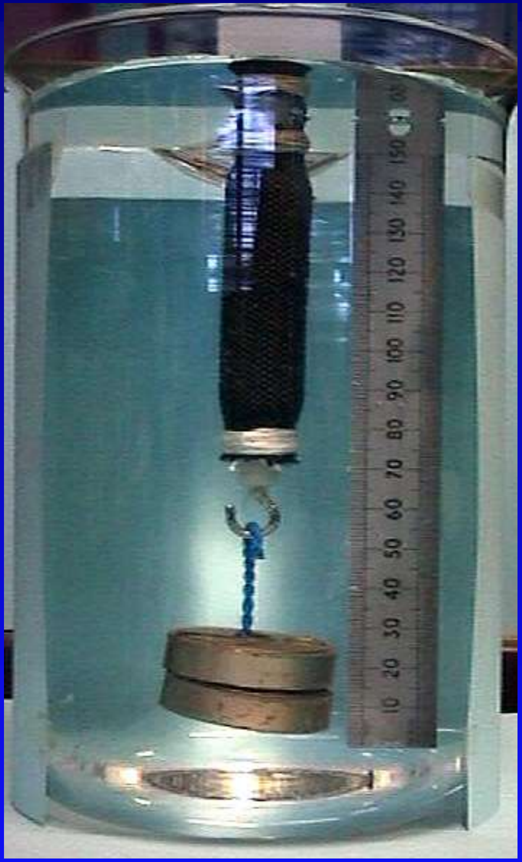



Figure 2. Axial and hoop strains in balanced braided or filament-wound cylinder under internal pressure

# High compliance system

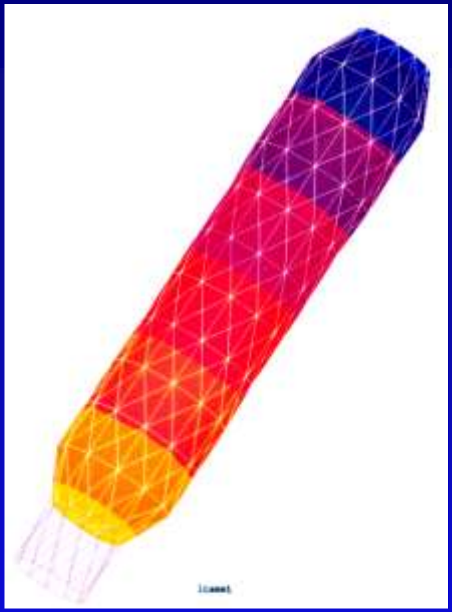


"FESTO" – Pneumatic Muscle

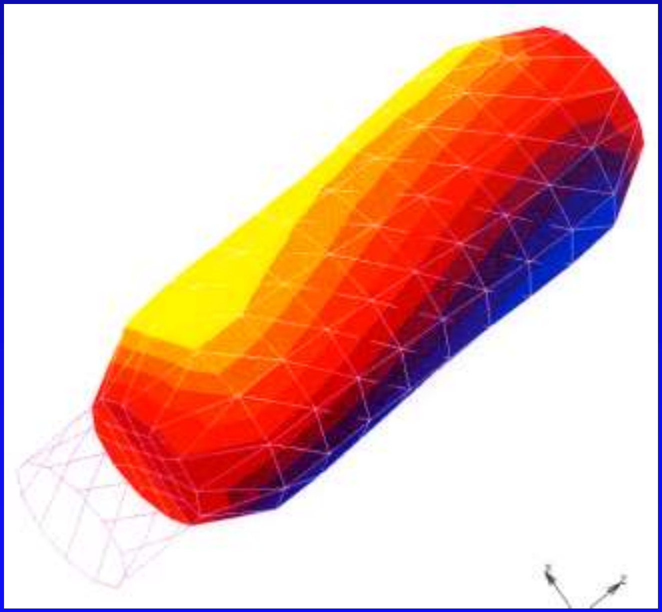


Swelling of gel and encapsulation in fibre structure leads to contraction of structure and force generation

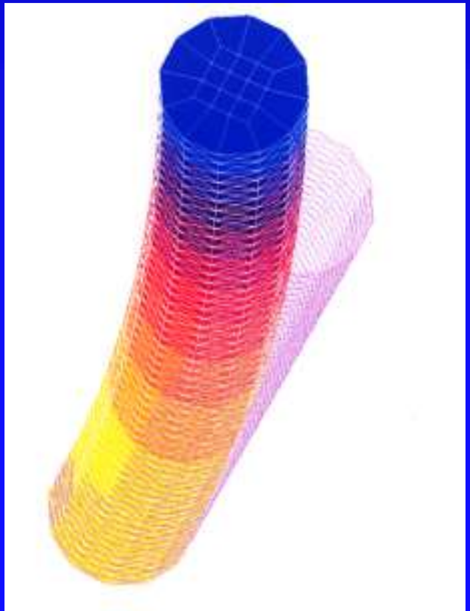
**Computer simulations (Finite Elements) of shape changes in biomimetic structures inspired from turgid plant cells, based on active polymer gels integrated with braided fibre structures**



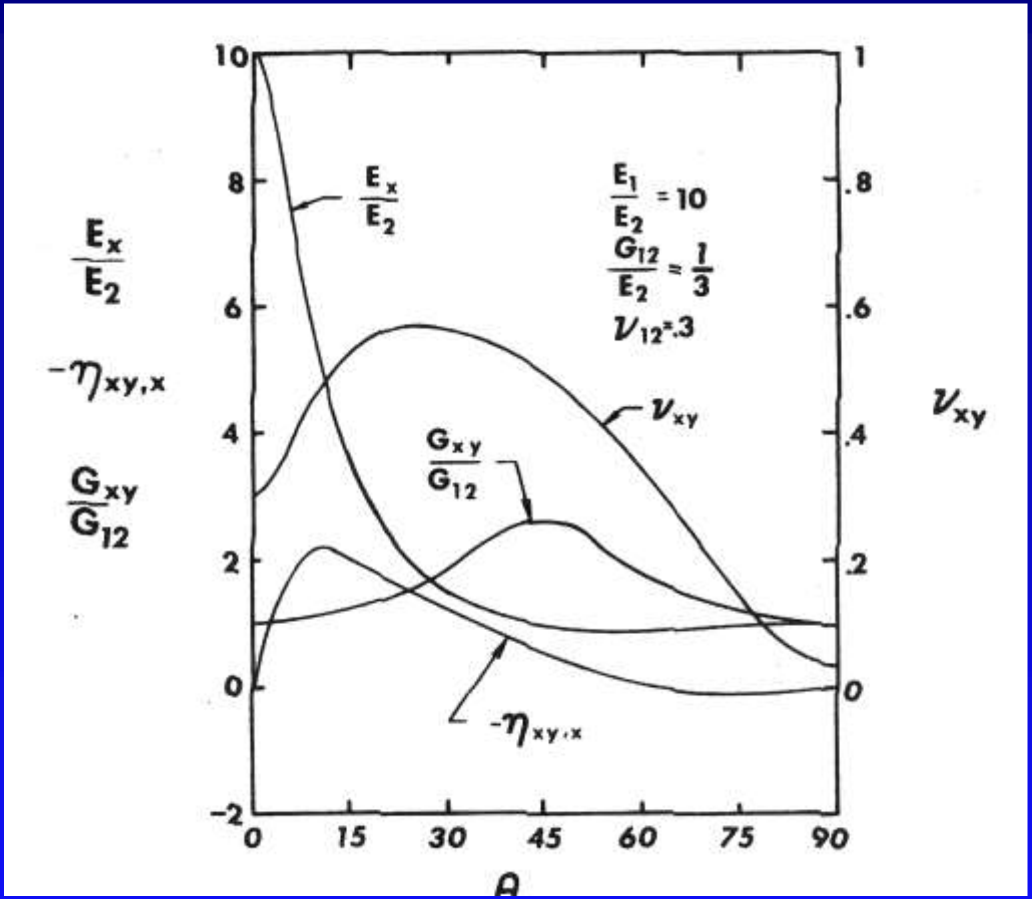
*Axial contraction*



*Twist*



*Bending*




**Changes in elastic properties with fibre angle (anisotropy)**

# Challenges

- Non – linear response (materials, geometry)
- Modelling aspects
- Self-repair
- Fatigue performance
- Fabrication limits / new fabrication routes (3D printing)

# Conclusions

- Fibres can provide a very extended design space (shape, geometry, deformability)

- Potential for highly integrated systems (load bearing, actuators, sensors,...)

- Jointless structures (smooth load transfer)

- Available fabrication technologies , scalable


*"The real voyage of discovery consists not in seeking new landscapes but in having new eyes"*

Marcel Proust