BIO-INSPIRED MATERIALS-STRUCTURE INTEGRATION FOR FUNCTIONAL DESIGNS IN CONSTRUCTION

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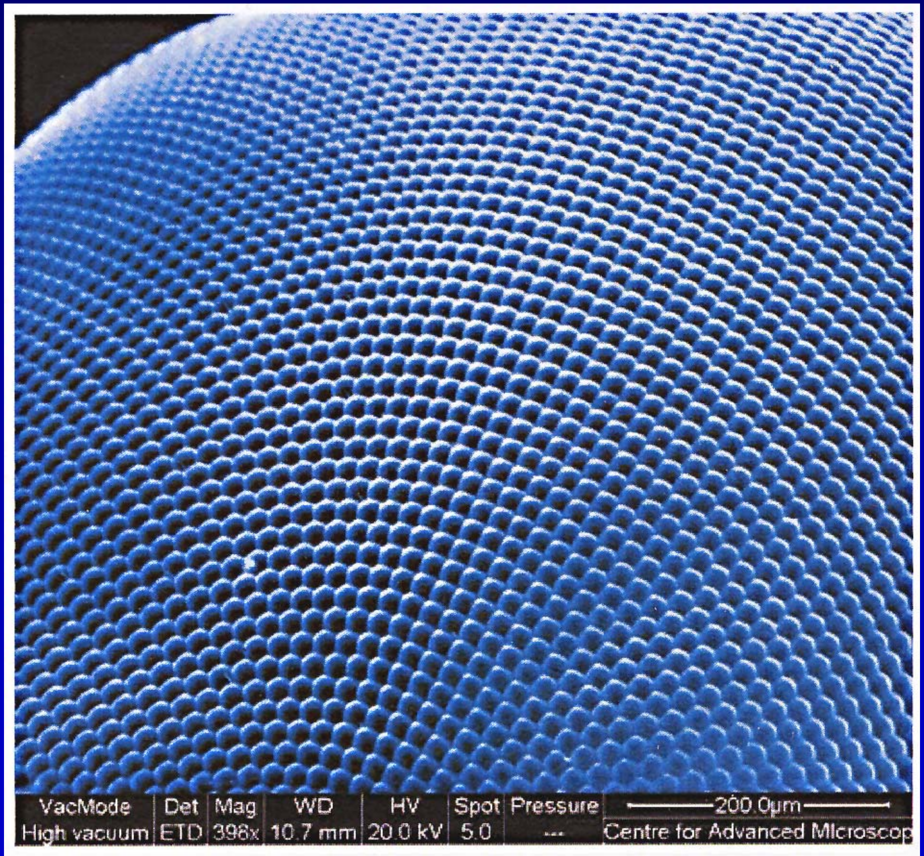
- **IN BIOLOGY SUCCESS IS MEASURED BY PERFORMANCE (SURVIVAL)**
- **THIS REQUIRES MECHANISMS FOR ADAPTATION TO ENVIRONMENT AND ENVIRONMENTAL CHANGES**
- **INTERACTIONS BETWEEN EXTERNAL INPUTS AND BIOLOGICAL PROCESSES ARE THE KEY TO MATERIALS-STRUCTURE INTEGRATION FOR FUNCTIONAL DESIGNS**

ENERGY CAPTURE
COLOUR GENERATION
HEAT TRANFER
MASS TRANFER
DRAG REDUCTION
SURFACE ADHESION / SURFACE REPULSION
STRUCTURAL OPTIMISATION
SENSING
ACTUATION
…………..

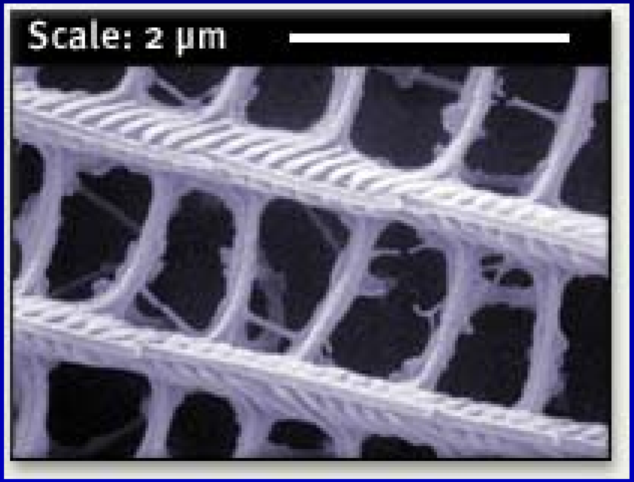
ENERGY CAPTURE

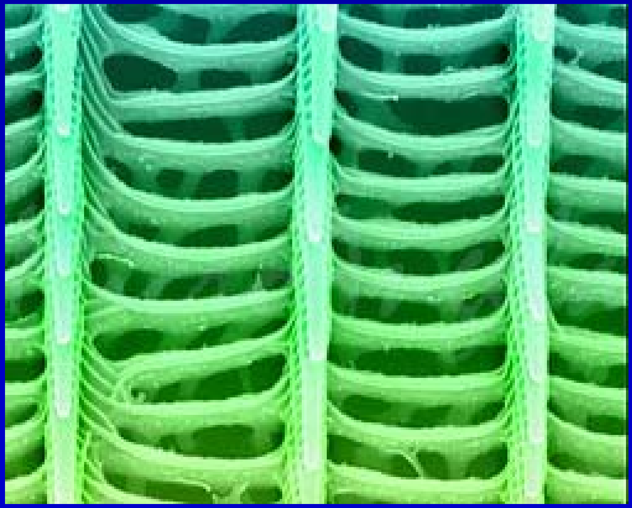


CfAM-Reading University, 2008

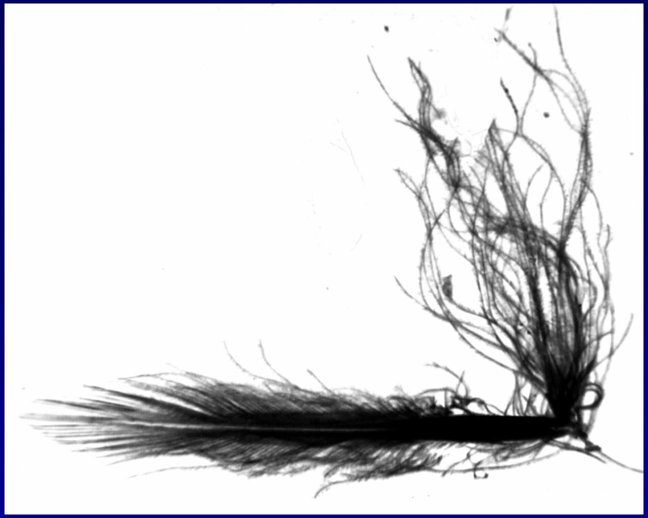
Insect compound eye

COLOUR GENERATION

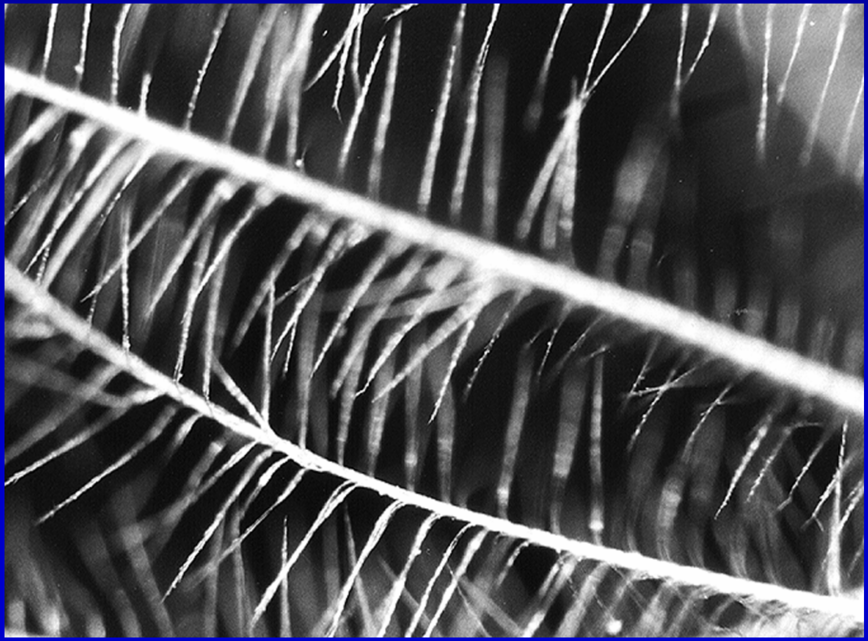




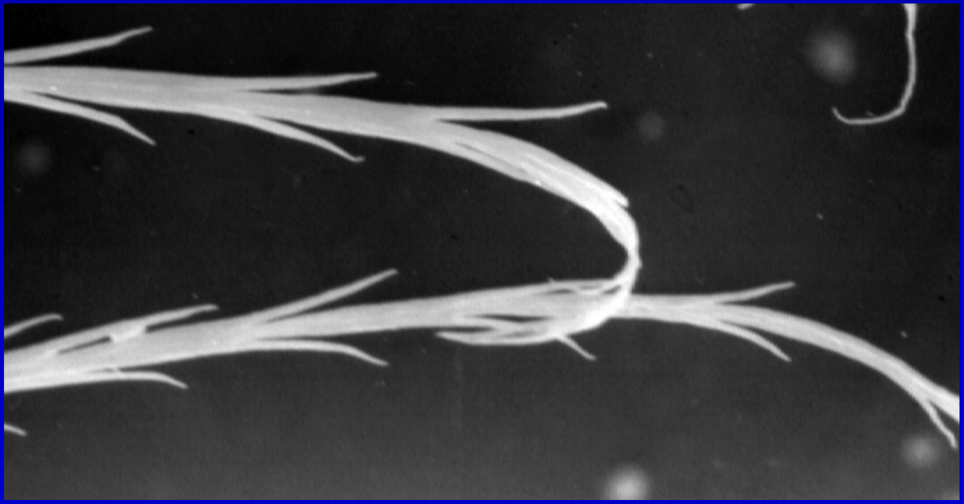
Scales of butterfly wings (physical colour, photonics)



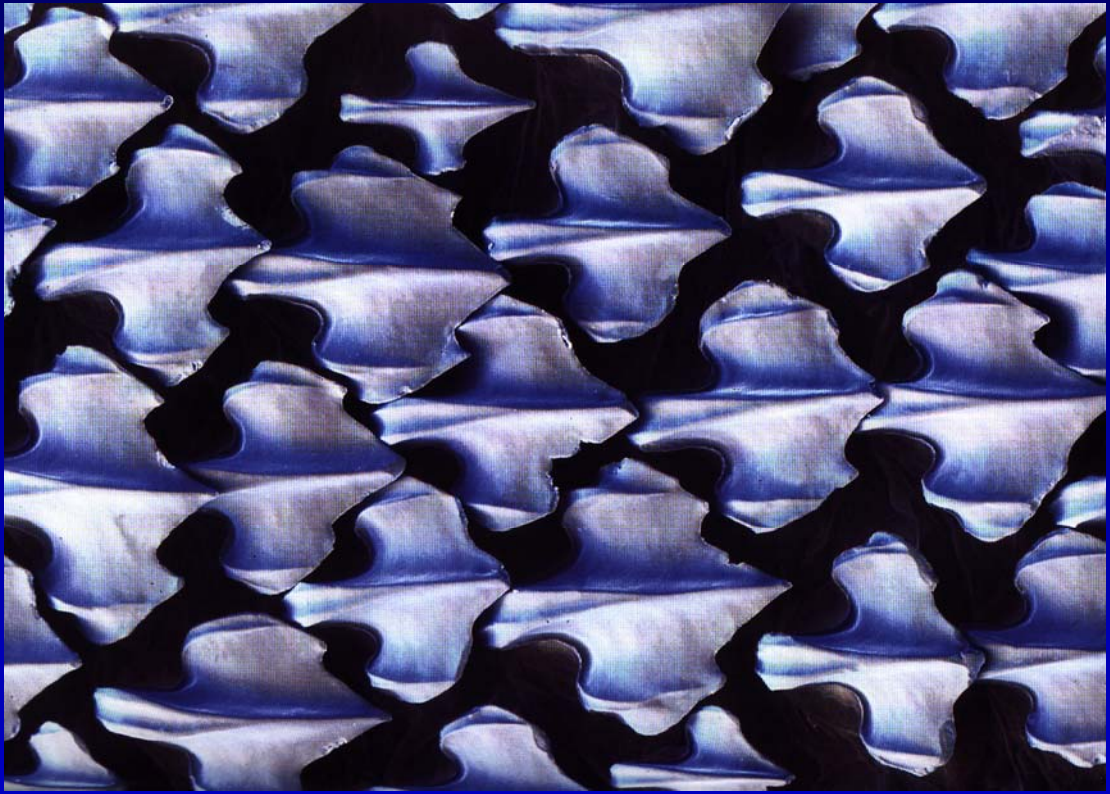
HEAT TRANFER



Penguin feathers (3D Velcro)



DRAG REDUCTION

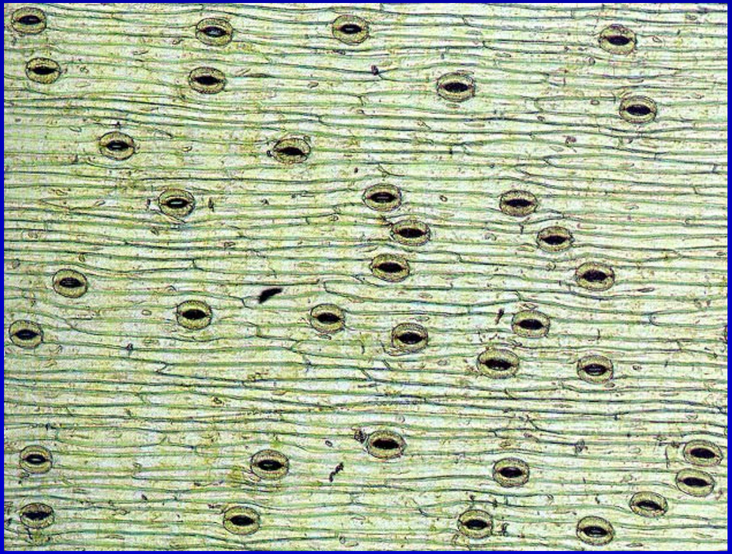


Shark skin

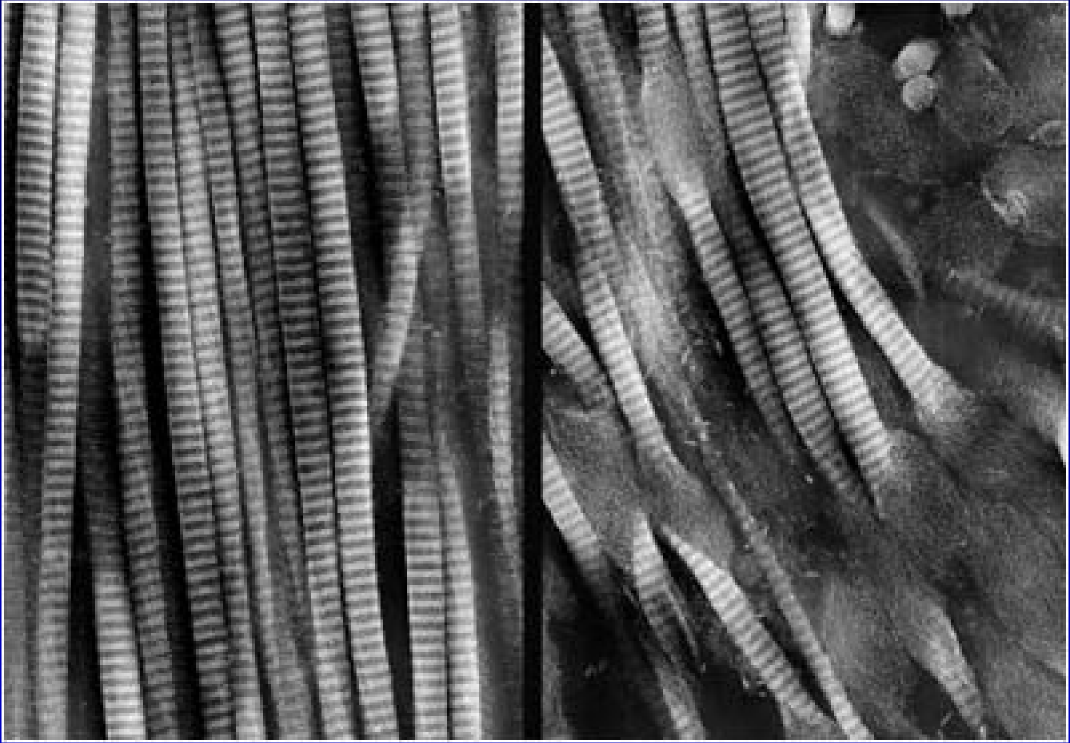
MASS TRANFER

Gunderson et al., 1995

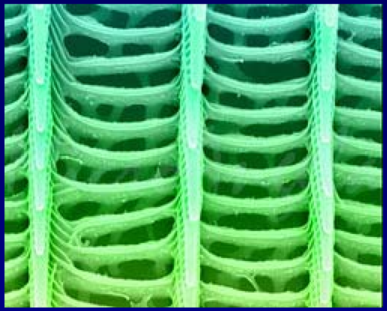
Pores in insect exoskeleton

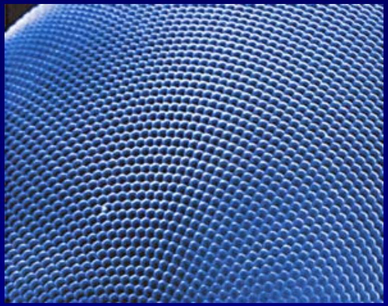

D. Attenborough, 1995

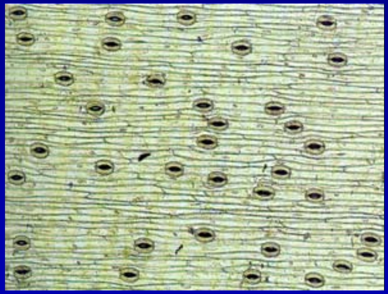
Stomata cells in plants leaves

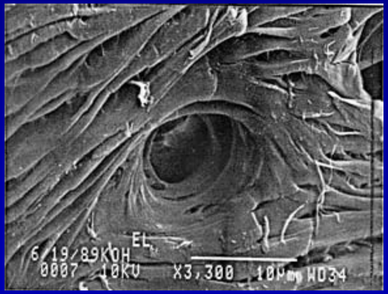


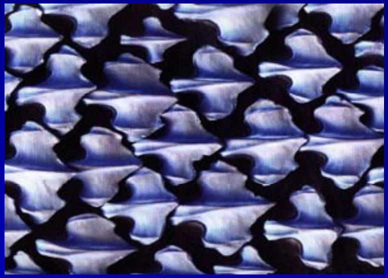
Collagen fibres in the cornea











All fibrous structures !!!!!!

Fibres represent physical *line elements* providing paths for transmitting, transferring and diffusing information (mechanical, chemical, etc.) into structures

Groups of fibres can be organised in 1D, 2D and 3D to create physical equivalents of lines, surfaces and solids such as those obtainable from textile technologies (which preserve fibre mobility) or composite technologies (where the fibrous networks are "rigidified" by bonding the fibres)

USING FIBRES LEADS TO THREE IMPORTANT EXPLOITABLE CONSEQUENCES

ANISOTROPY

Directionality of physical and mechanical properties

HETEROGENEITY

Position- dependent properties

HIERARCHICAL STRUCTURES

Bottom-Up assembly of structures + Interfaces

Biological systems are dominated by fibrous composite structures which are used to:

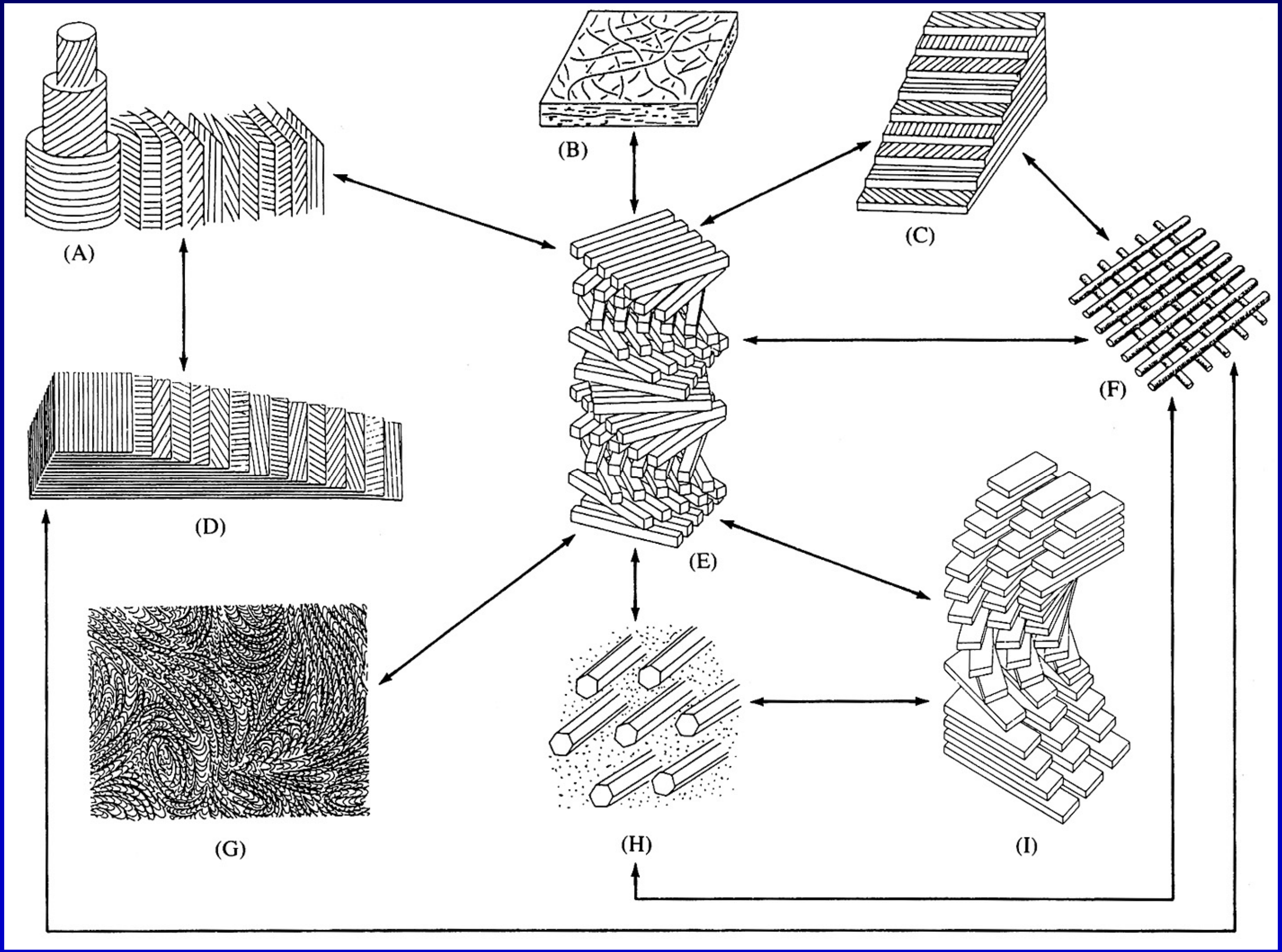
- **CREATE FUNCTIONAL ARCHITECTURES AND SHAPES**

- **INTRODUCE AND EXPLOIT HETEROGENEITY AND ANISOTROPY**

  (locally, globally)

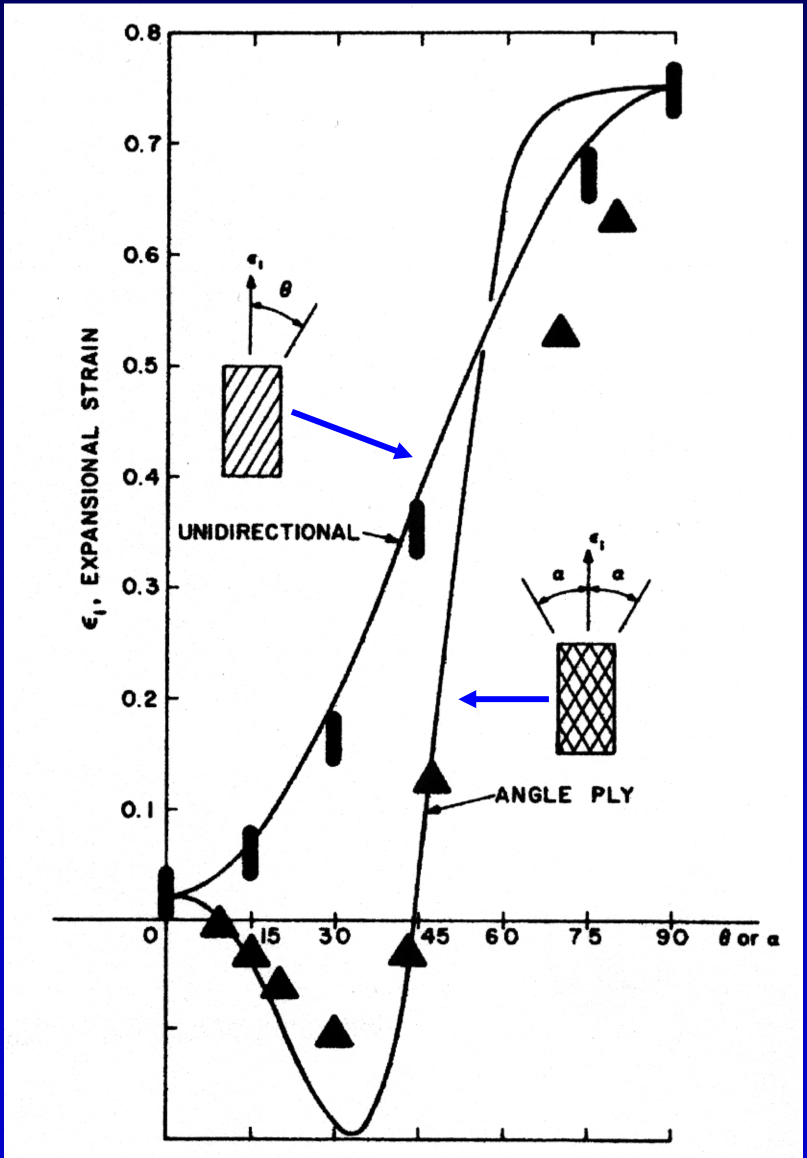
- **MODULATE PHYSICAL PROPERTIES**

  (functionally-graded materials / structures)



Range of fibre geometries & architectures found in nature

A.C. Neville, 1993



Hygro- or thermal expansivity of angle-ply structures

Emergent behaviour from fibrous composites

Individual plies with non-zero coefficients of thermal expansion can create a laminate structure with zero thermal expansion coefficient

Halpin, J.C. and Pagano, N.J., 1978

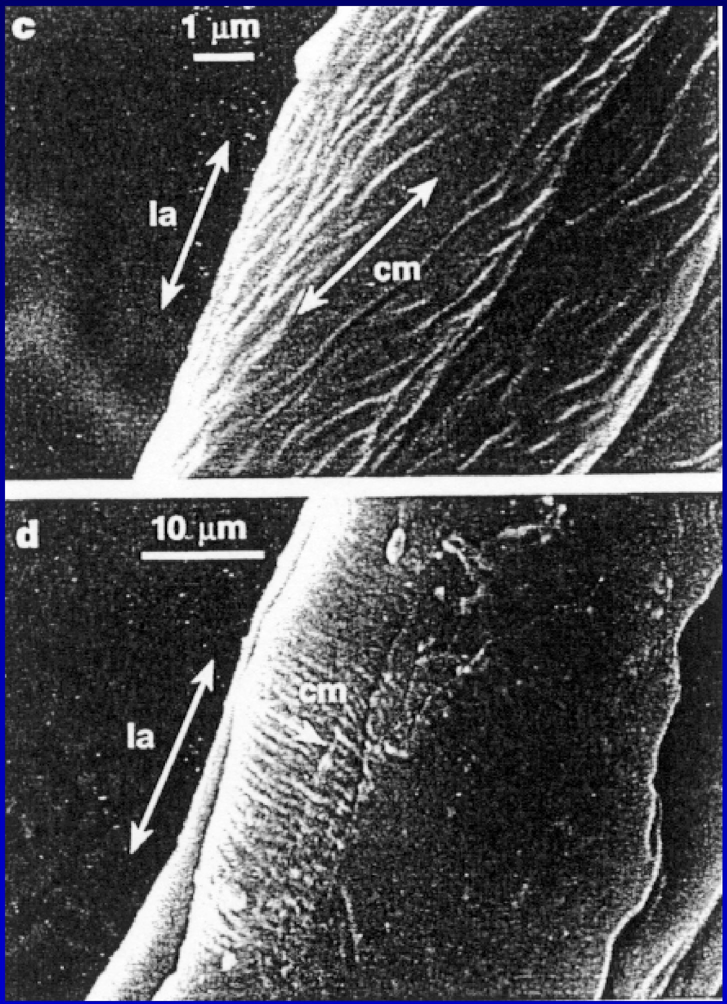


Twisting seed pod

Differences in fibre orientation + layering

Passive response

Integrated sensing



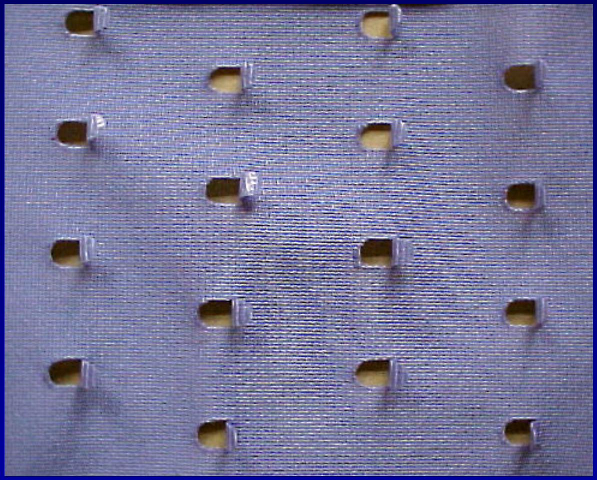
Passive response

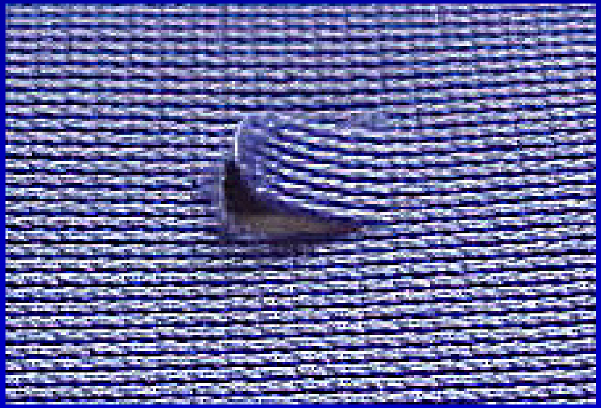
Integrated sensing

Differences in fibre orientation + layering

Dawson *et al., 1998*

Differences in fibre orientation = Shape change





Smart adaptive fabrics

Dawson *et al.*, 1998

Shape adaptation in fibrous systems

Gravitropism in trees

Reaction wood

Adaptation of an individual (phenotype rather than genotype)

Optimisation can only be relative and not absolute, in space and time

Capacity to adapt is essential when knowledge of the environment, current and future, is imperfect

Morpho-mechanical computation

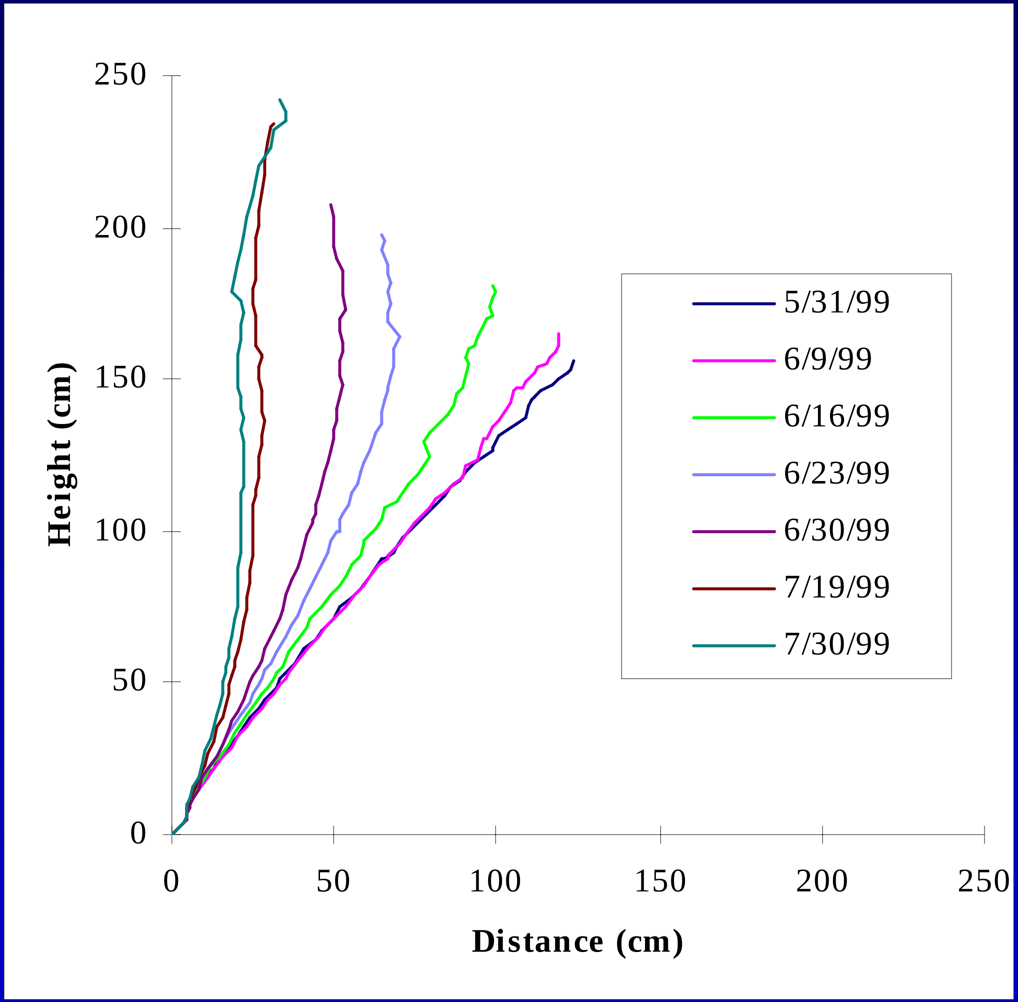
Stimulus → Transduction → Signalling Regulation → Response

Statoliths

Starch grains inside cell touching the cytoskeleton

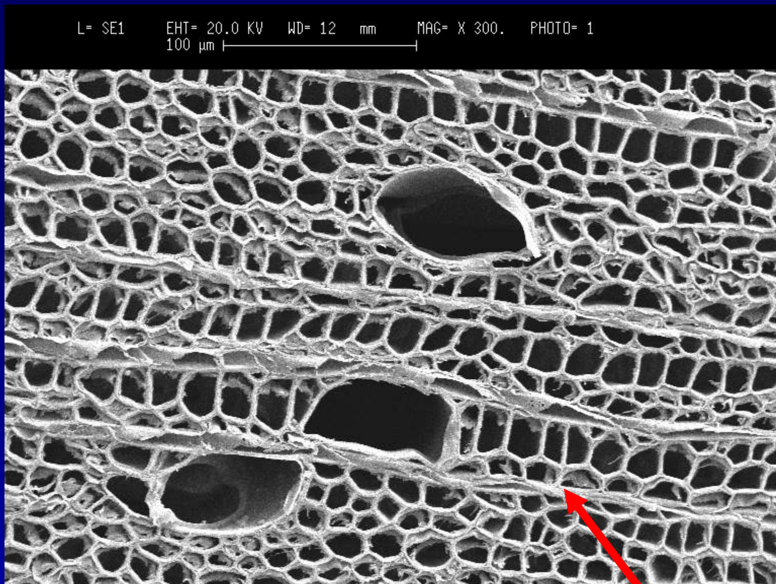
????

Offset angle from vertical

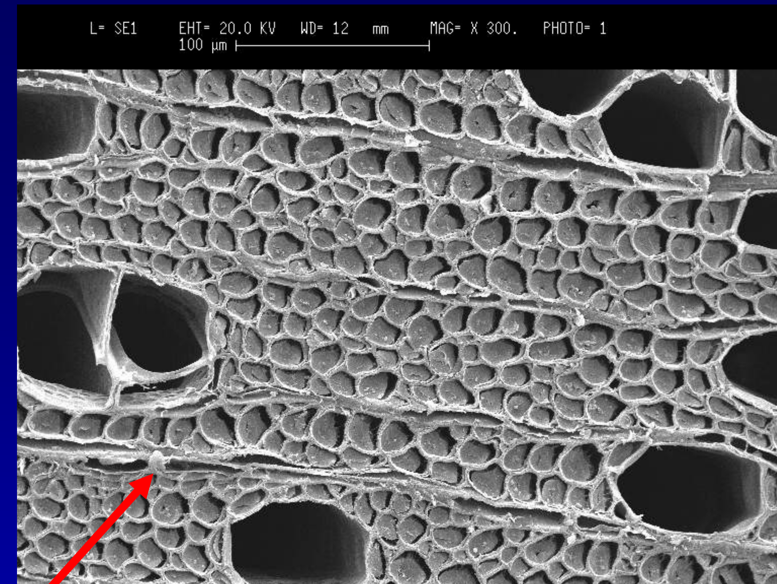


Reorientation of young poplar trunk as a function of time

Coutand *et al.*, 2004



Normal wood

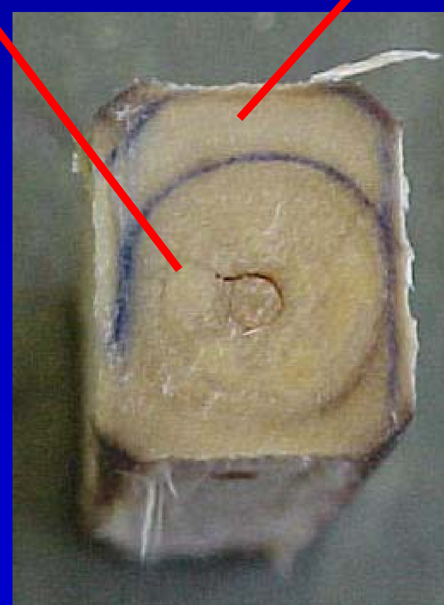


Tension wood

Local level = cell wall

Regional level = tissue

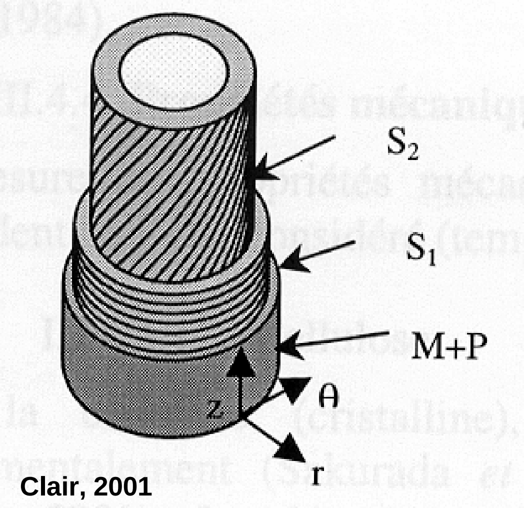
Global level = trunk



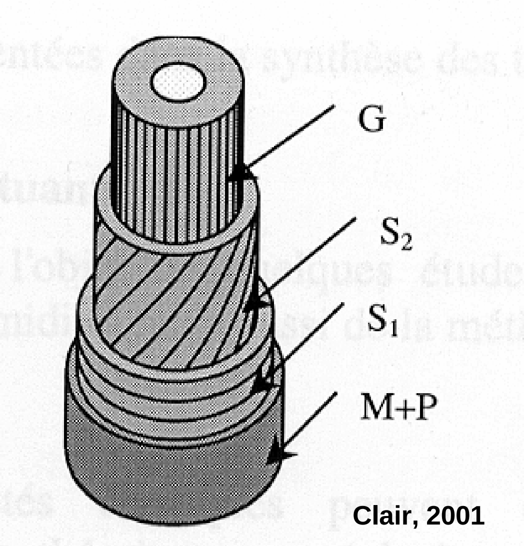
Distribution of tension wood in young poplar (+ mild eccentricity)

Coutand *et al.*, 2004

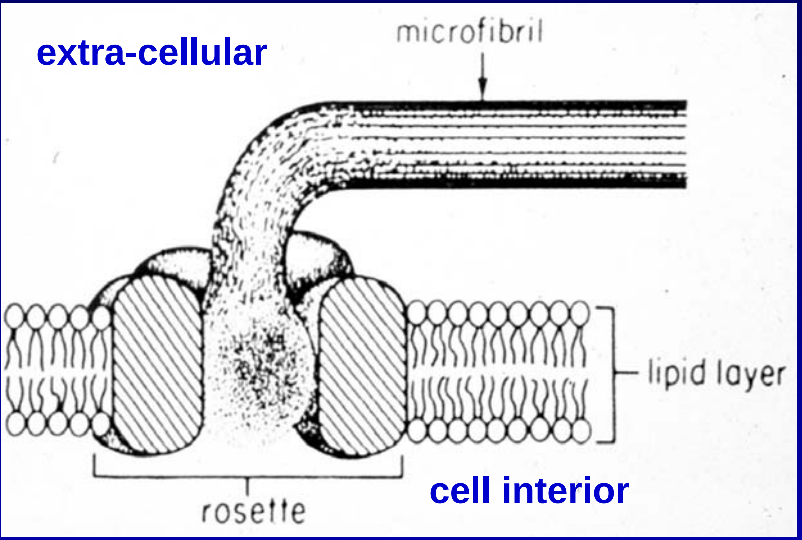
Fibre fabrication, deposition, orientation (geometrical control)

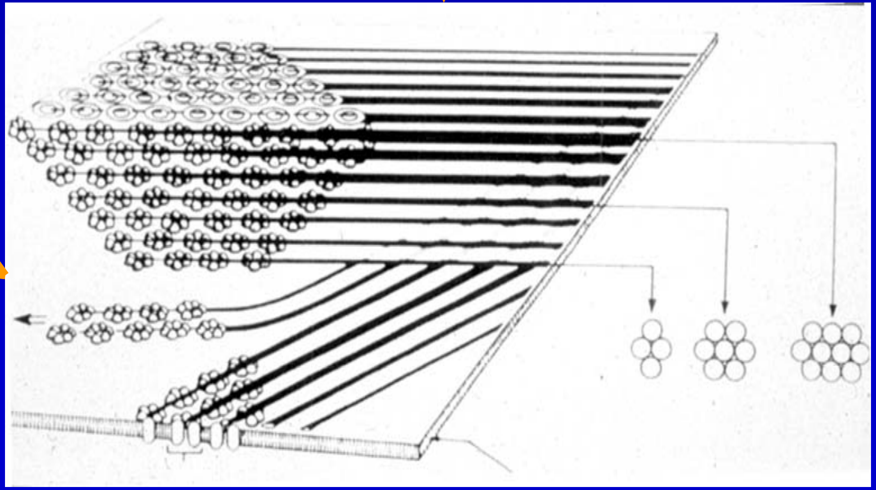


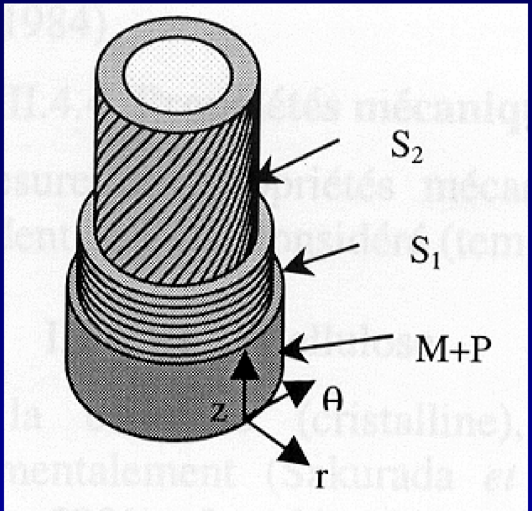
Normal wood



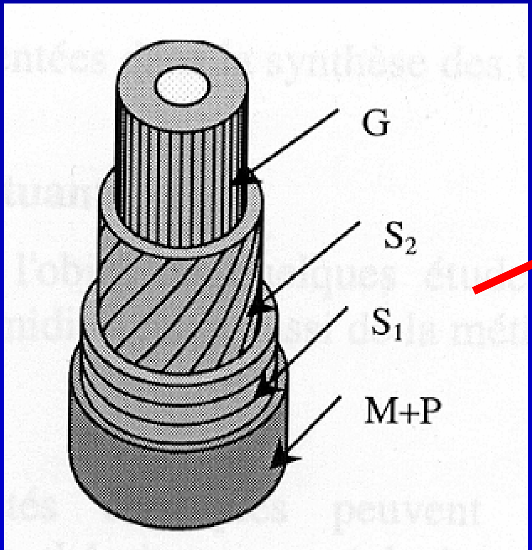
Tension wood





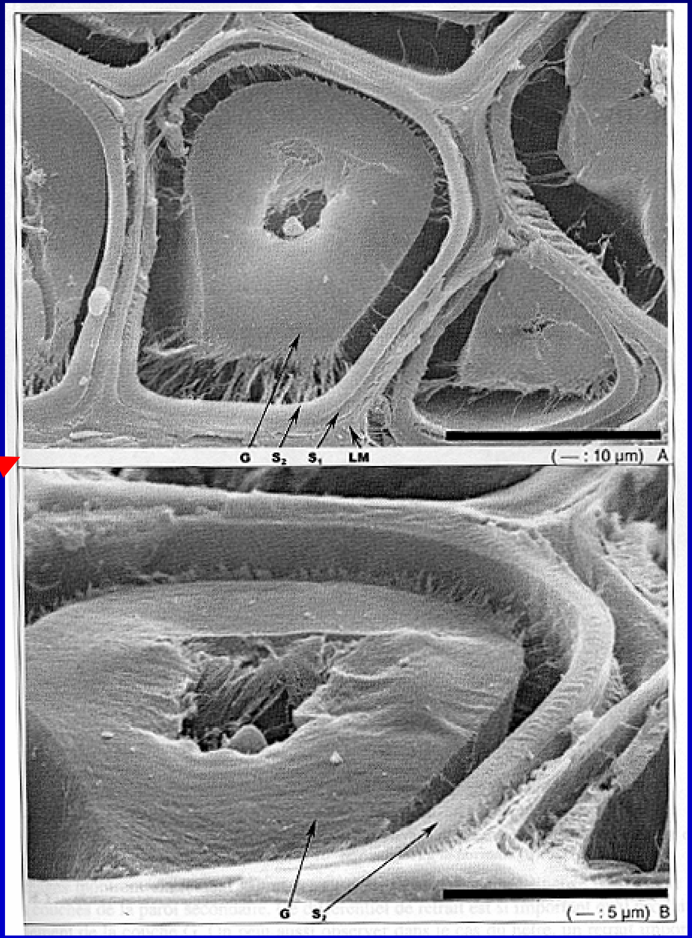


Normal wood



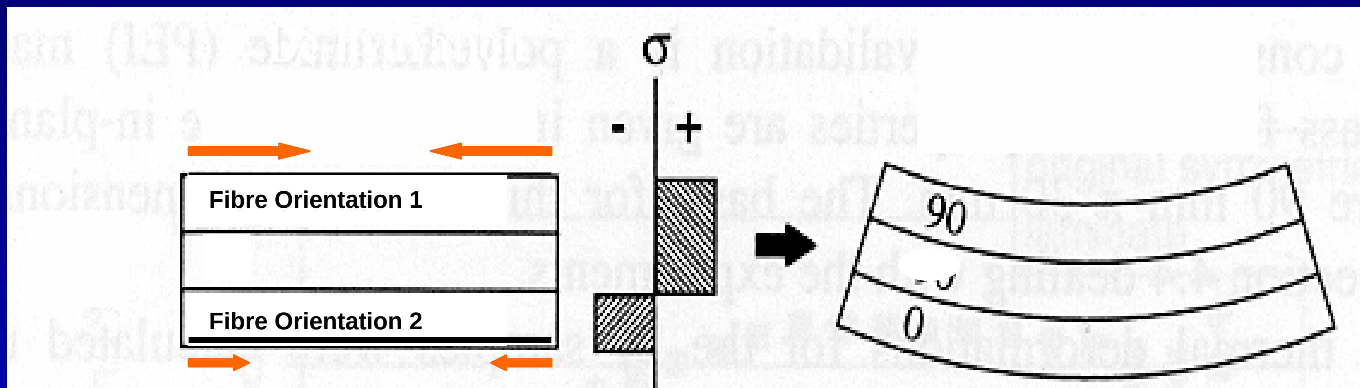
Tension wood

Tension wood shrinks more than normal wood during "maturation"



Clair, 2001

Basic mechanism for shape change in plants



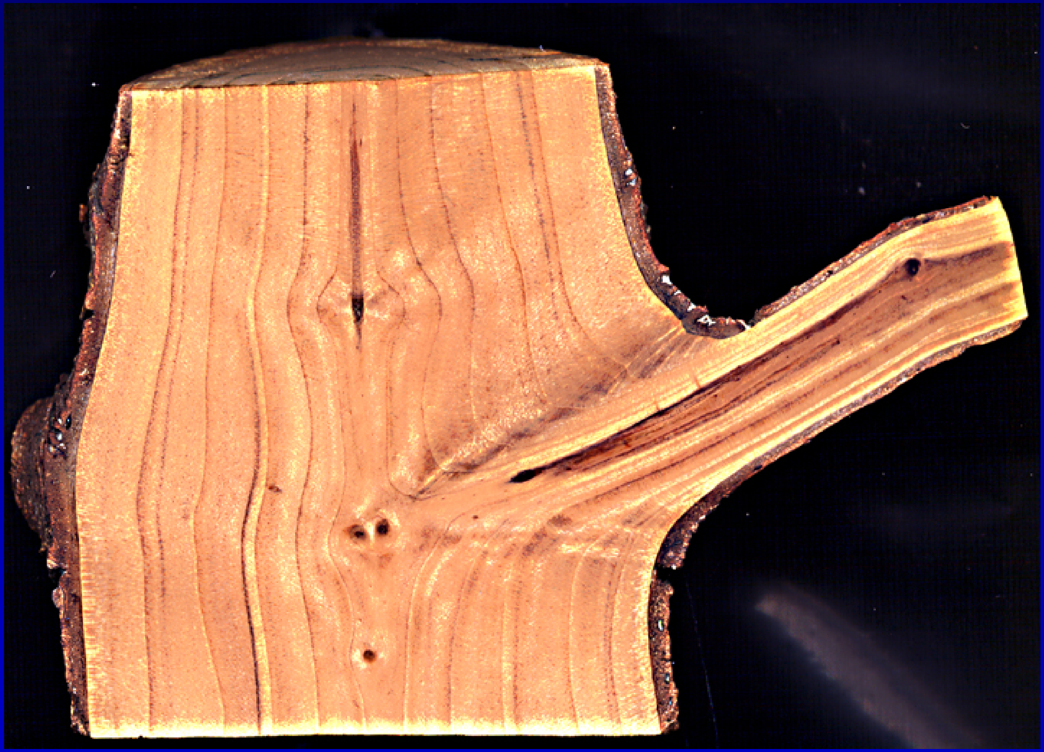
Non-symmetric laminate ⟶ **Shape change (curvature)**

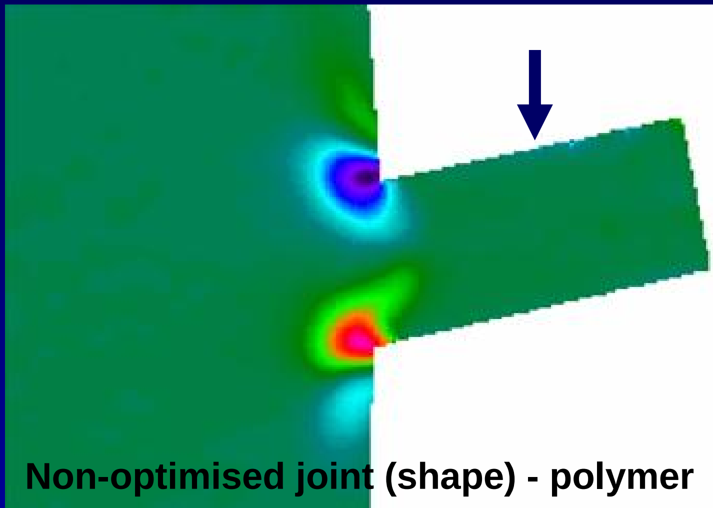
De-hydration

Differentiation at the "local" level converted into effect on the "global" level

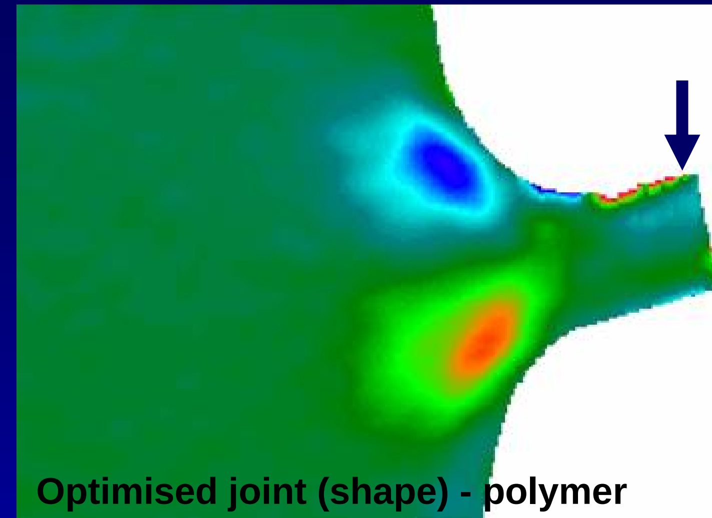
<u>CREATE THE DIFFERENCE – EXPLOIT THE DIFFERENCE</u>

Fibres for functionally-graded materials & structures





Non-optimised joint (shape) - polymer



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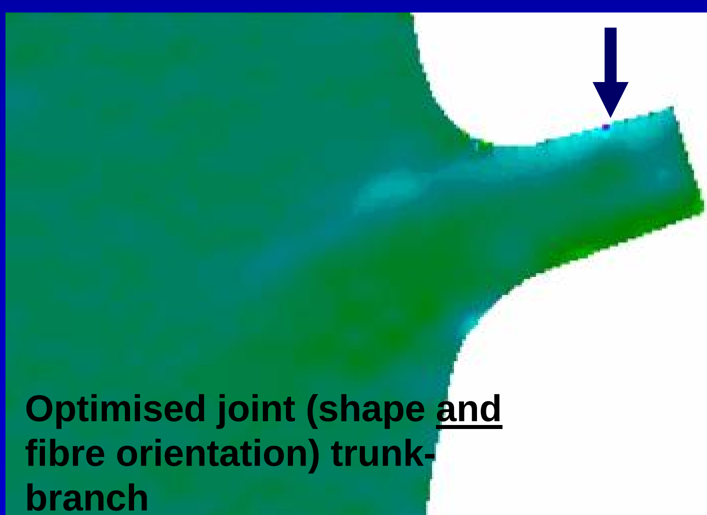
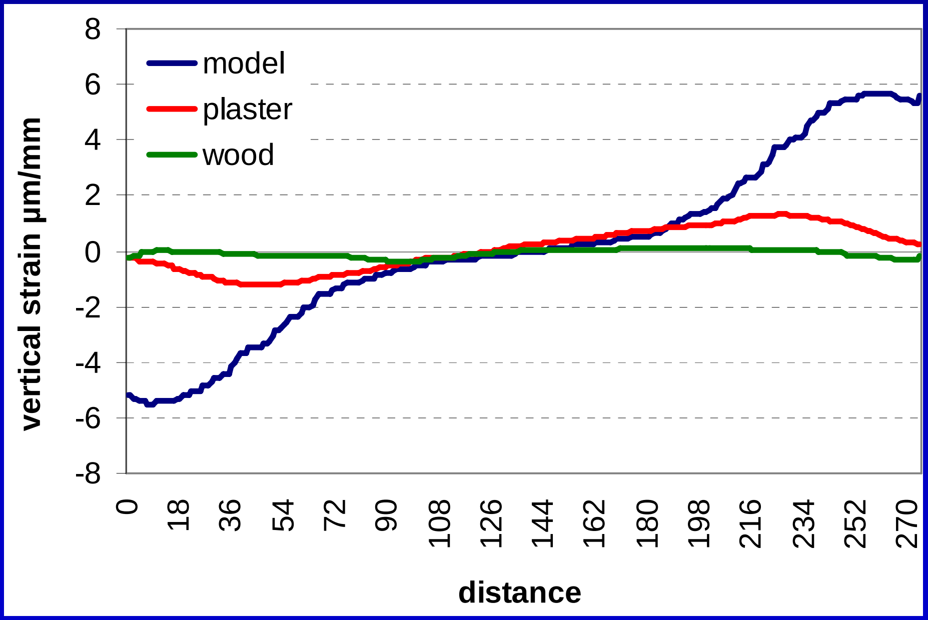


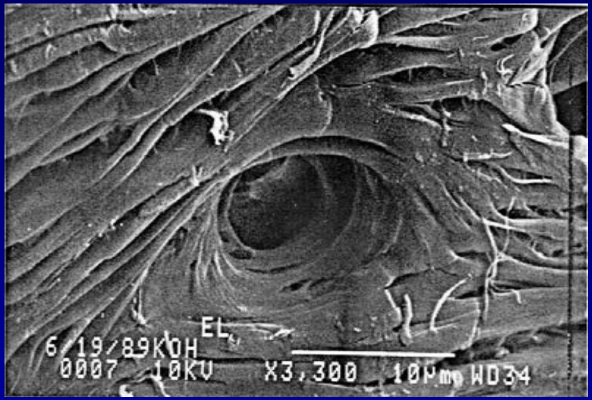
Optimised joint (shape <u>and</u> fibre orientation) trunk-branch



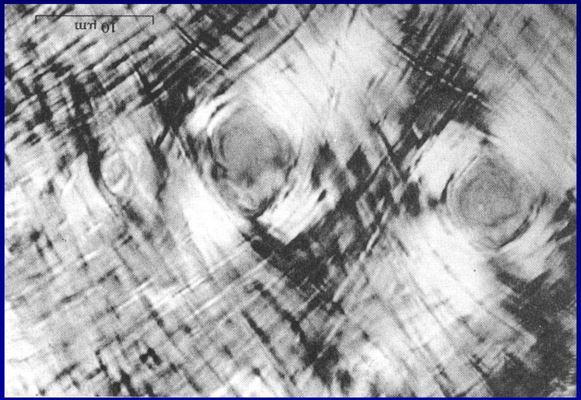
Strain field in vertical direction

Muller et al., 2006

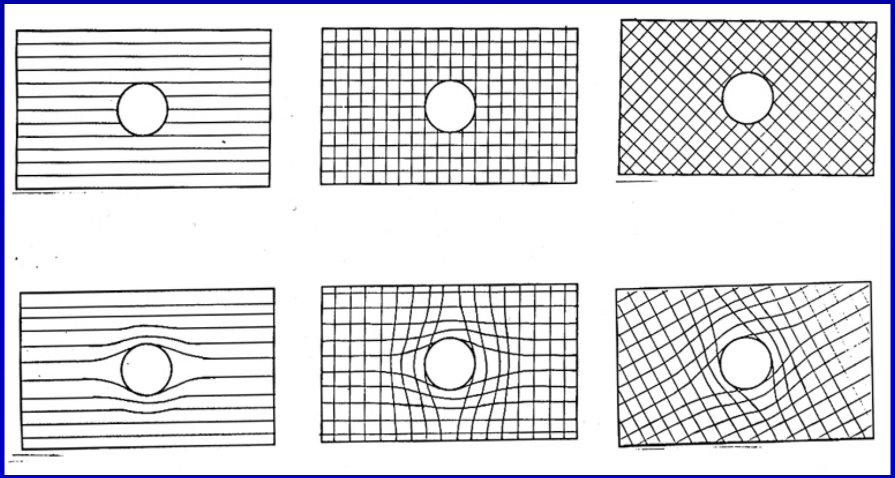
Local modulation in fibre orientation = Minimisation of stress concentrations



Gunderson et al.,1995



A.C. Neville, 1993



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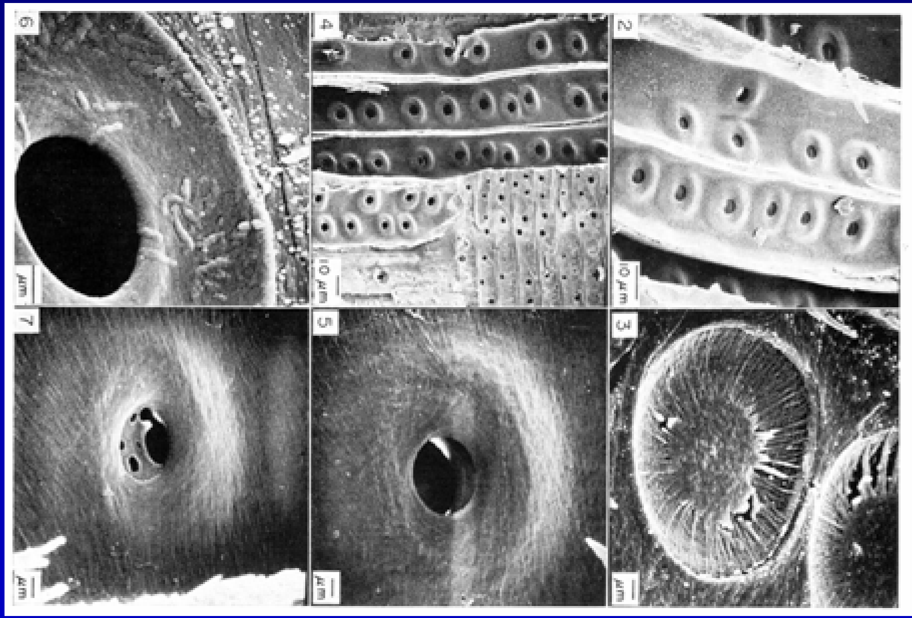
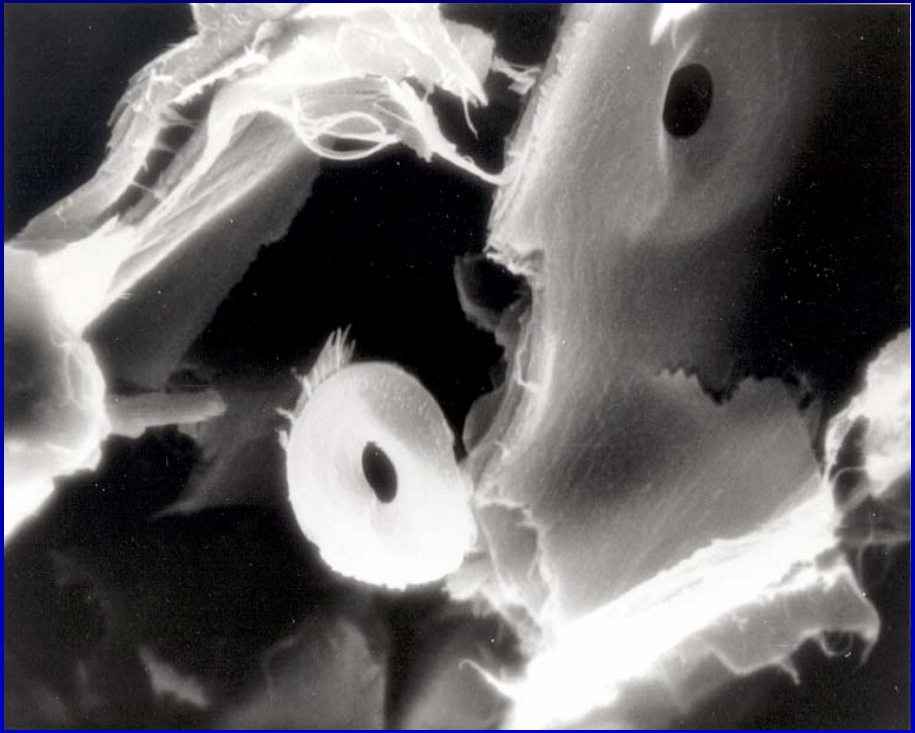


Bolton and Petty, 1975

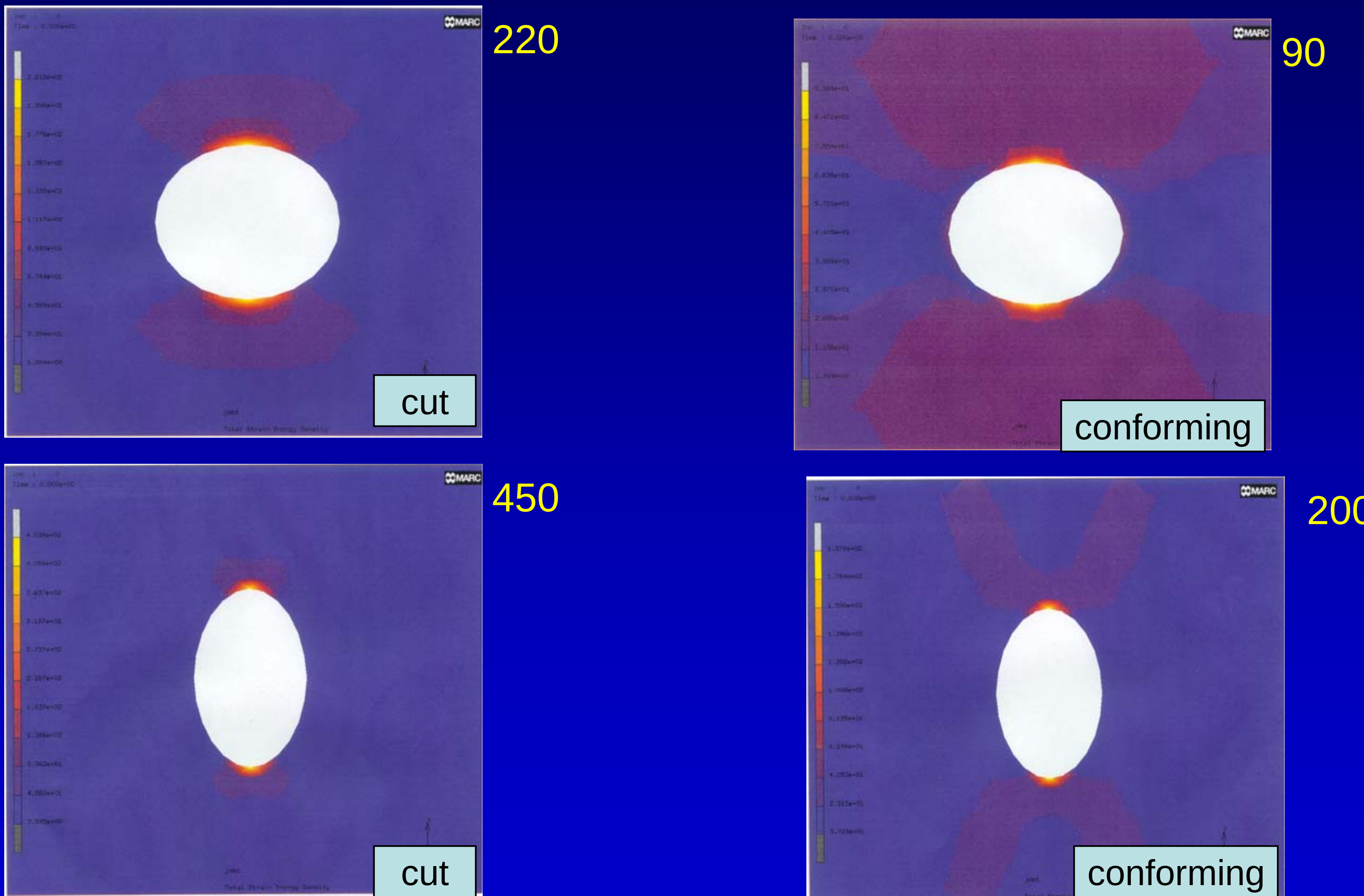
Bordered pits in wood cell walls



Jeronimidis, 1998

Fracture in wood cell bordered pit with conforming fibres

Local modulation in fibre orientation = Minimisation of stress concentrations



Differences in strain energy near circular and elliptical holes for “cut” and “conforming” fibres

Skordos et al.,2001

DIFFERENTIATION AT THE “MATERIAL” LEVEL

(Anisotropy, Heterogeneity, Hierarchies)

+

DIFFERENTIATION AT THE “STRUCTURE” LEVEL

(Shape, Dimensions, Geometry)

↓

FUNCTIONAL INTEGRATION AT THE “SYSTEM” LEVEL

(Emergent behaviour / Adaptation)

IN SUMMARY, FIBROUS COMPOSITES PROVIDE:

- an almost unlimited ‘design space’ in terms of geometry and topology
- high levels of functional integration (functionally - graded properties)
- continuous load paths
- possibility of adaptive response
- optimisation strategies
- robustness
- easy integration of sensing functions (fibre optics)
- bottom up assembly of functional hierarchies

BIOLOGY WITHOUT FIBRES WOULD BE FORM WITHOUT SMARTNESS, GEOMETRY WITHOUT SUBSTANCE…….

SUCH LIFE MAY NOT HAVE BEEN ABLE TO EVOLVE

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THANK YOU FOR YOUR ATTENTION