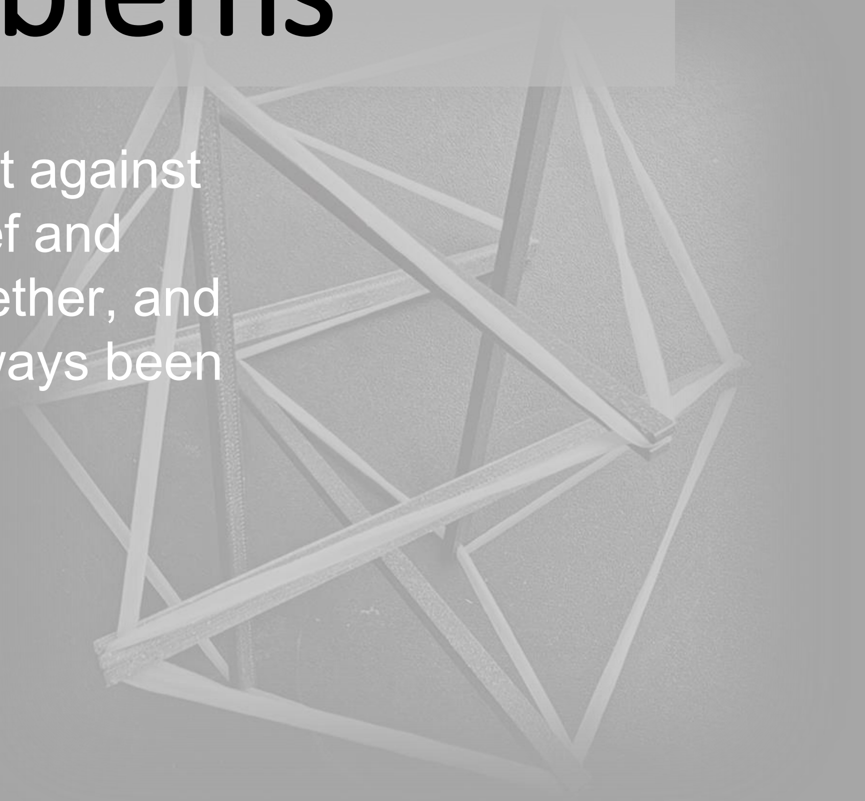
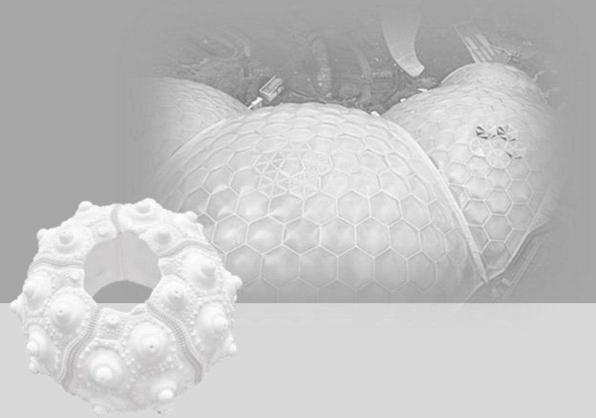
# How and what creation teaches us to solve mechanical problems

"It is the constantly ongoing, never-ending fight against skepticism and dogmatism, against unbelief and superstition that religion and science wage together, and the trend-setting watchword in this fight has always been and will always be:
Toward God!"

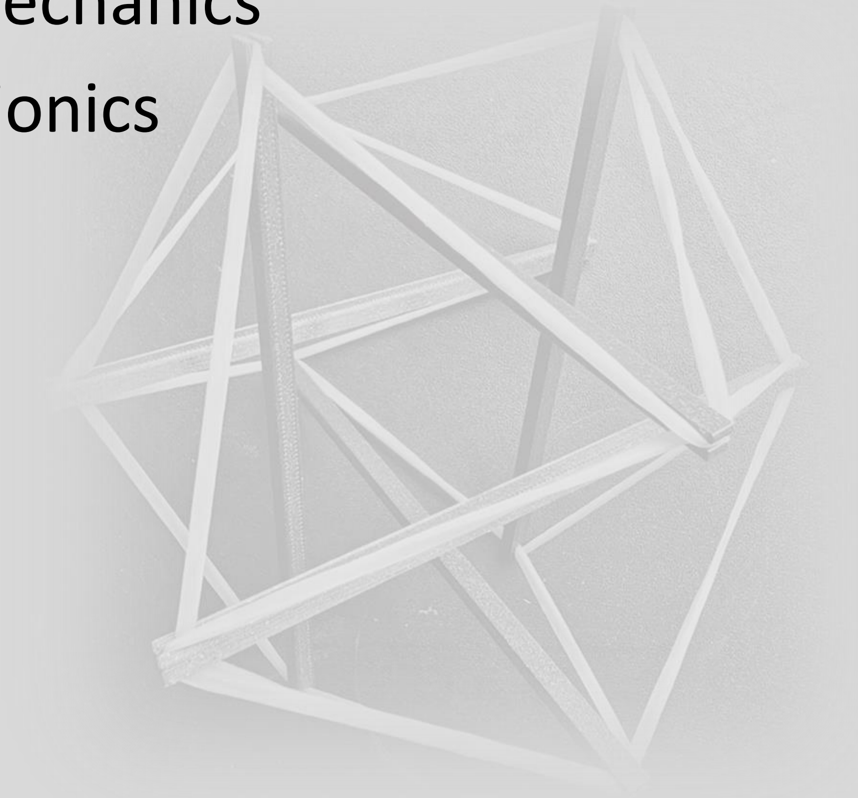
Max Planck
Religion and Sciences, Presentation given in Baltic States May 1937





# Outline

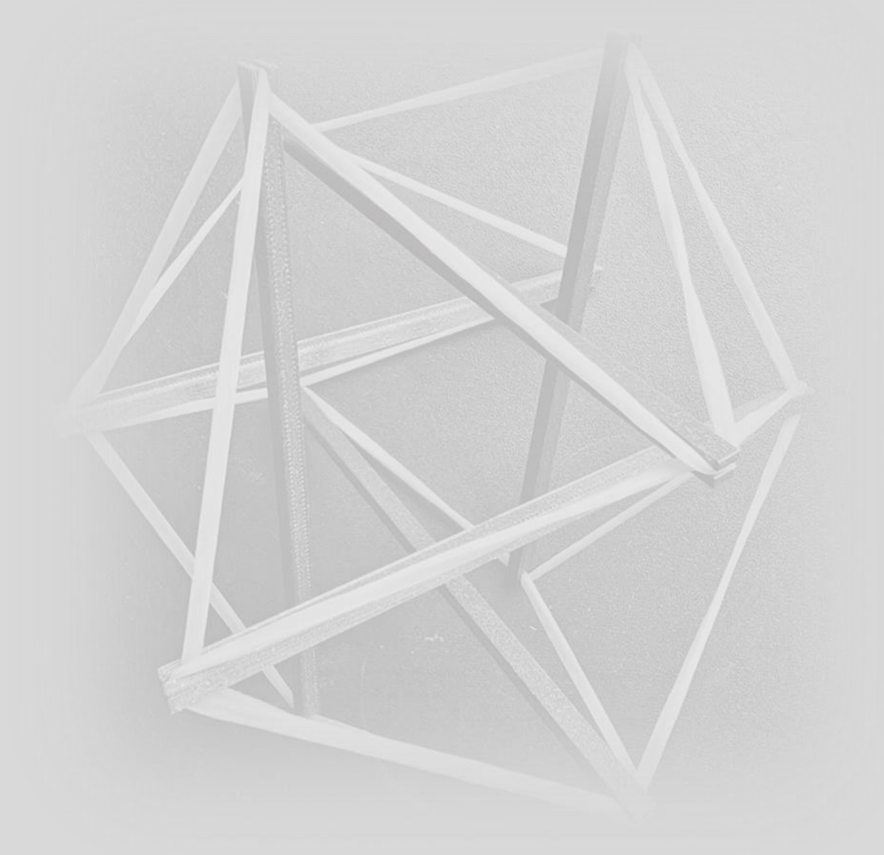
1. Introduction to bionics and structural mechanics
2. Personal contact and experience with bionics
3. How we (can) learn from creation
4. Examples



# Bioinspired areas in civil engineering



- Structural design
- Material design
- Monitoring design
- Energetic design
- Air conditional design
- Acoustic design
- Sustainabilty desing
- Preservation design



# 1. Introduction – What is bionics?



- The term "bionics" in german is biology + technology
- 1970 ABC US Science Fiction Series "The Bionic Woman" –> artificial body parts
- Cambridge dictionary 2018:

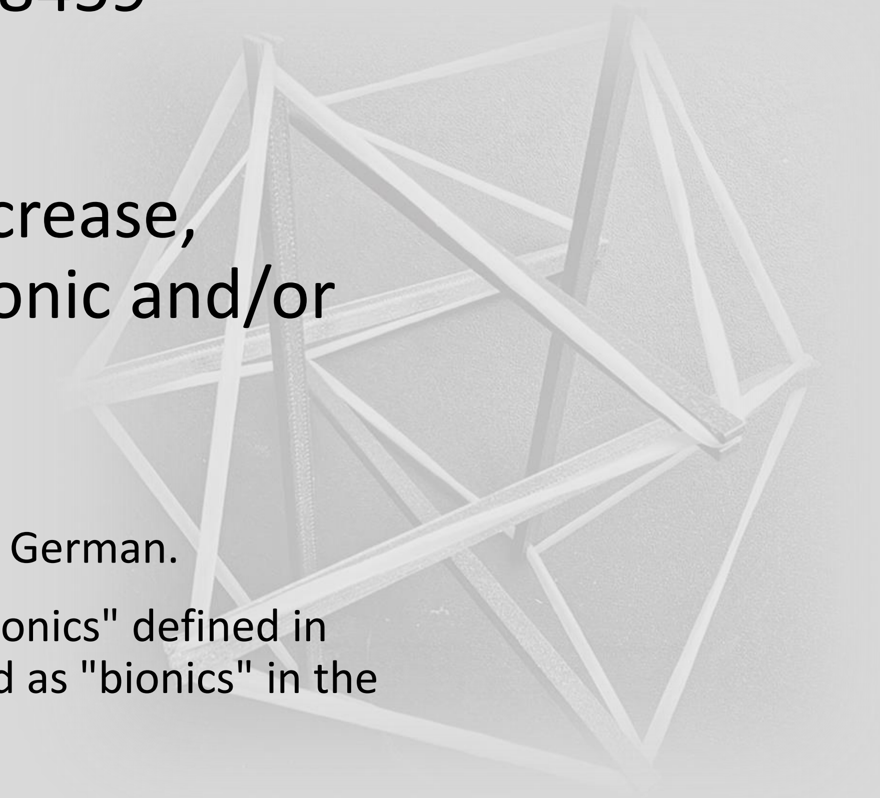
  "The science of creating artificial systems or devices that can work as parts of living organisms."

# bionics = biomimetics μίμησις (*mīmēsis*), imitation

Definition in VDI** 6220 and DIN ISO 18457-18459

## Bionics

technical discipline that seeks to replicate, increase,
or replace biological functions by their electronic and/or
mechanical equivalents.



**Note:** The term "biomimetics" defined in DIN ISO 18458 is "bionics" in German.

In order to avoid a double use of the term "biomimetics", the term "bionics" defined in ISO 18458 has therefore not been translated but has also been defined as "bionics" in the German language.

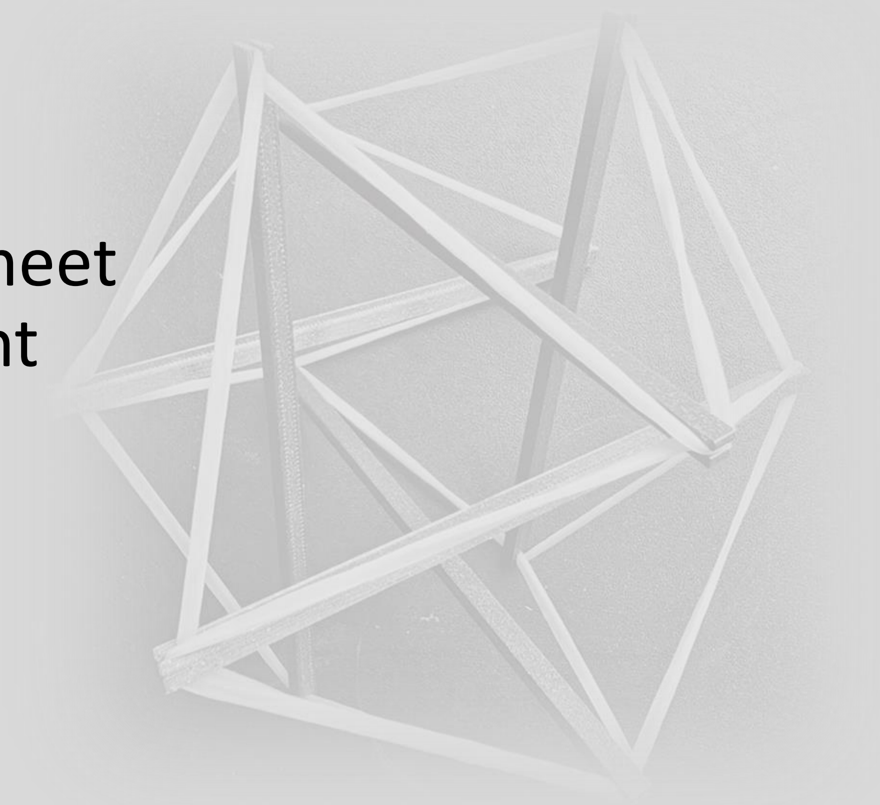
** association of german engineers

# biomimicry



- **biomimicry** (biomimetism, biomimesis)

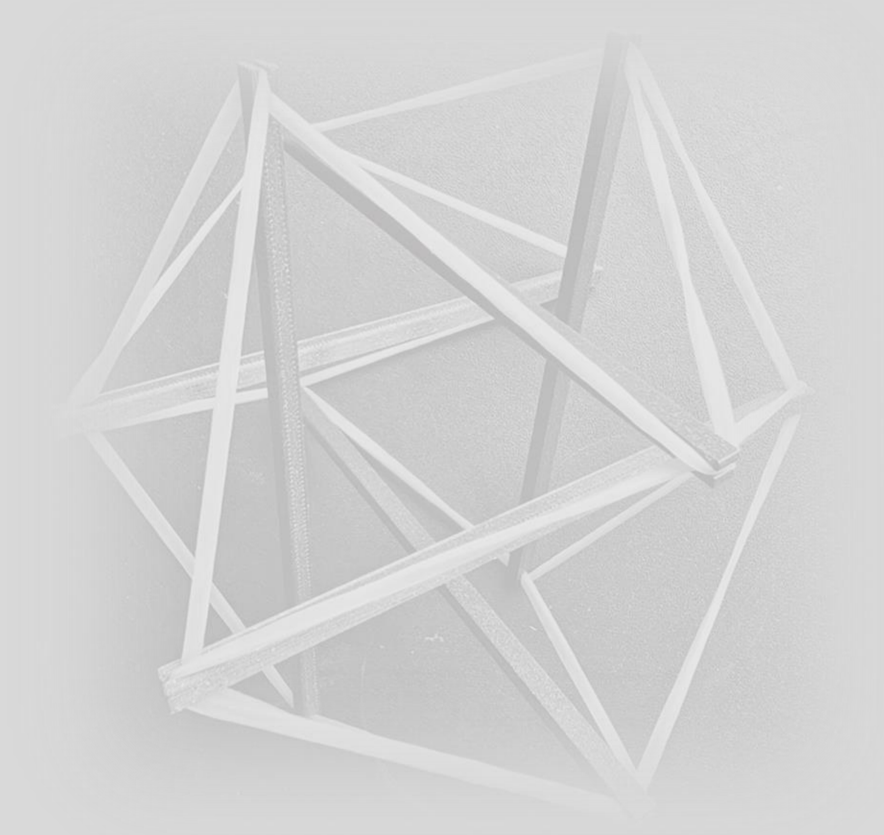
philosophy and interdisciplinary design approaches taking nature as a →model to meet the challenges of →sustainable development (social, environmental, and economic)



# The tree and its structural challenges



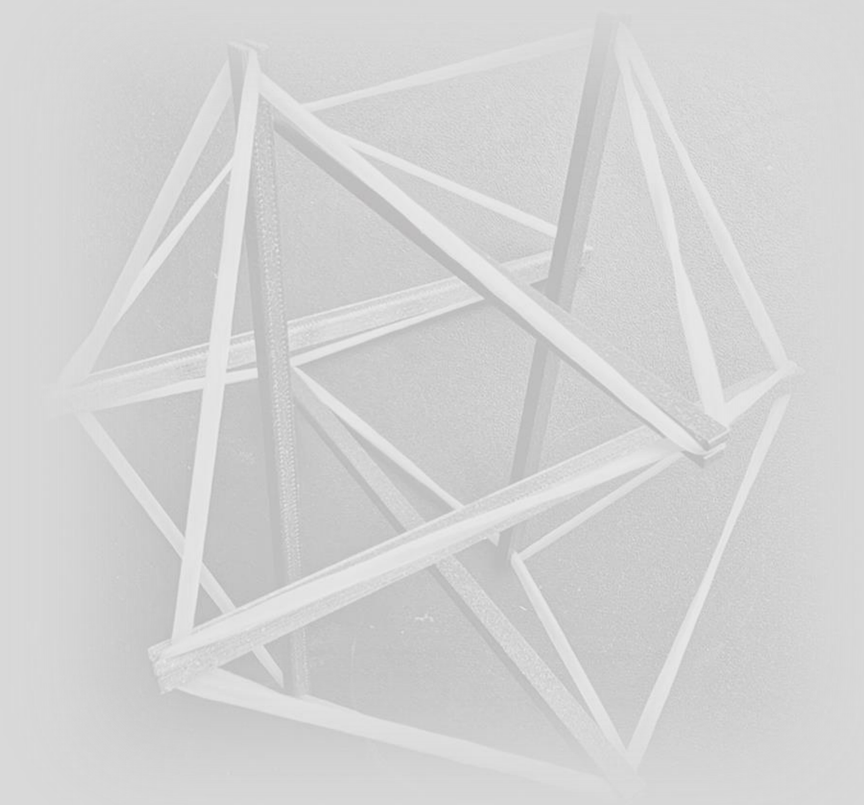
- dead load, self weight, permanent
- live load, not permanent -> fruit, leaves
- wind loads, not permanent
- snow and ice loads, not permanent
- thermal loads (winter, summer), varying
- dynamic loads i.e. earthquake



# Structural mechanics - basics



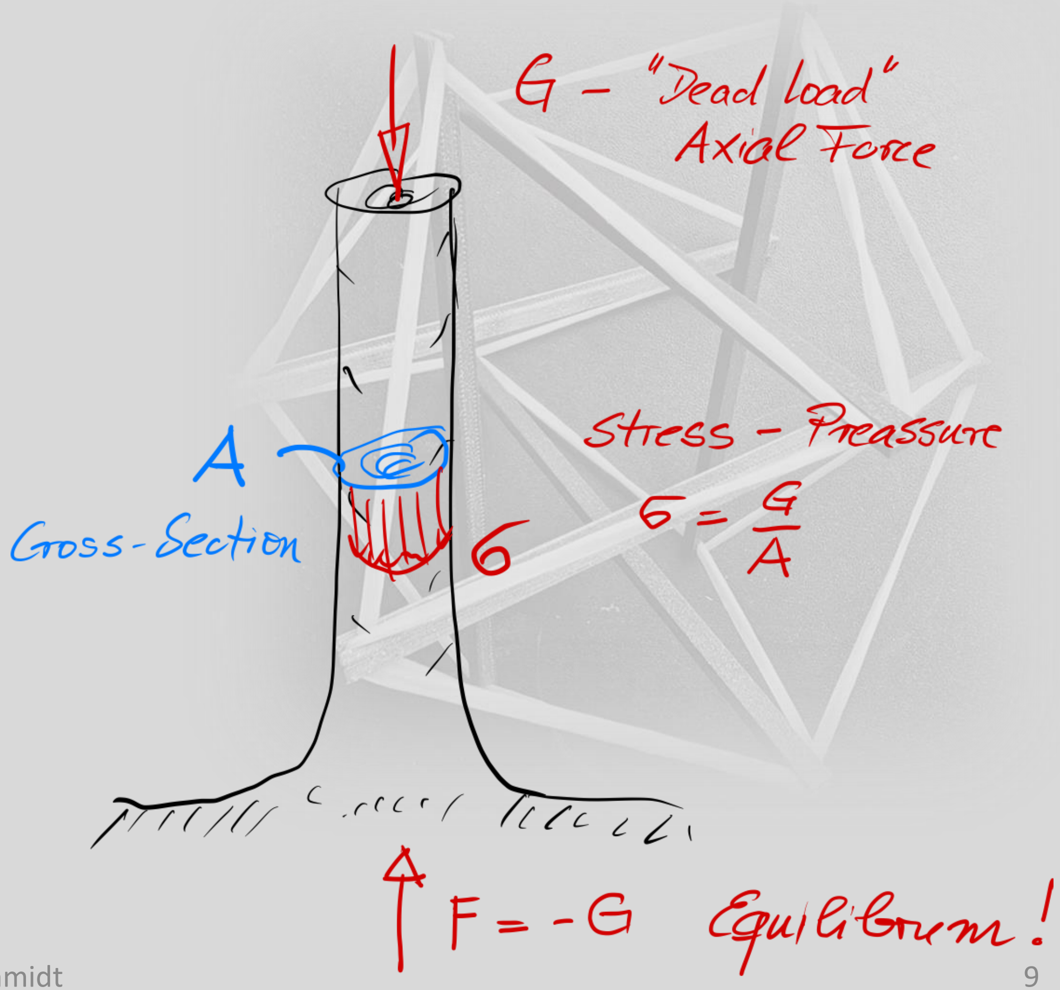
- Gravitiy
- Equilibrium
- Forces-> deformations
- Stresses-> strains



# The tree and its structural challenges

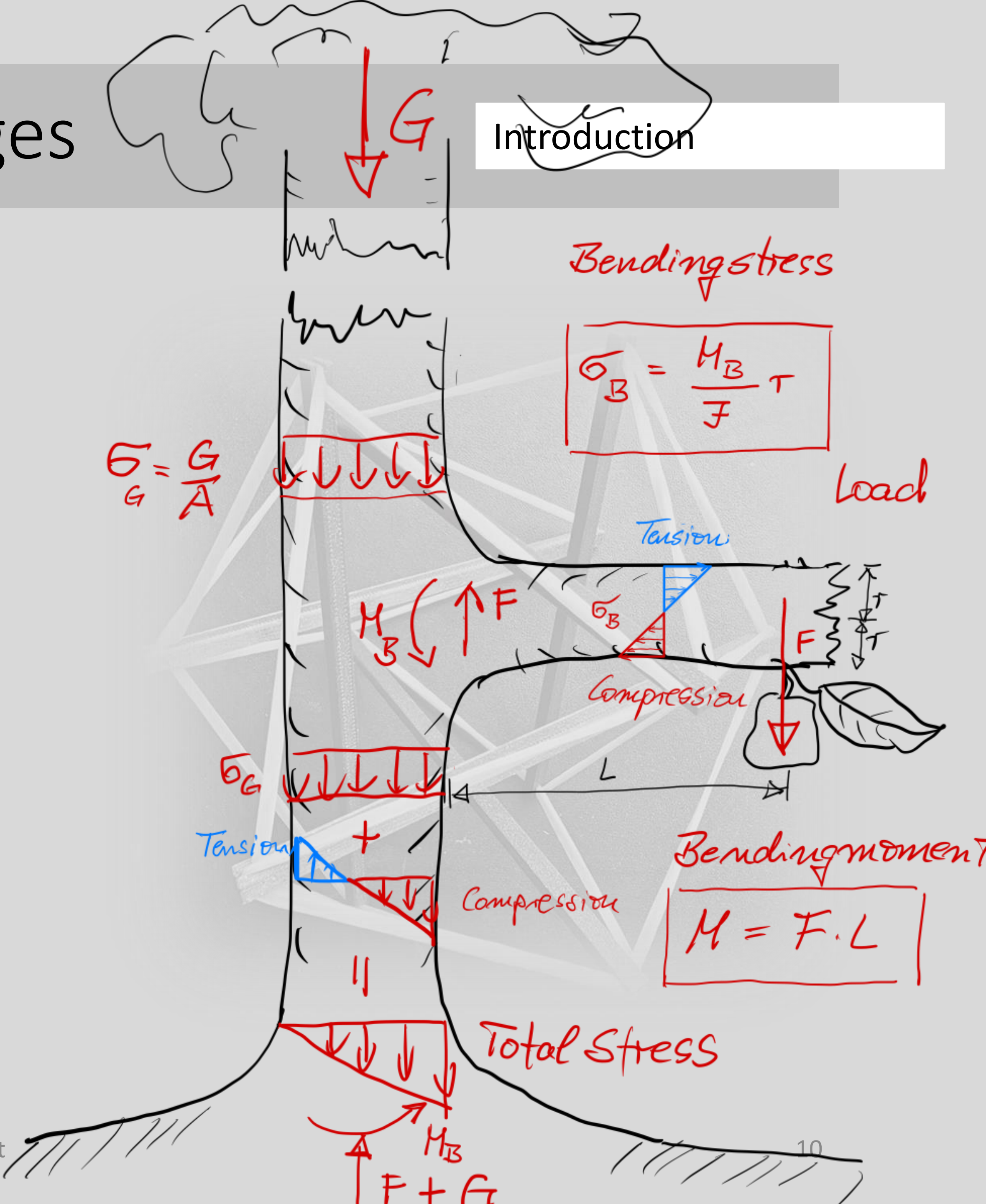


- Dead load, self weight, permanent

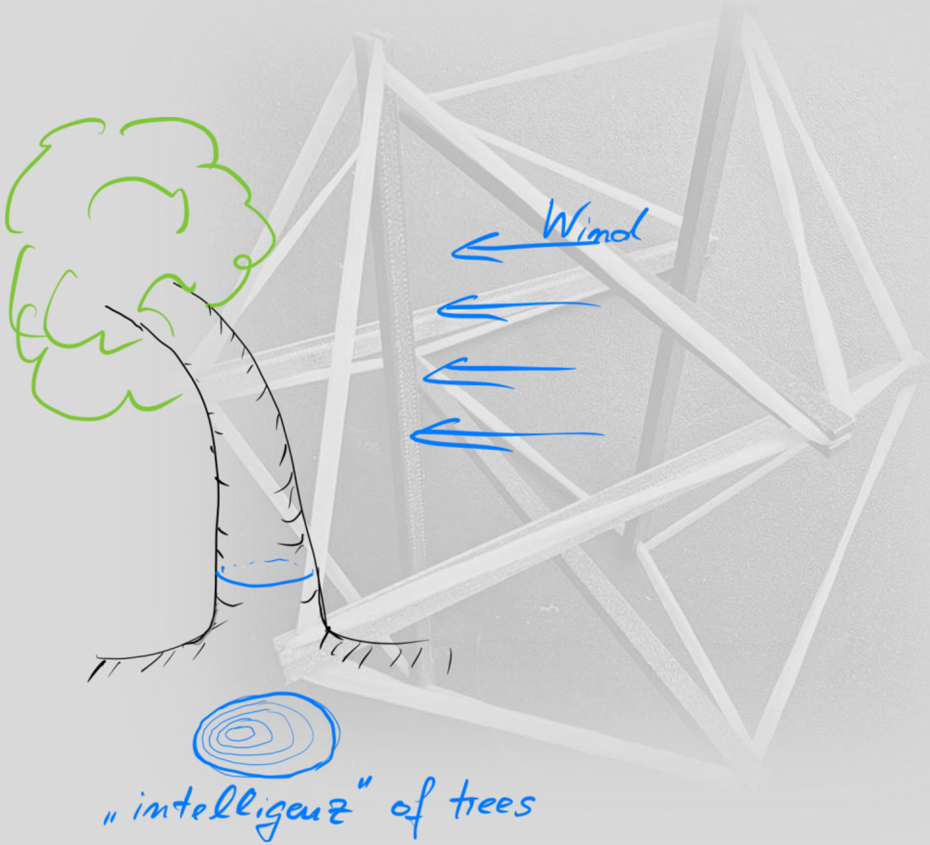
# The tree and its structural challenges

- live load - fruit, leaves, birds, cats, …



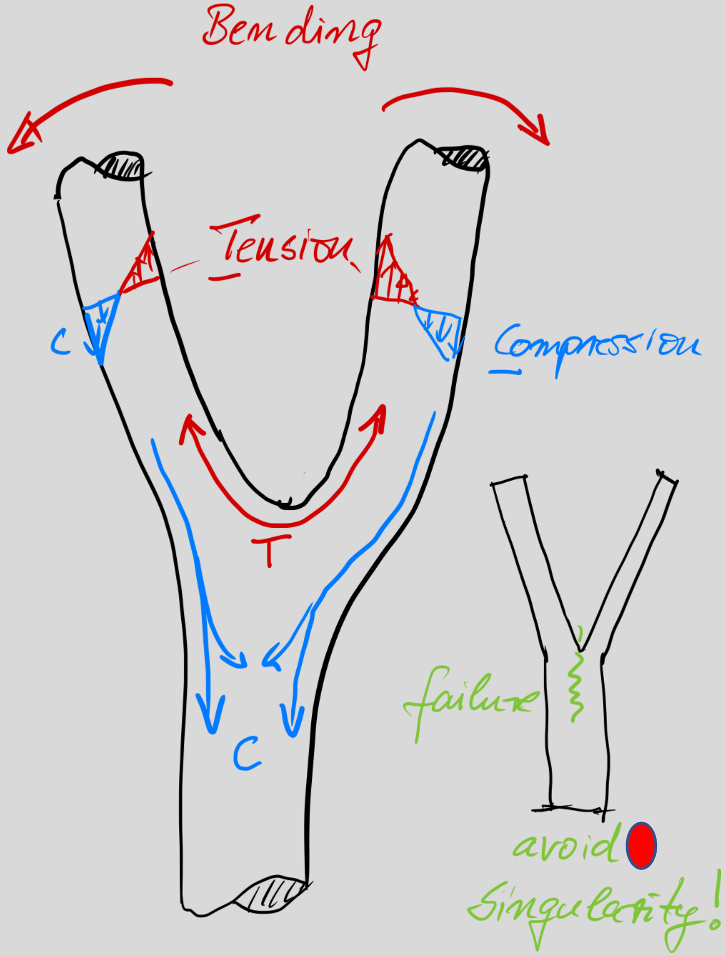
# The tree and its structural challenges

- wind loads

# What we learn from trees - the axiom of uniform stress



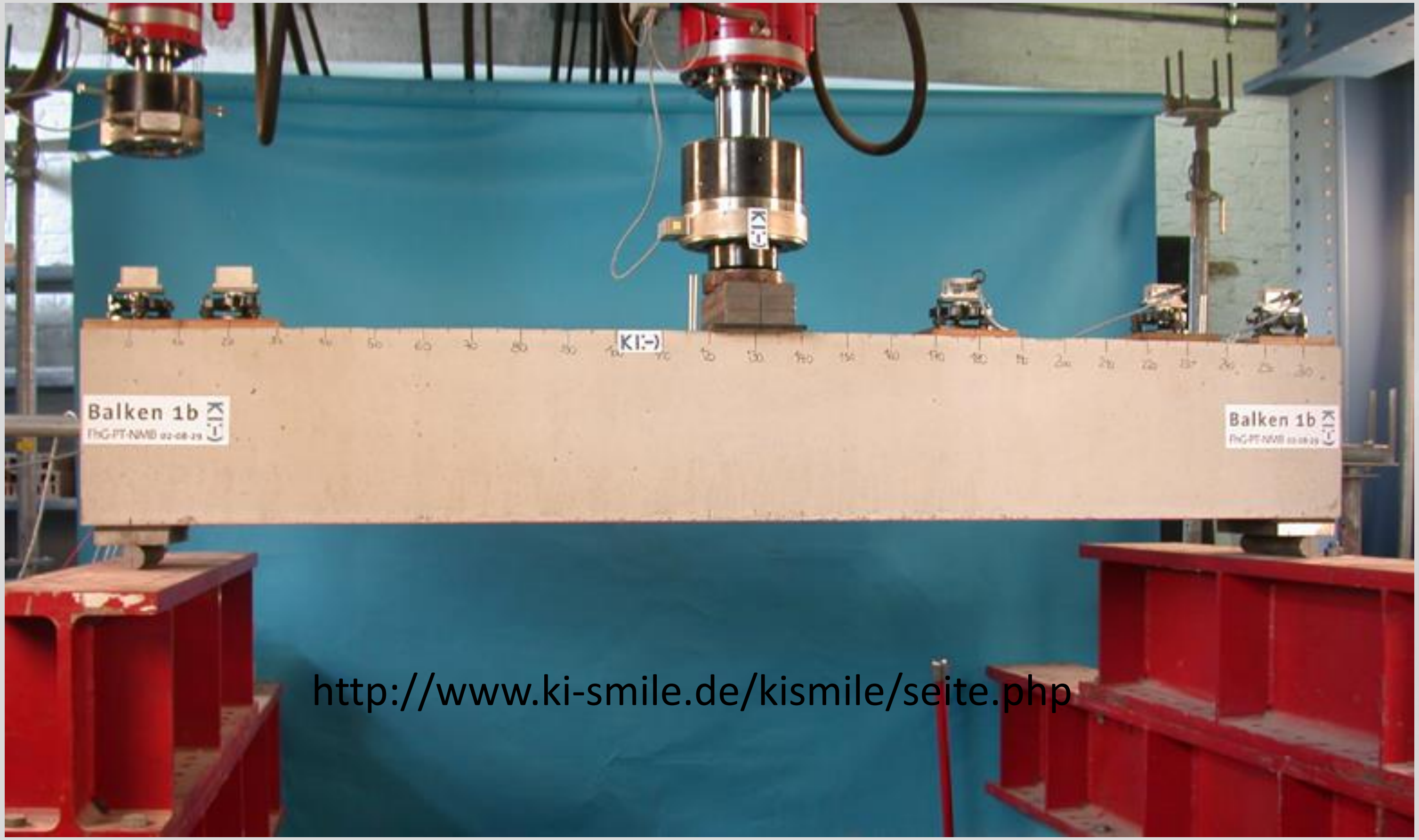



Adaptive growth reduces stress-concentrations on the surface. Unavoidable stresses are distributed evenly on the surface of a tree

The mechanical self-optimisation of trees
C. Mattheck & I. Tesari
Institute for Materials Research II, Forschungszentrum Karlsruhe GmbH, Germany

# A beam and its structural challenges

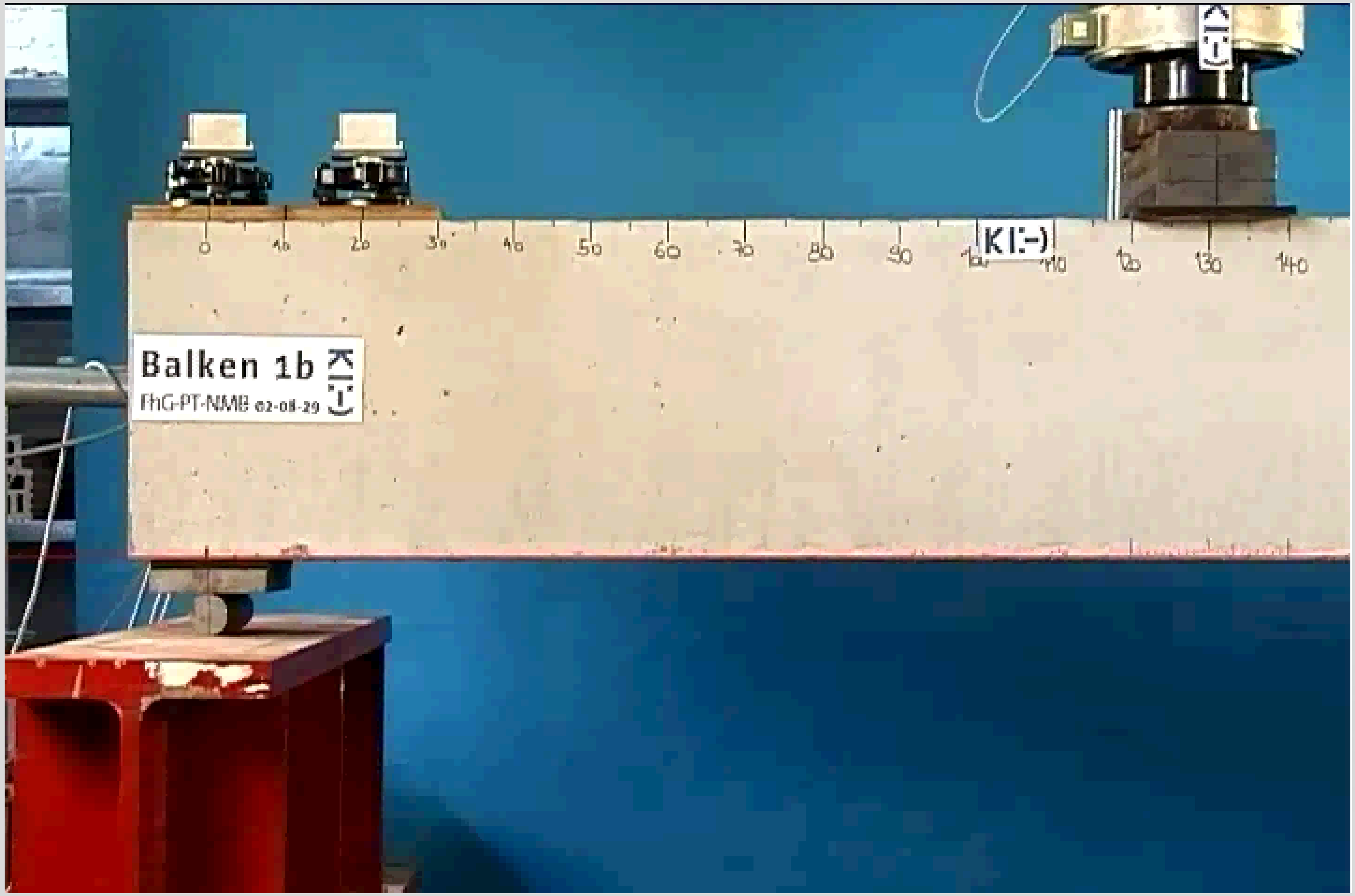
Introduction

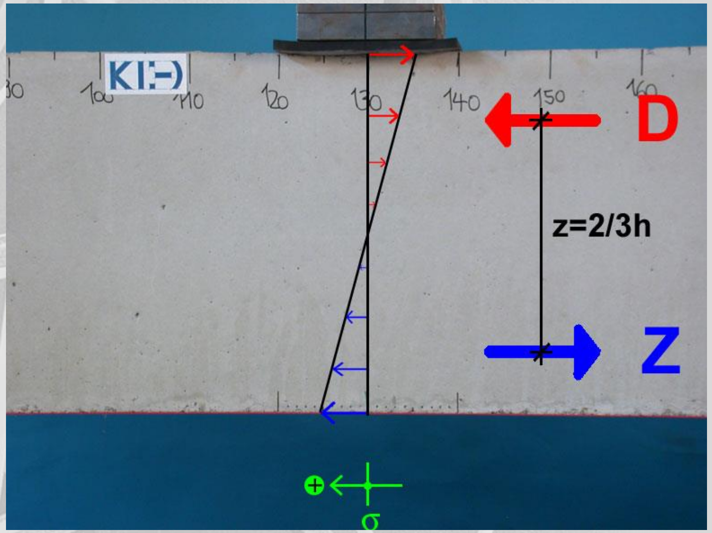



http://www.ki-smile.de/kismile/seite.php

# Beam bending failure

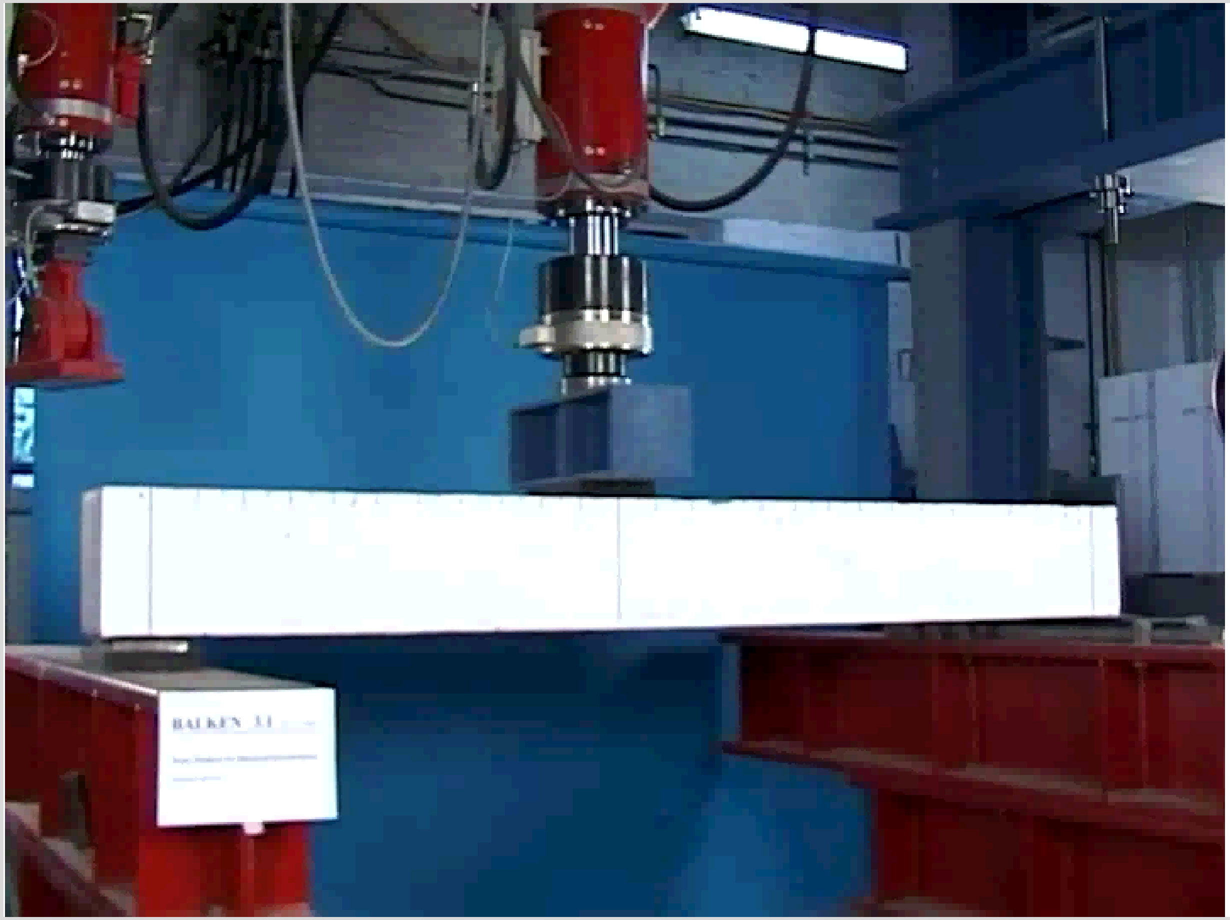


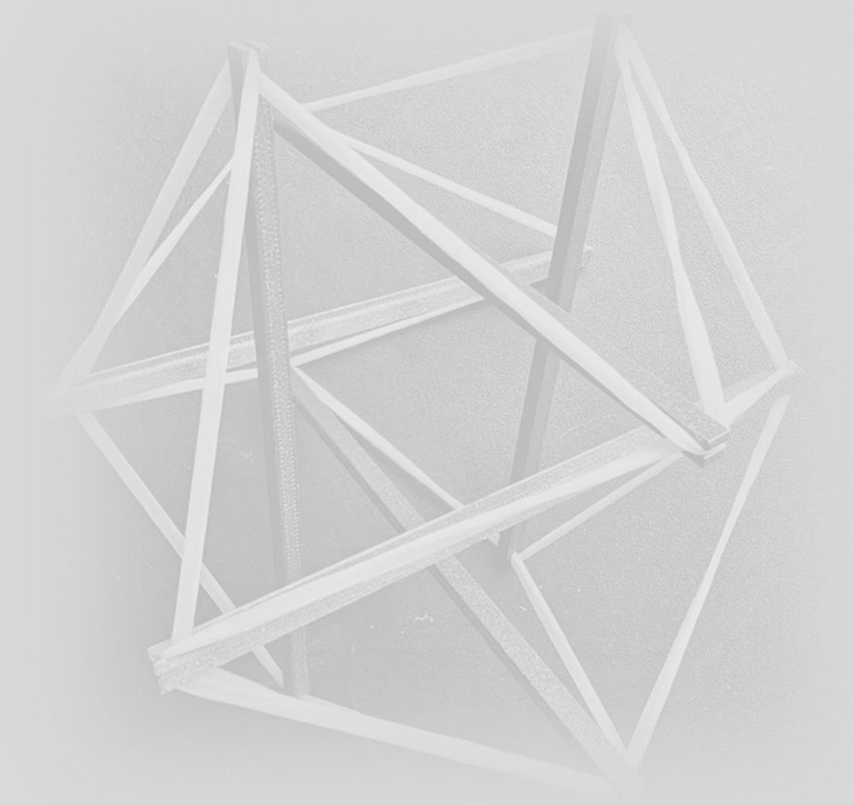


# Beam shear failure

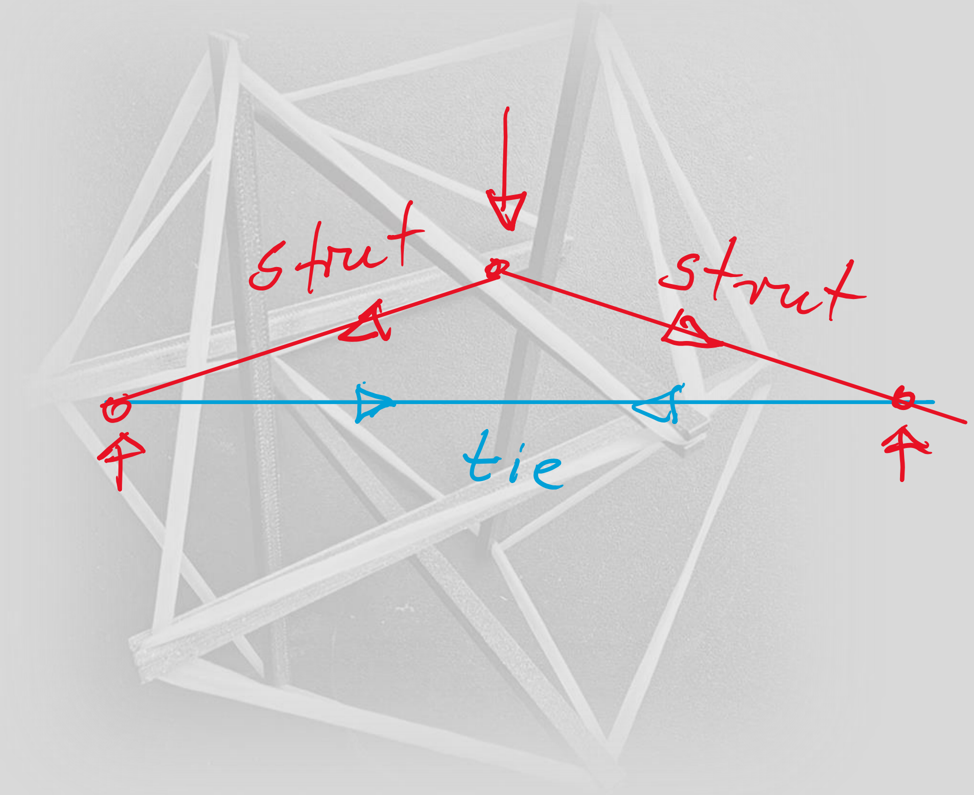
Introduction





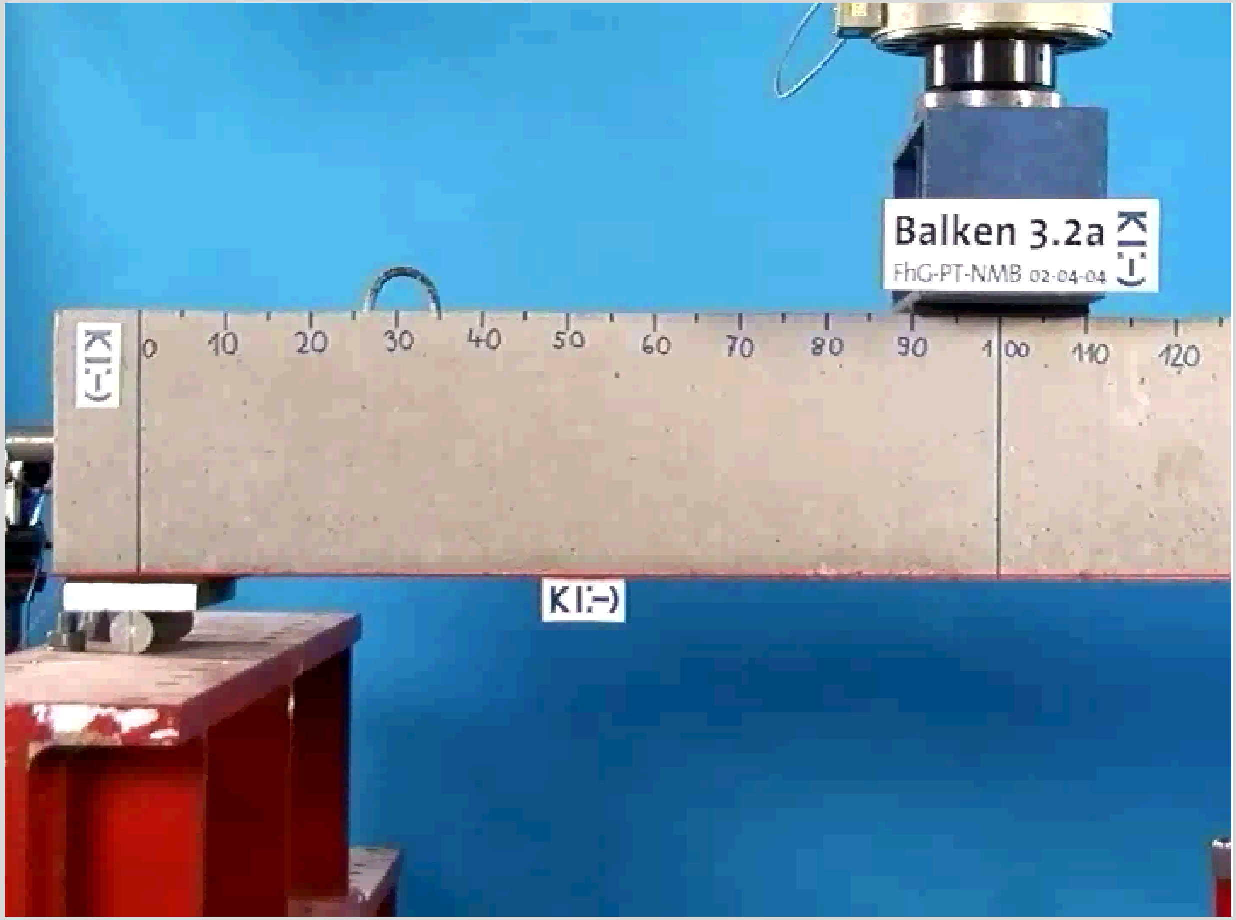
# Simplified mechanical truss model





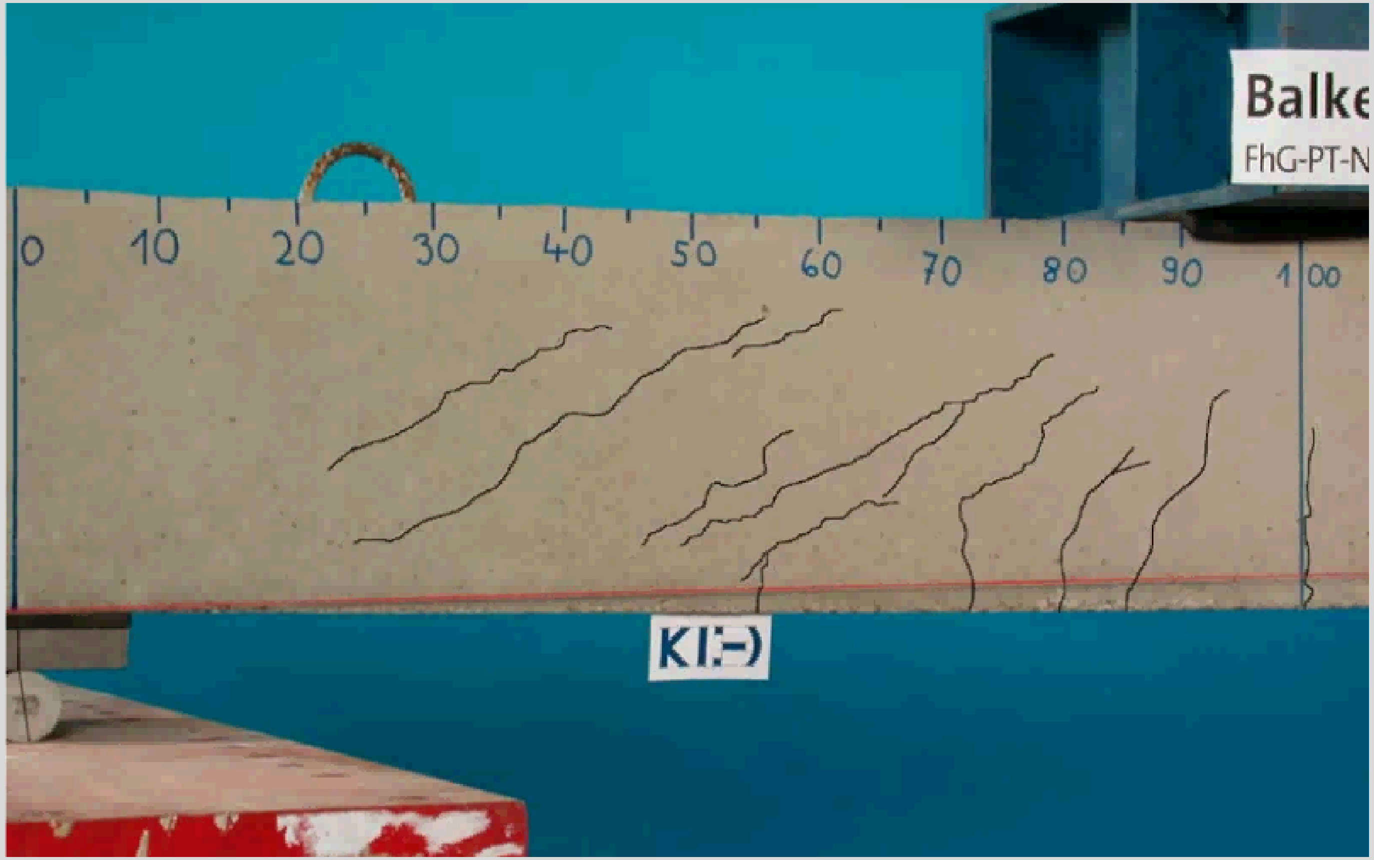
# Beam shear failure prevented

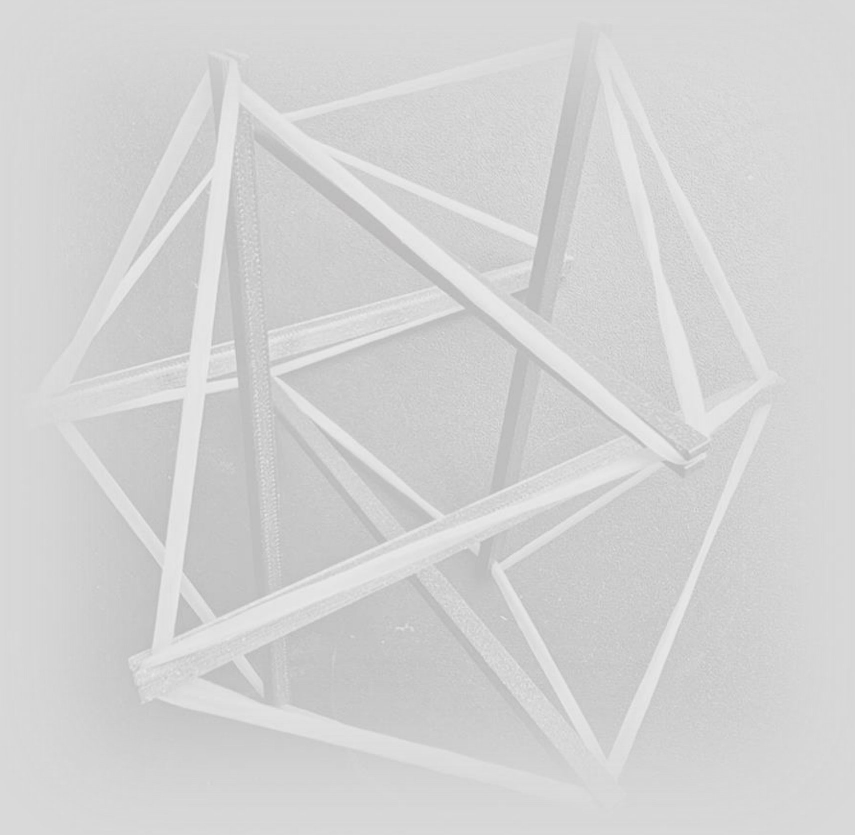




# Simplified final truss model

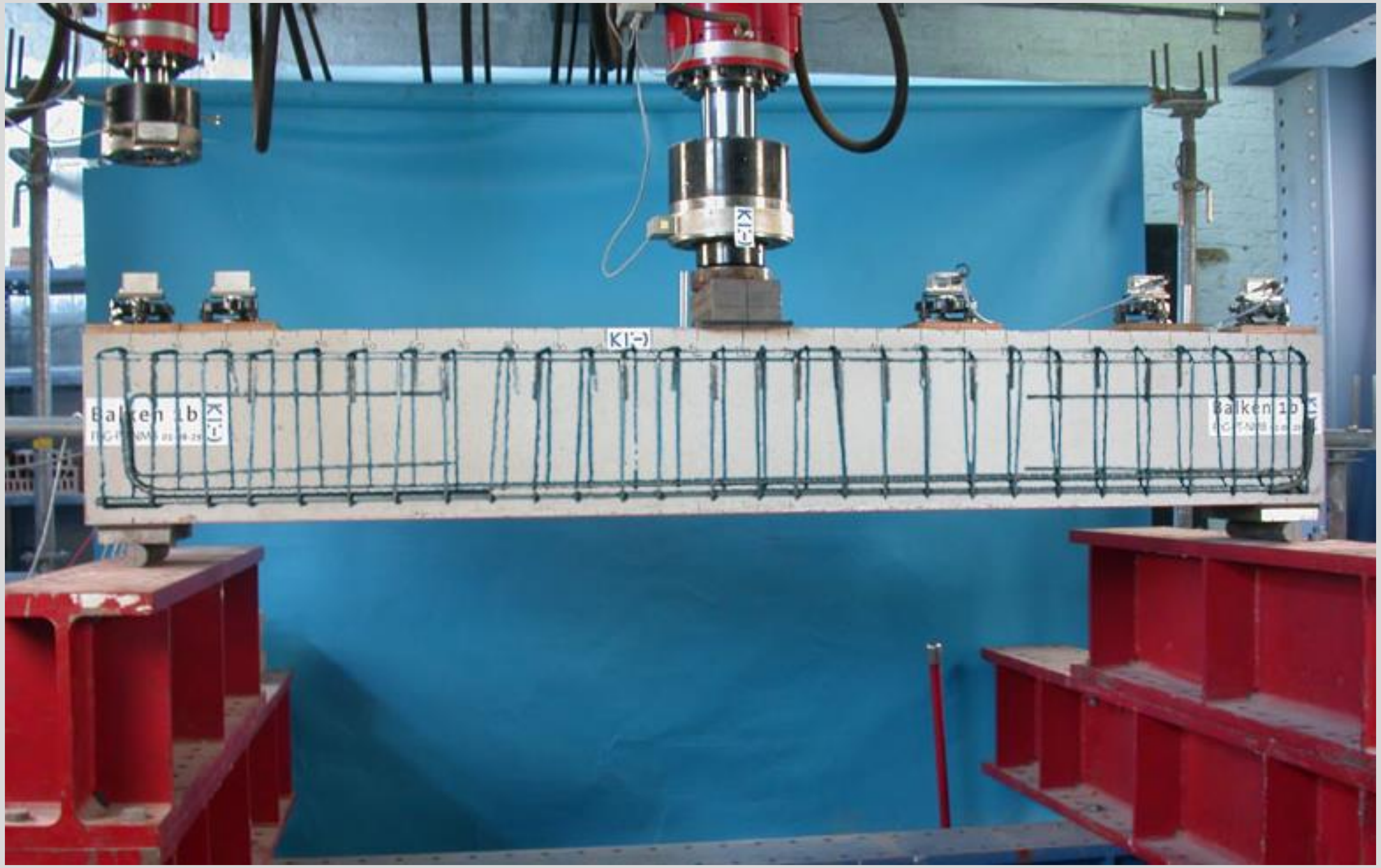




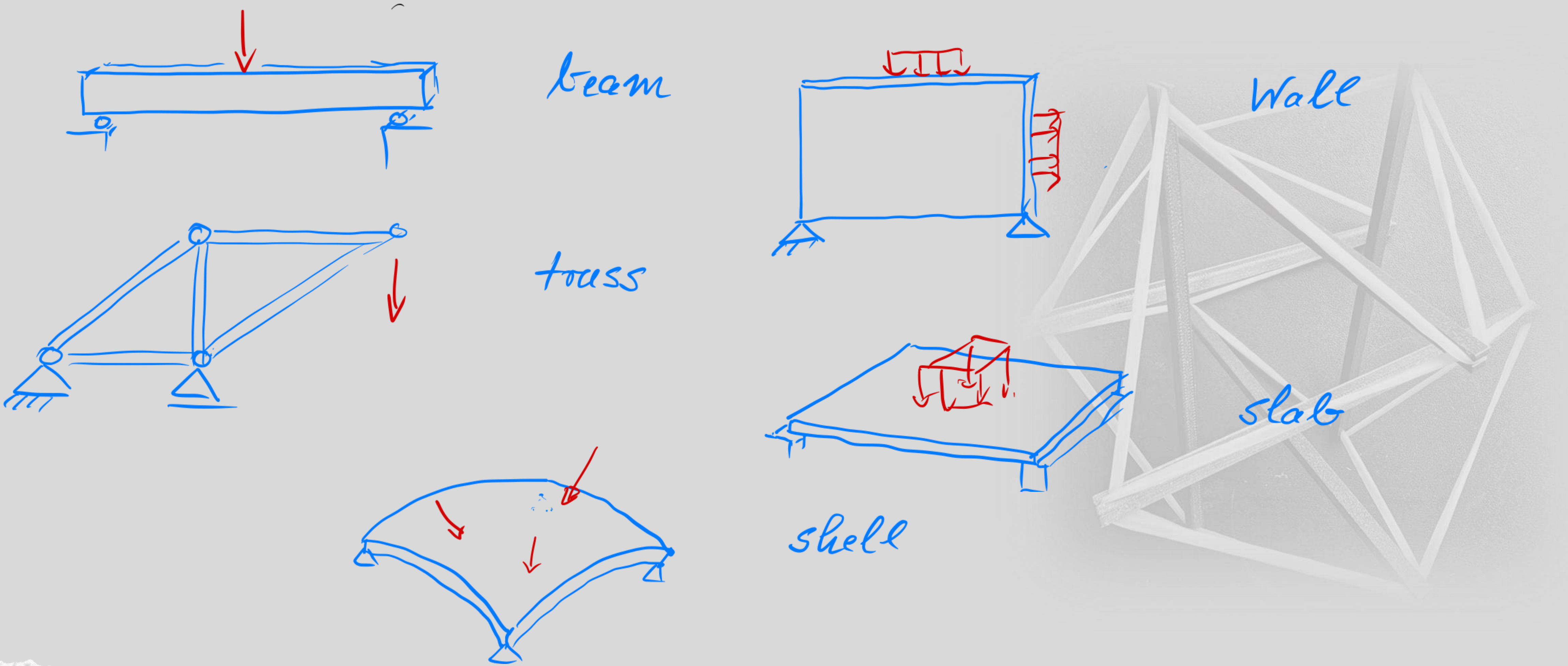
# bio-inspired beam strengthening





# Basic structural elements





# 2. Personal contact with bionics

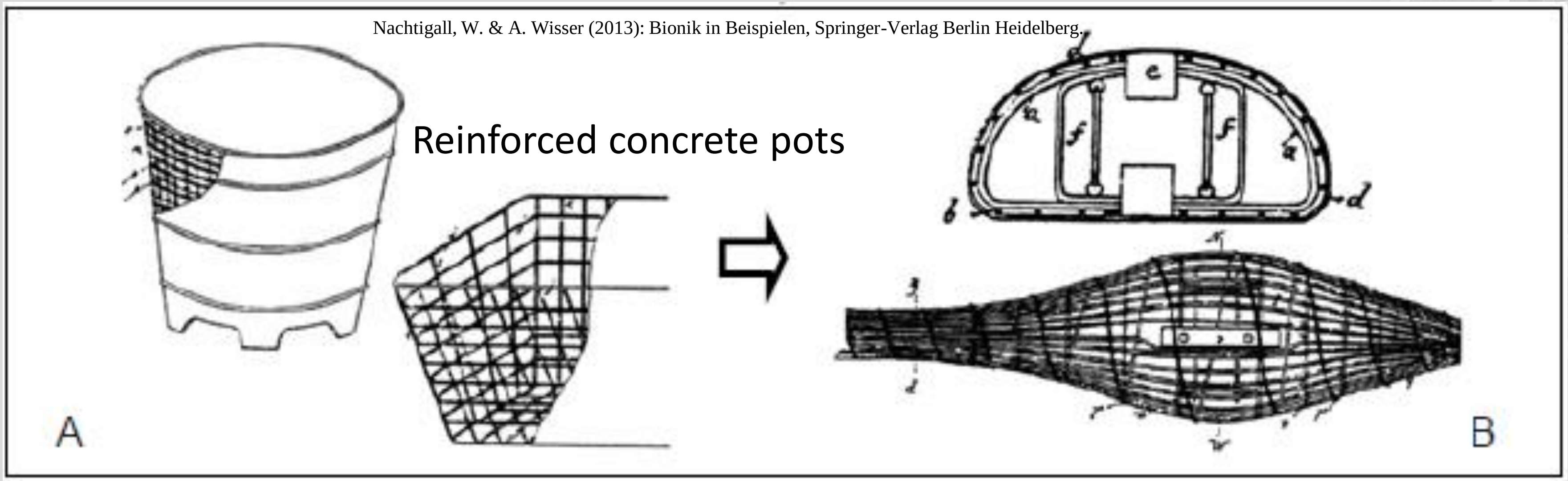


- Joseph Moniers – reinforced concrete
- Heinz Isler – shells
- A. Baumgartner, Claus Mattheck – tiger claw
- Nervous system – health monitoring

# Reinforced concrete

Personal contact

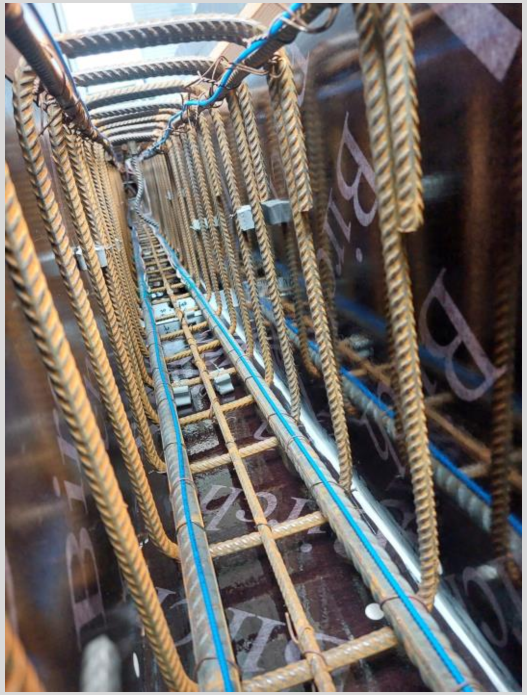
- A bionic product!?
- Who invented it?
- Joseph Monier 1867

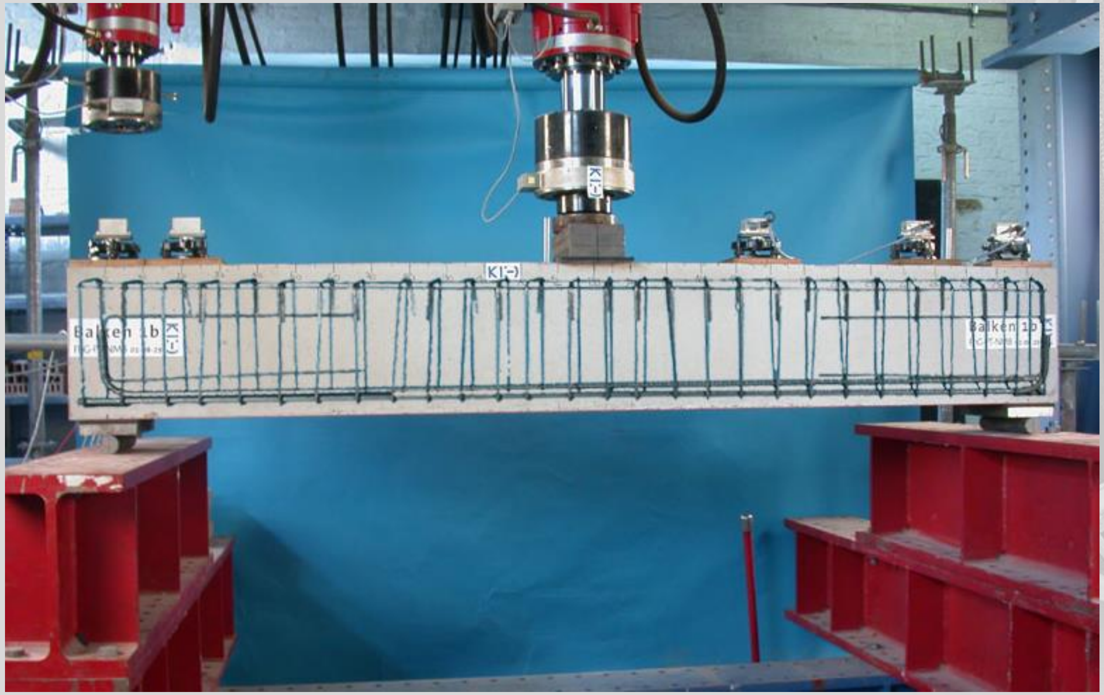



# Health monitoring

Personal contact

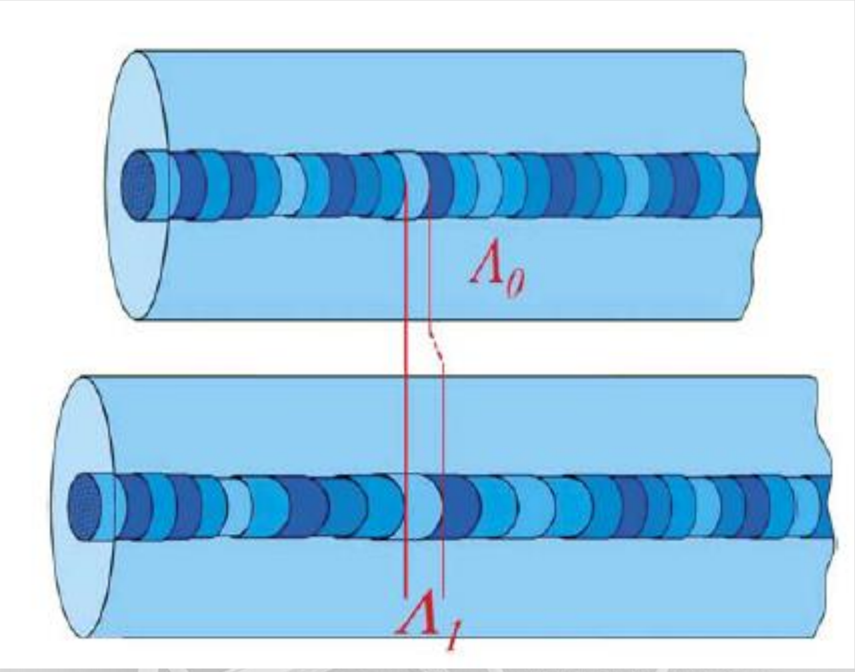
## Reinforcement with fiberoptic "nervous system"





# Road surface "nervous system"

Personal contact

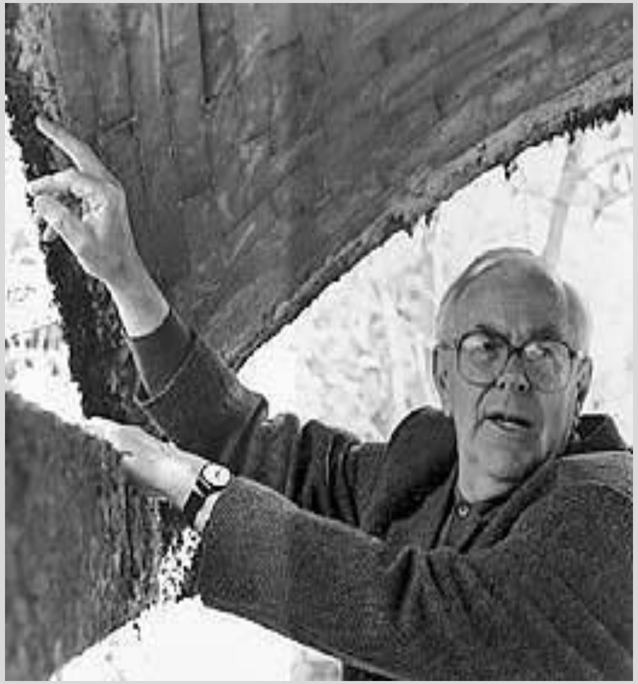

Based on rayleigh scattering measuring changes in refraction along a fiber with an optical frequency domain reflectometer (OFDR)

# Isler – learning from cabbage leaves

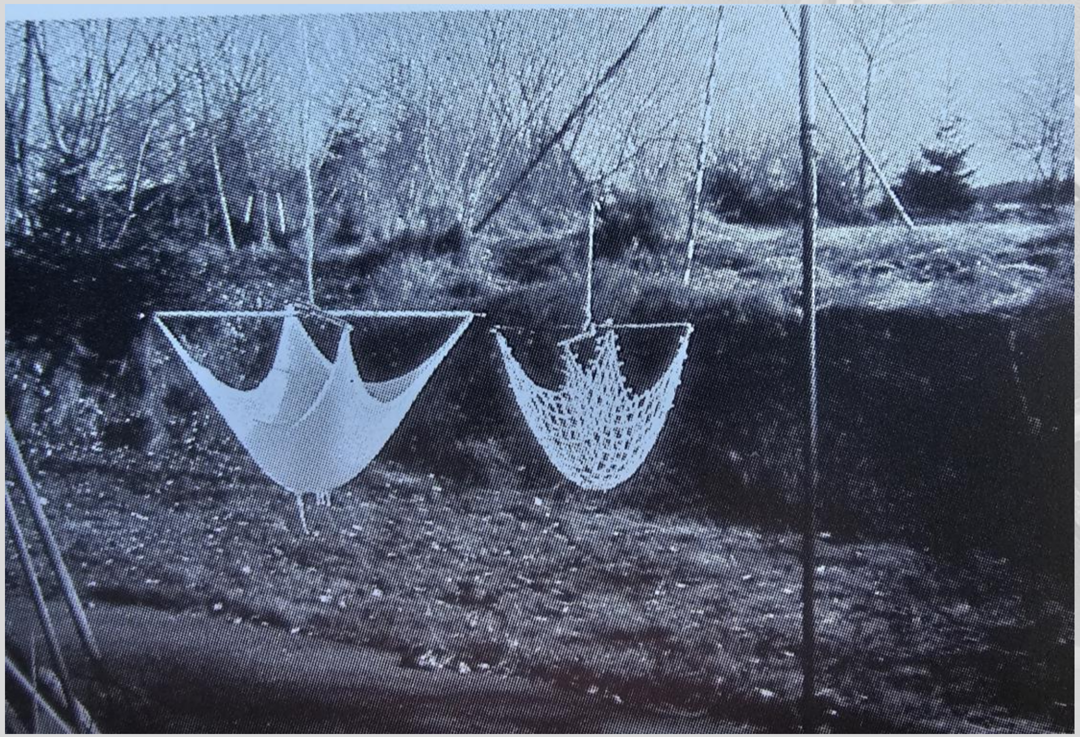
# Isler – sheets/nets

Personal contact

- Isler explaining his "sheets analogy" – ice shells



https://www.db-bauzeitung.de/allgemein/heinz-isler-1926-2009/

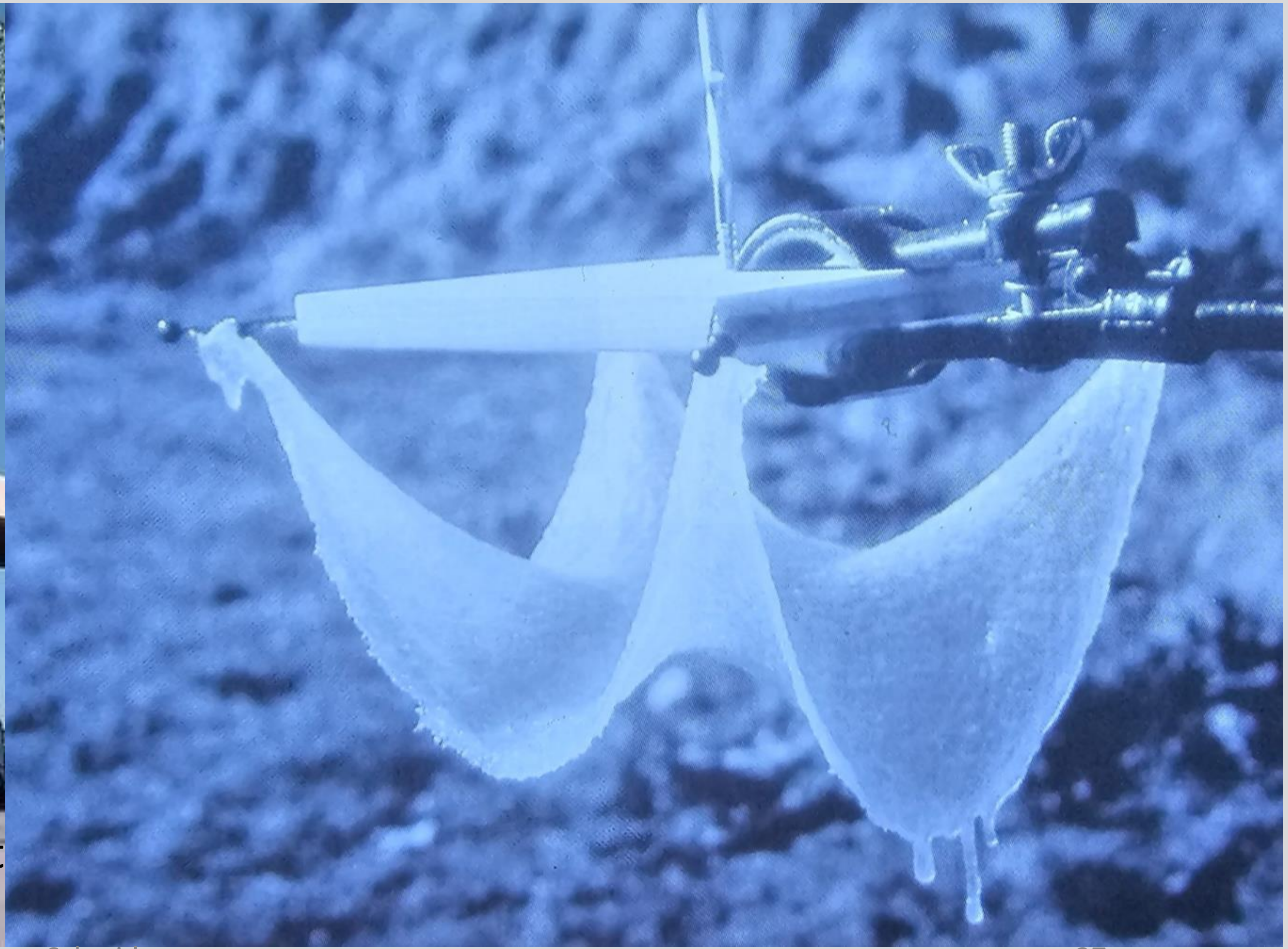


sheet + gravity + water + temperature = shell structure

# Isler Shell

Personal contact


https://www.bernerzeitung.ch/die-stararchitekt
tankstelle-336064100917



# What we (can) learn from a tiger claw

Personal contact

ELSEVIER

International Journal of Fatigue
Volume 14, Issue 6, November 1992, Pages 387-393

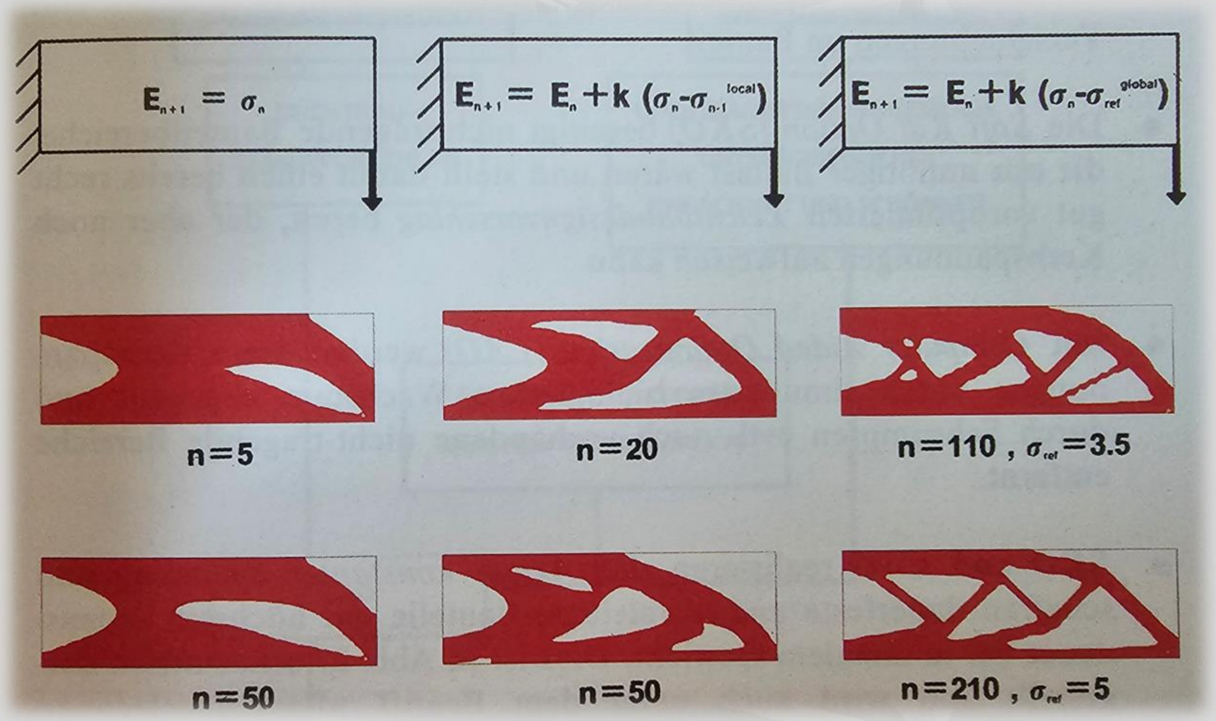
## SKO (soft kill option): the biological way to find an optimum structure topology

A. Baumgartner, L. Harzheim, C. Mattheck

# creation – optimization

Personal contact

Soft kill optimization (iterative process)

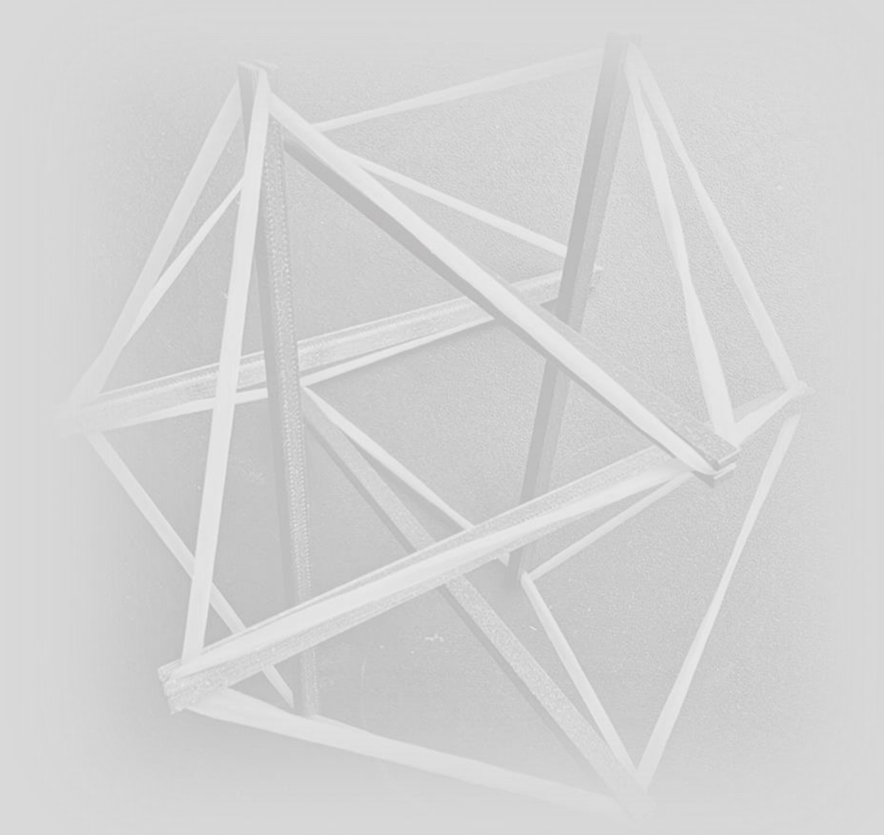


# How we (can) learn from creation



Systematic/Engineering approaches

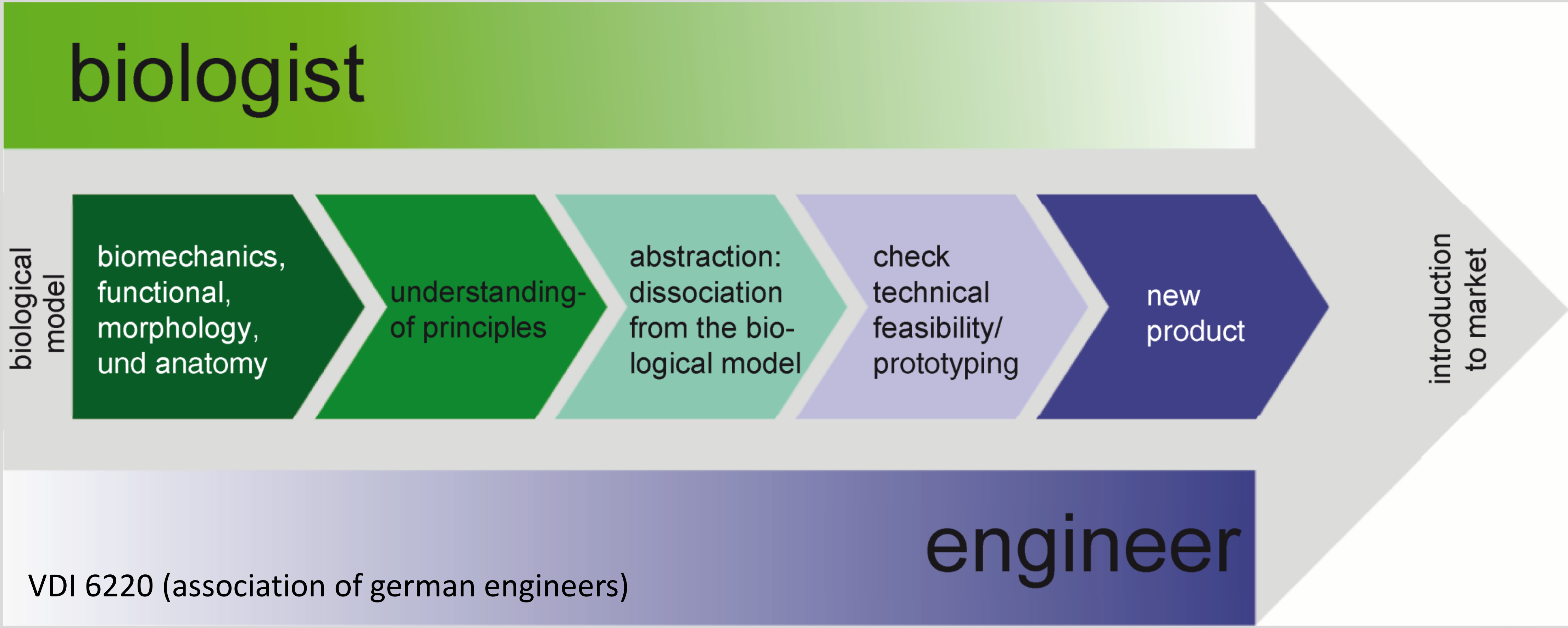
1. Biology push – bottom up
2. Technology pull – top down



vdi association of german engineers

# Biology push – top down

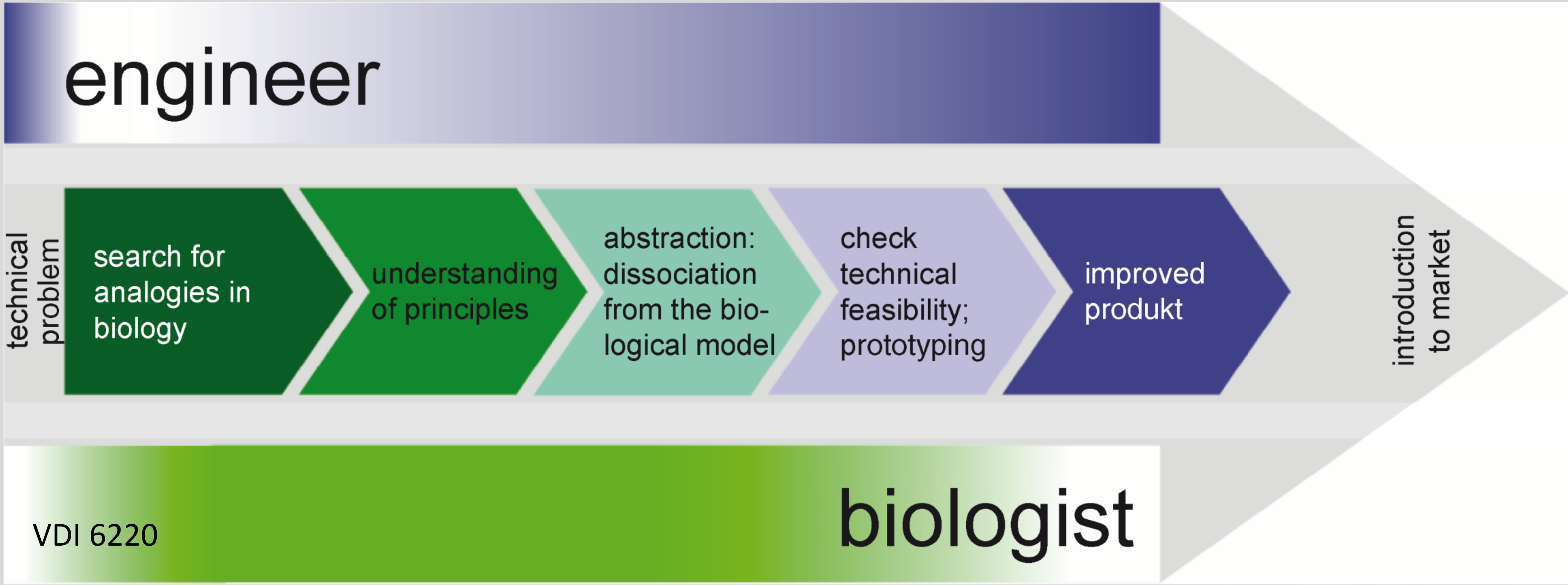
How we (can) learn




*Speck, T.*; *Harder, D.*; *Milwich, M.*; *Speck, O.*; *Stegmaier, T.*: Bionik: Die Natur als Innovationsquelle. – In: *Knecht, P.* (Hrsg.), Technische Textilien, 83 – 101. Deutscher Fachverlag, Frankfurt, 2006

# Technology pull – bottom up

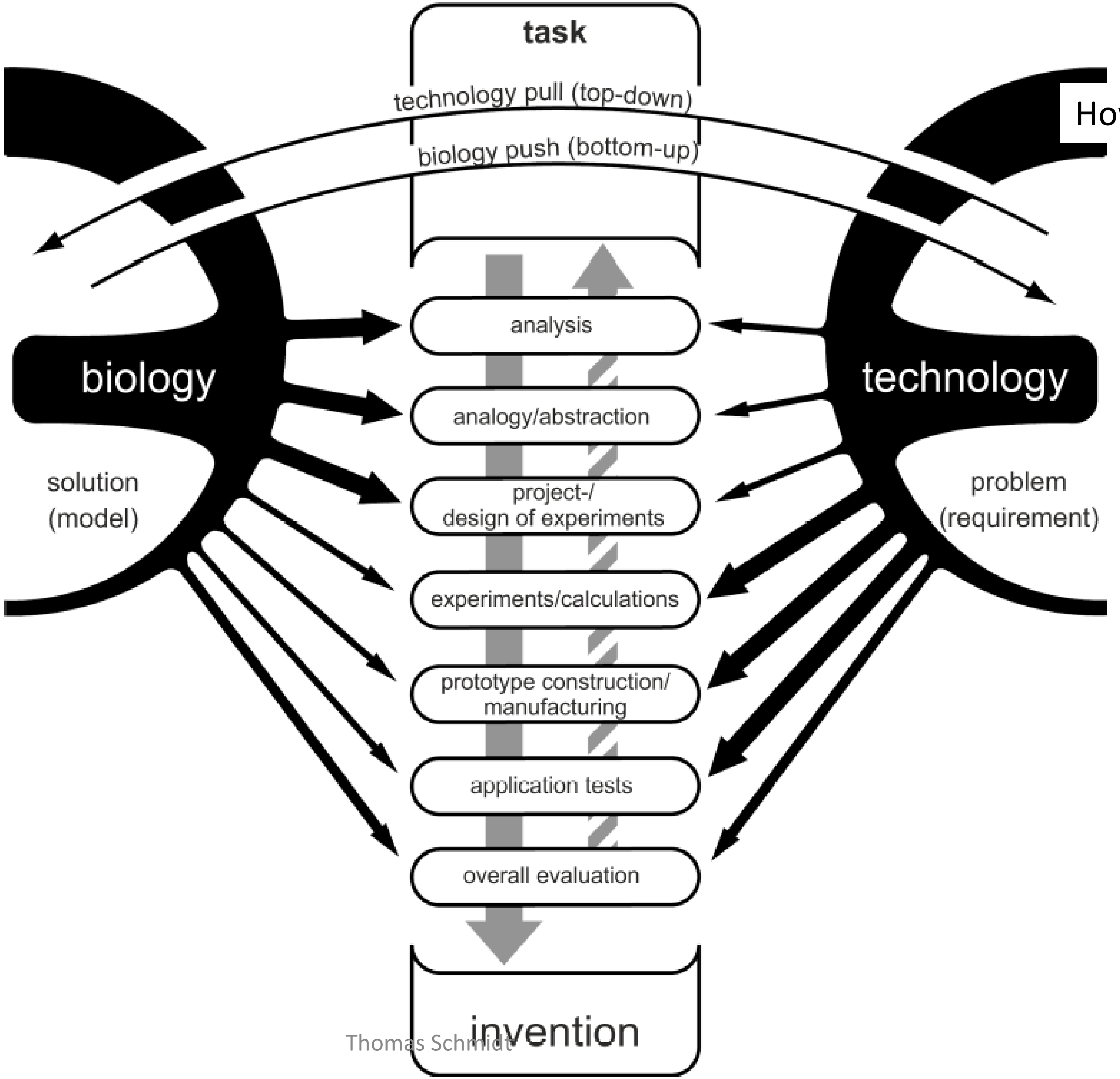
How we (can) learn




*Speck, T.*; *Harder, D.*; *Milwich, M.*; *Speck, O.*; *Stegmaier, T.*: Bionik: Die Natur als Innovationsquelle. – In: *Knecht, P.* (Hrsg.), Technische Textilien, 83 – 101. Deutscher Fachverlag, Frankfurt, 2006

# Bionic method

How we (can) learn



# Criteria of a bionic product

1. The technical application must have a biological model.

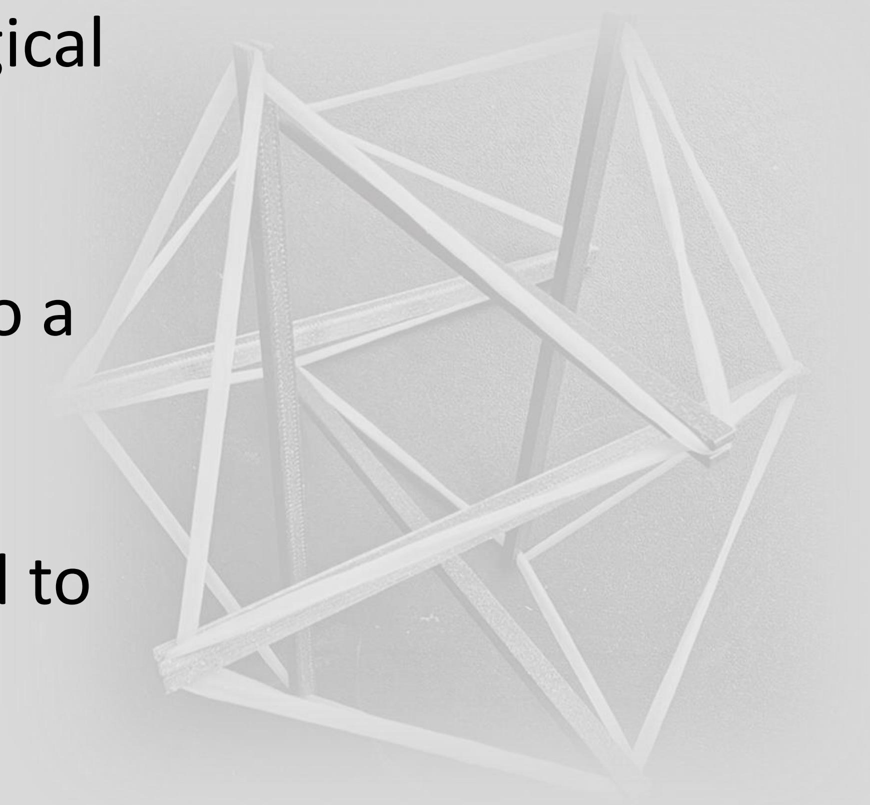
2. The biological model must have been abstracted.

3. The transfer to at least a prototypical application must have taken place.

# Biomimetic development process

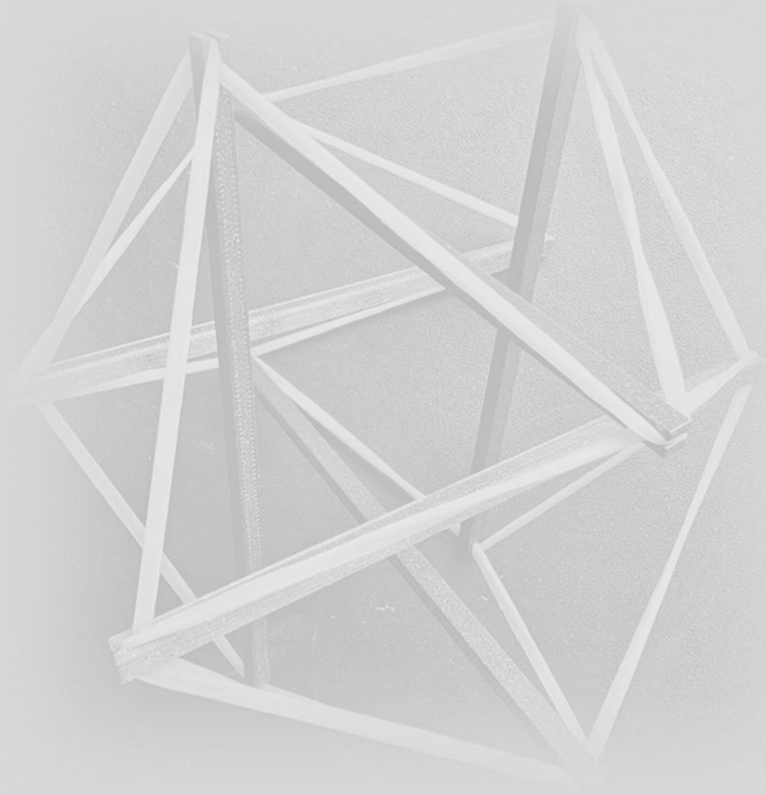


- **Step 1:** A shape-function analysis of a biological system is carried out (analysis).
- **Step 2:** The biological system is abstracted to a model (abstraction).
- **Step 3:** The model is transferred and applied to develop a solution or product (application).



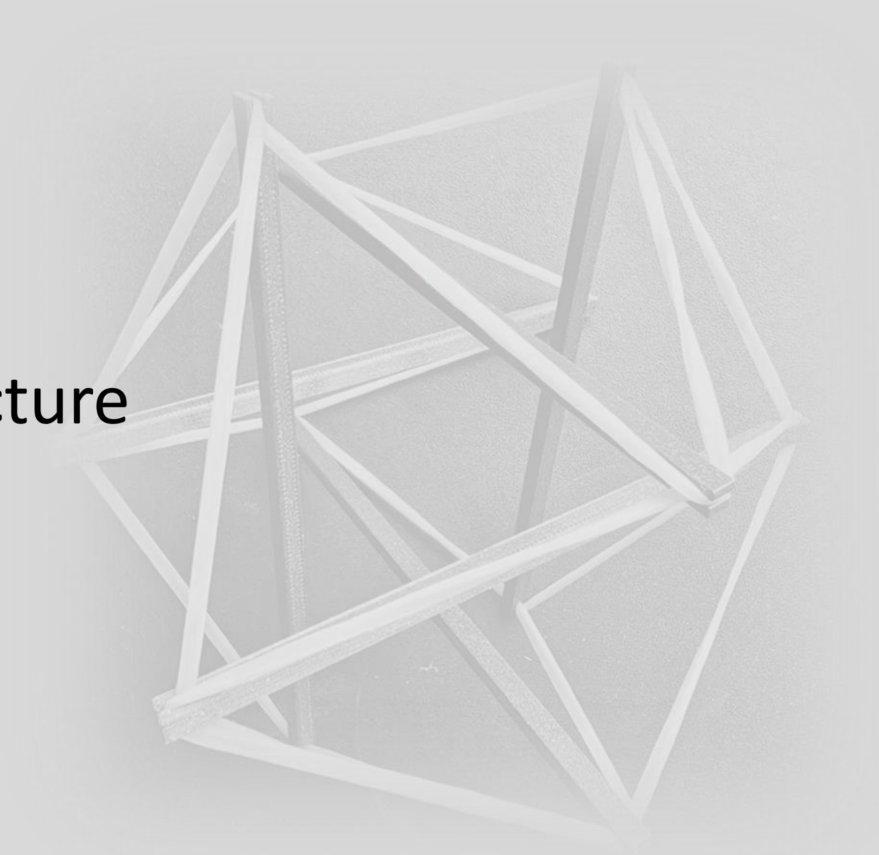
# ELisE a tool for lightweight optimization

How we (can) learn

# 4. Examples

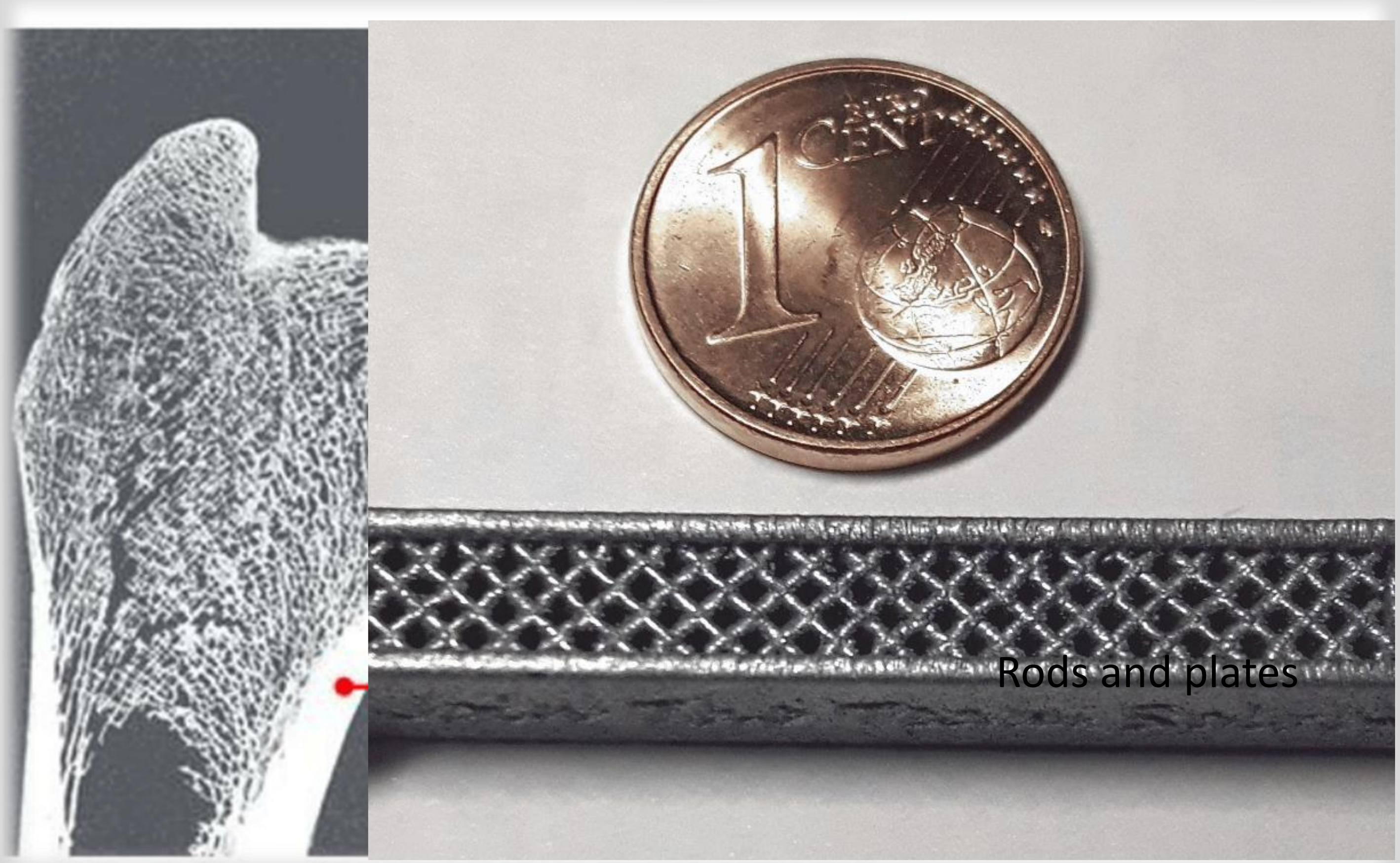
- The Eiffel Tower a "bone clone"
- "The Wonder of Jena"
- The Eden Project – sea urchins "on shore"
- The Kurilpa Bridge – a tensegrity cell structure
- Excavator arm vs. spider leg



# Eiffel Tower

Examples

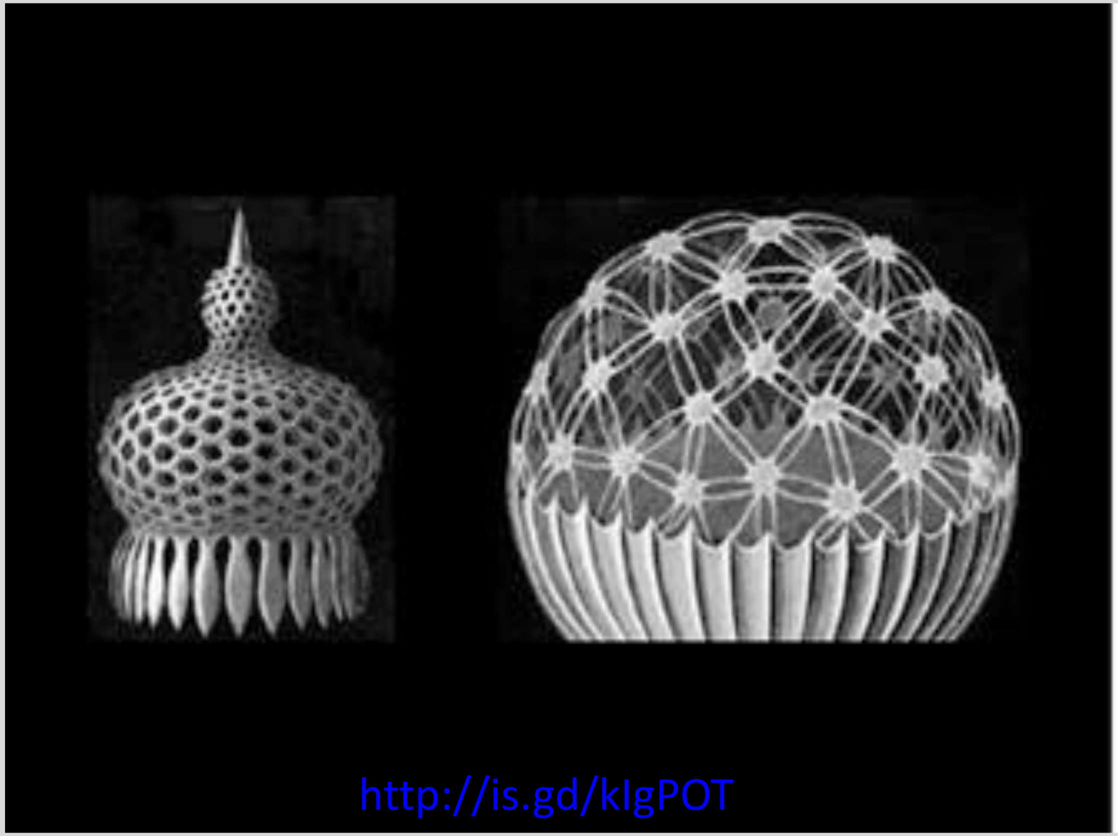
constructed from 1887 to 1889 as the centerpiece of the [1889 World's Fair]



Rods and plates

# The Wonder of Jena

Examples



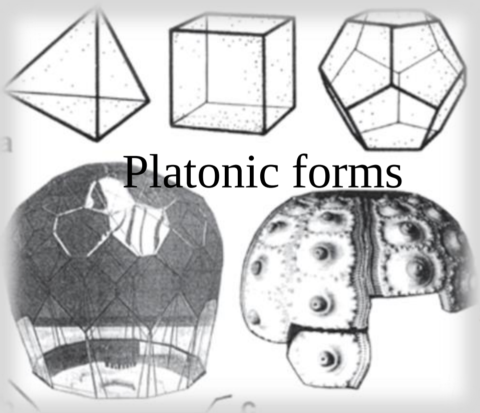

Ernst Haeckel and his *Art Forms in Nature*


photograph from a commercial postcard

Strength, stability, material efficiency, versatility, energy efficiency, scalability

# The Eden Project

Examples



Platonic forms

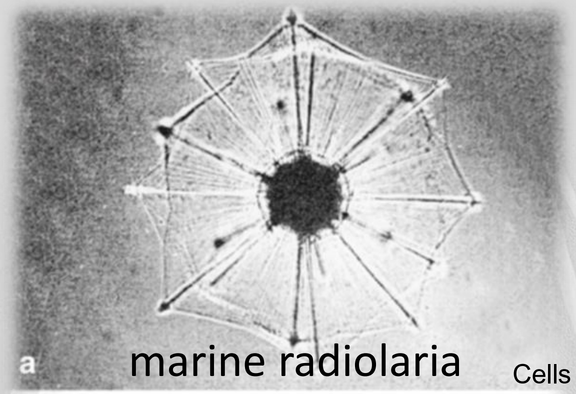
sea urchins

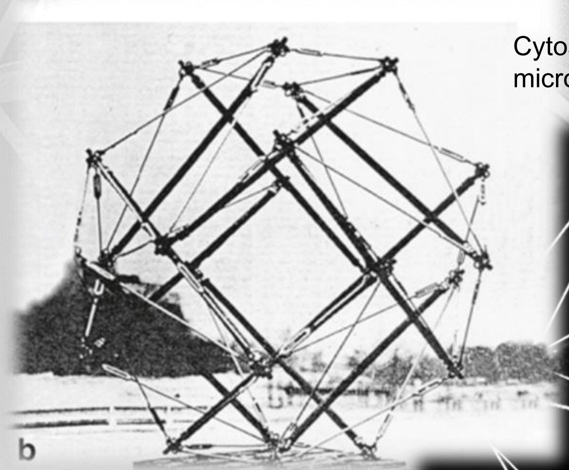
https://upload.wikimedia.org/wikipedia/commons/thumb/a/a6/Eden_Project_Panorama_1.jpg/1920px-Eden_Project_Panorama_1.jpg

# Tensegrity

Examples

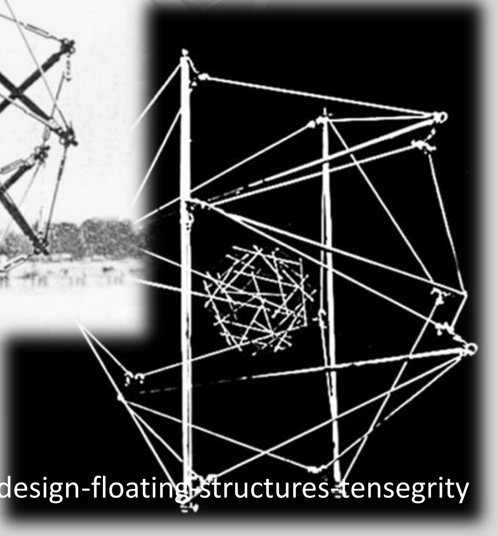
*The Kurilpa Bridge (originally the Tank Street Bridge) over the Brisbane River in Brisbane, Queensland, Australia*




Cells

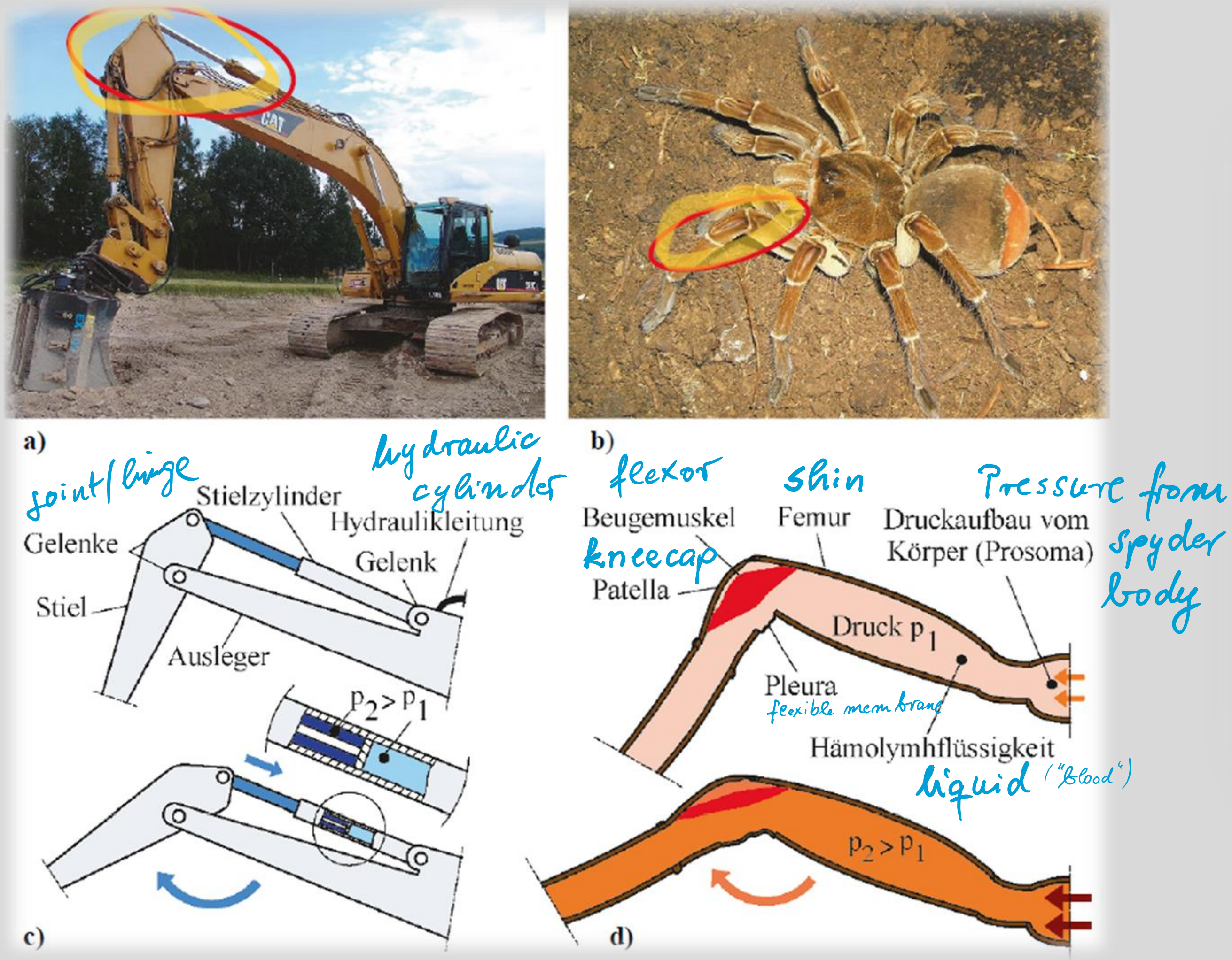
Cytoskeleton with micortubulus (struts
microfilament (ties)



https://www.ansys.com/blog/design-floating-structures-tensegrity

# Excavator arm vs spider leg





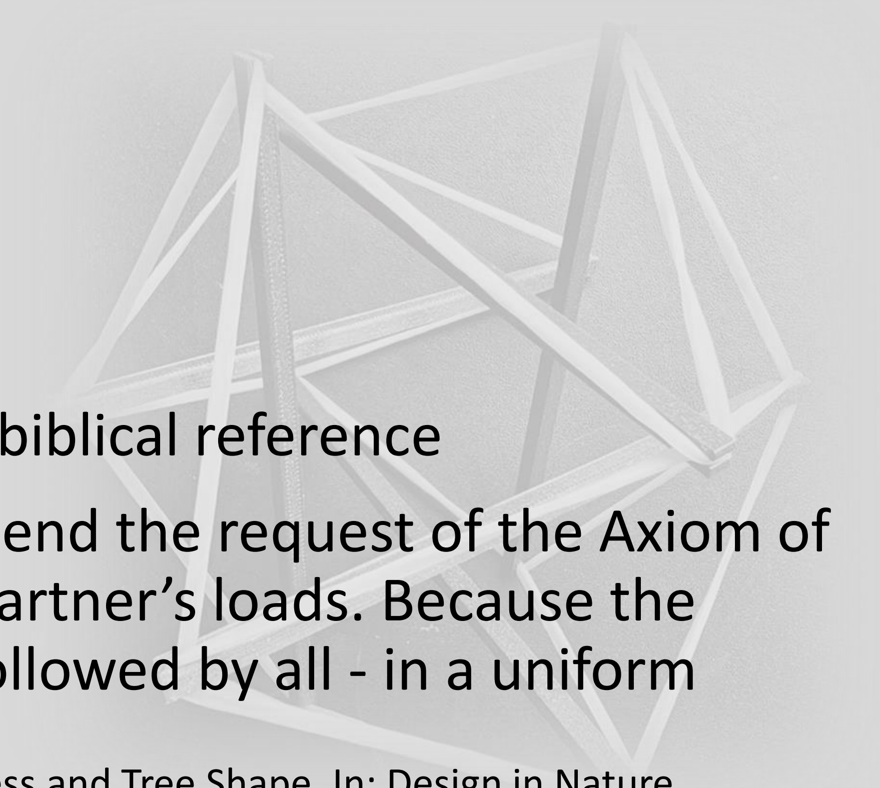
# Exhibition – architecture & biomimetics

Examples

# 5. Spiritual applications

- We need to be reinforce against stress

- Axiom of uniform stress



"Before we proceed it may be mentioned that the biblical reference

…Bear one another’s burdens, ... (Gal 6:2) is in the end the request of the Axiom of Uniform Stress. That doesn’t mean: Take all your partner’s loads. Because the advice is directed to all its results - consequently followed by all - in a uniform "stress" distribution."

Mattheck, C. (1998). The Right Load Distribution: The Axiom of Uniform Stress and Tree Shape. In: Design in Nature. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-58747-4_6

# Masonry and layered materials



- Lobatus gigas

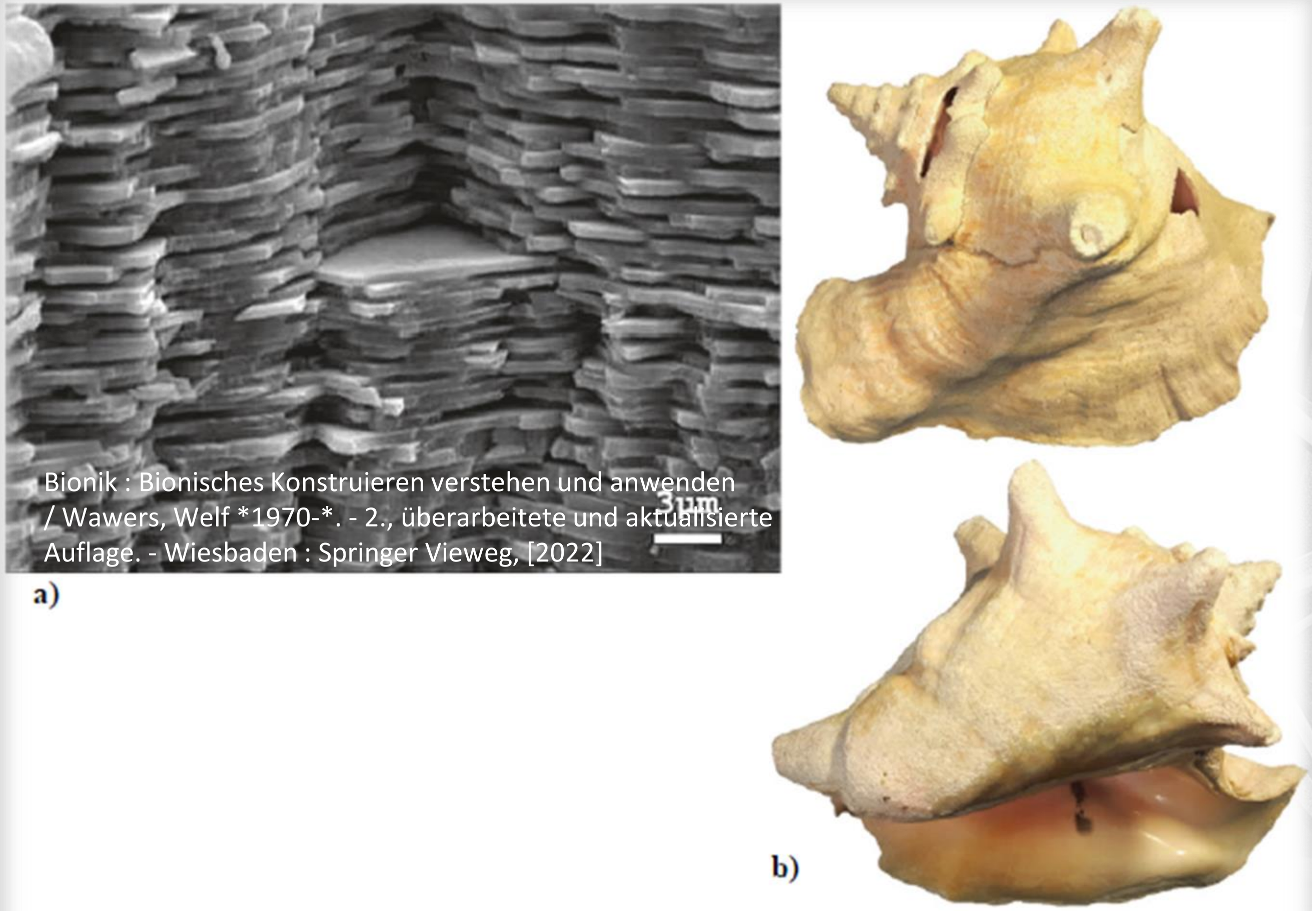



Abb. 3-30 a) REM-Aufnahme einer Perlmutt-Bruchfläche mit den typischen „gestapelten“ Aragonitplättchen. b) Gehäuse der großen Fechterschnecke *Lobatus gigas*