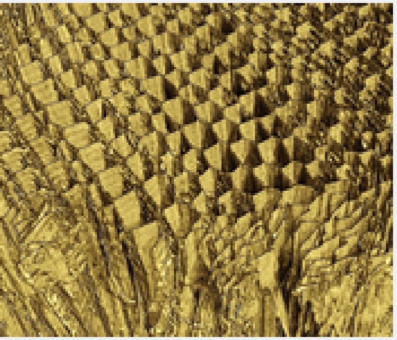
Lesnická a dřevařská fakulta

NUMERICKÁ OPTIMALIZACE DŘEVAŘSKÉHO VÝROBKU

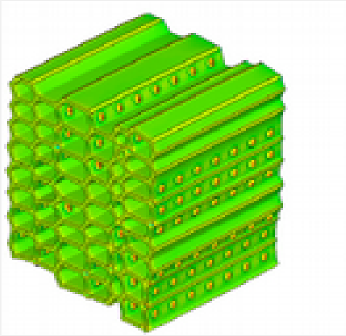
Jan Tippner, LDF MENDELU

FEA of wood microstructure, Javořík 2002, MENDELU

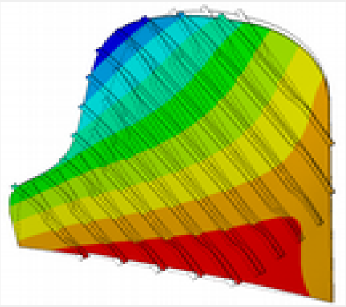
FEA of piano soundboard swelling, Tippner 2011, MENDELU



wood scanned at 500nm, source: www.ximea.com



using of CLT, source: blog.loadingdock5.com



using of OSB, Jim DeStefano, P.E., www.structuremag.org

Mendelova univerzita v Brně

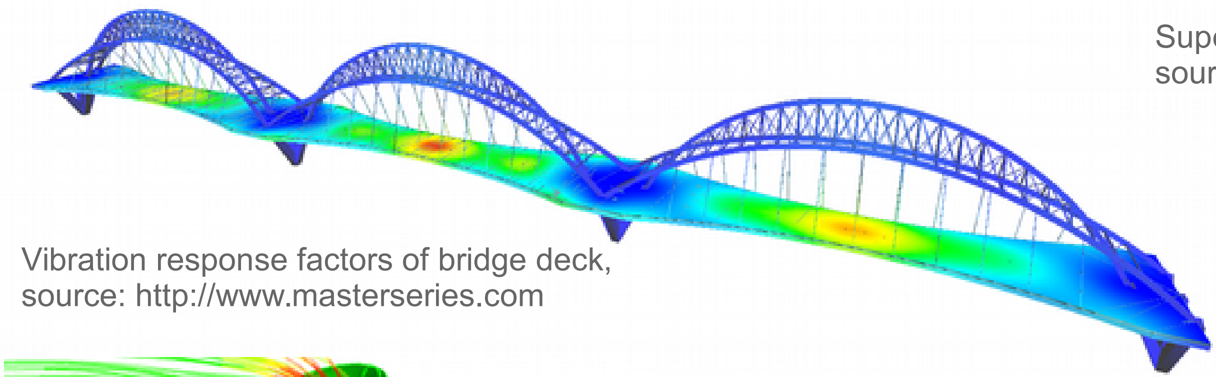
Aplikace FEM ve Wood Science and Technology

Fields of wood physics: laws (phys. models)

- **wood & heat transfer:** Fourier's laws, Newton's law of cooling, Navier-Stokes law (fluid dynamics), Stefan-Boltzman's law
- **wood & water transfer:** Fick's laws, Darcy's laws
- **wood & mechanics:** Hooke's law, general equation of motion (static/dynamics)
- **acoustics:** general equation of motion, wave equation

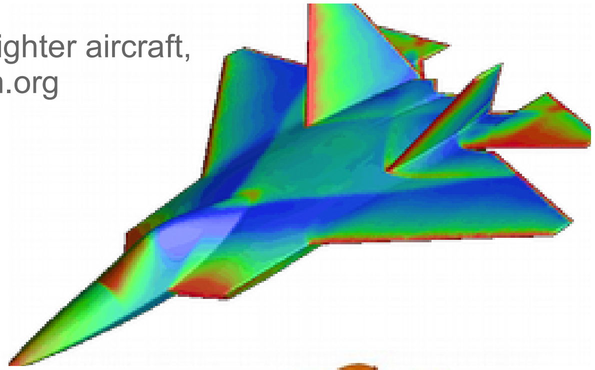
- usually described by differential equations – **partial differential equations (PDE)**
- PDE **straightly solvable in basic problems**, hardly solvable with complicated geometry, anisotropy, in-elasticity, multi-physics etc.
- robust solution with using of **numerical methods** – e.g. **finite element method (FEM)**

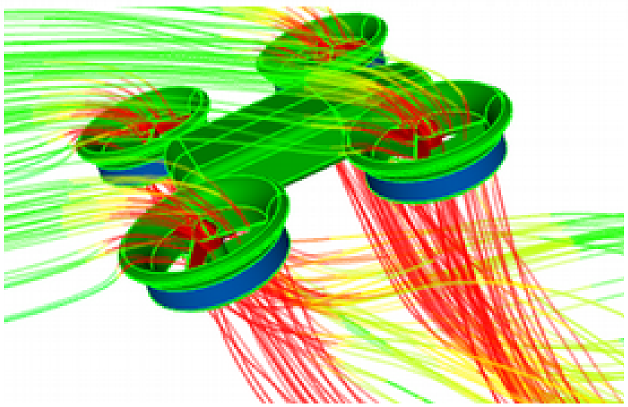
CAE: CAD, CAM,… CAA (FEA, CFD)



Vibration response factors of bridge deck,
source: http://www.masterseries.com

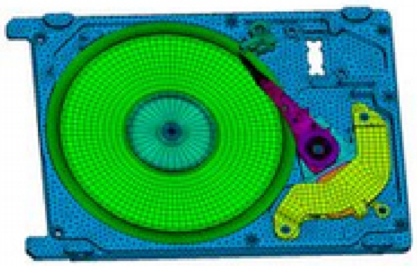
Supersonic flow past a fighter aircraft,
source: http://www.tafsm.org

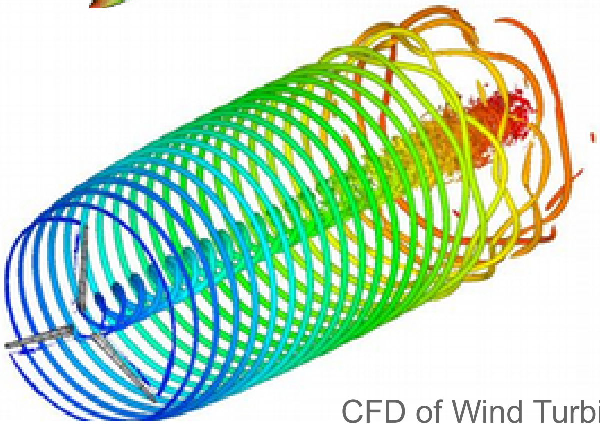




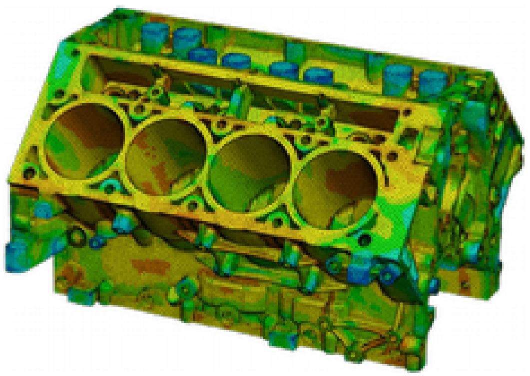
Quadcopter CFD Simulation,
source:http://www.symscape.com

Operational Shock Modelling of HDD,
source: https://www.a-star.edu.sg



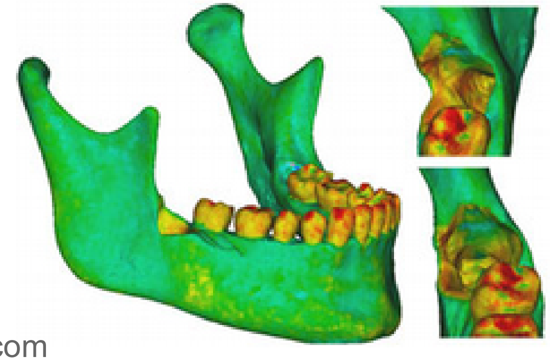


CFD of Wind Turbine,
source: https://www.liverpool.ac.uk



Automotive FEA, source: https://www.tentechllc.com

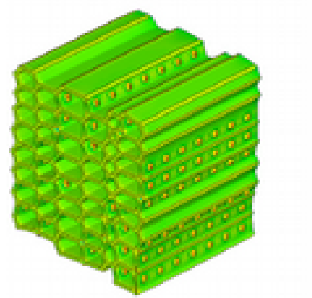
FEA of Mandible after Removing a 3. Molar,
source: http://www.jcda.ca/article/a72



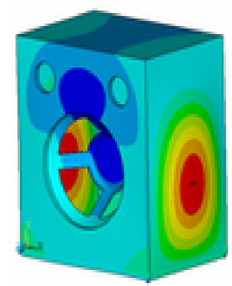
Pressure plots & streamlines - bicycle in wind tunnel, source: http://www.digitaleng.news

Examples of FEA in Wood Science & Technology

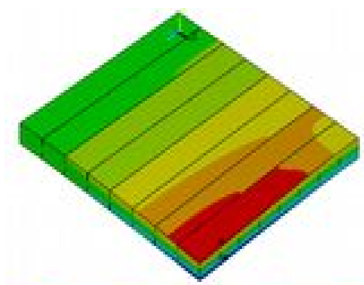
Mechnaics - Wood cell submicrostructure



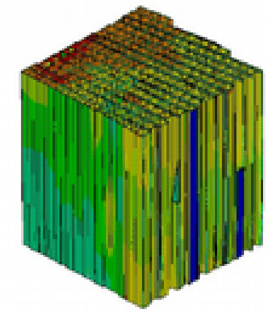
Acoustics - Loudspeaker

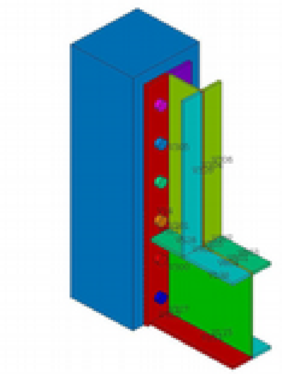


Stress/strain - CLT Panel

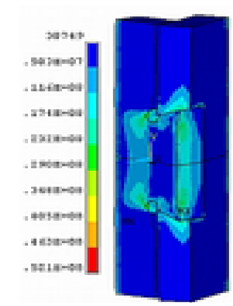


Multiphysics - Wood microstructure

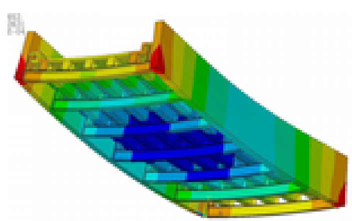


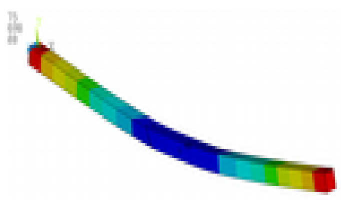


Mechanics of joints



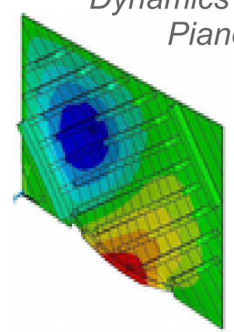
Mechnaics - Bridge

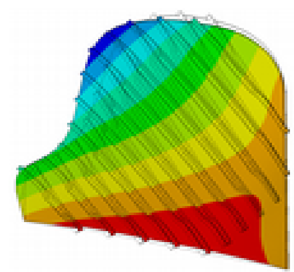


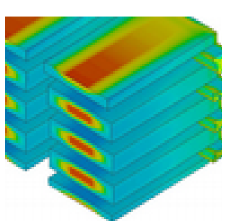


Mechanics – Historical Wood Jointings

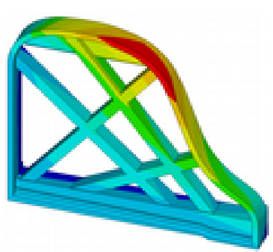
Dynamics / Hygroexpansion Piano soundboard

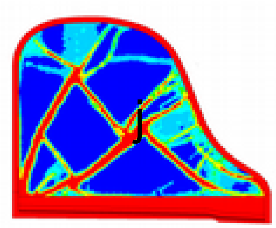




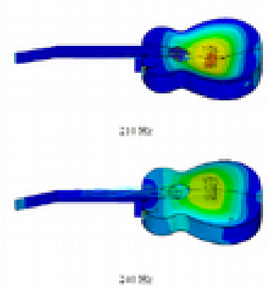


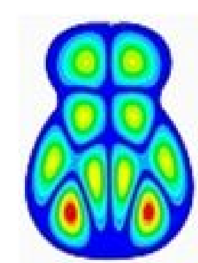
Thermal/Stress - Wood drying



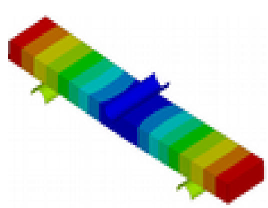


Mechanics/Dynamics - Frame of piano





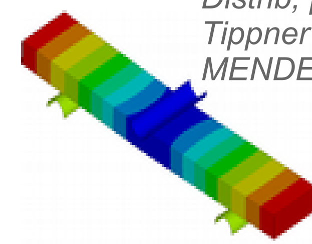
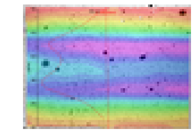
Dynamics - Guitar



Mechanics – Standard tests

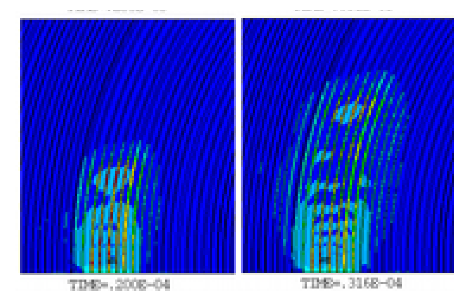
Laboratory of Numerical Simulations in Brno, CZ

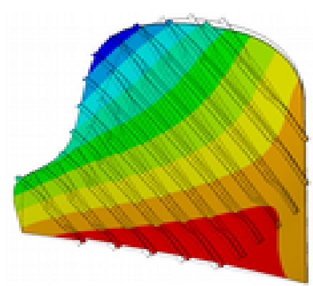
- **Static structural analyzes** – material WBC, constructions
- **Dynamics and acoustics** of wood and wood products
- **Computational fluid dynamics (CFD)**
- **Wood macro- & micro- structure modeling**
- **Thermal analyzes** – cooling, heating, heat transfer
- **Coupled field analyzes –** Strain x Moisture, Strain x Thermal
- **Electro-magnetic field transfer** through the wood and wood products
- **Optimization – design & topological**
- **Propabilistic analyzes** (ANSYS PDS)

Distrib, props. MDF, Tippner et al. 2012, MENDELU

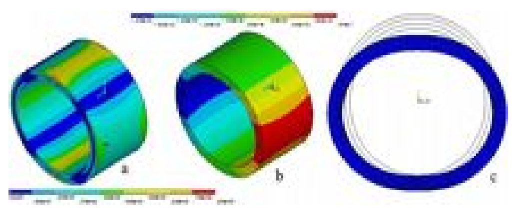
Stress-wave propagation, Sebera et al. 2011, MENDELU

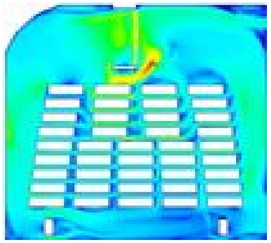




FEA of piano soundboard swelling, Tippner 2011, MENDELU

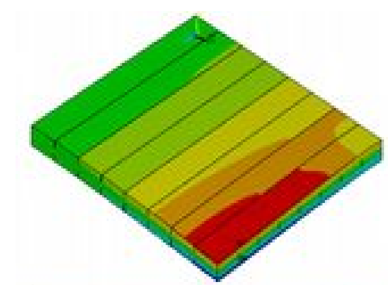
Bamboo test, Sebera 2010, MENDELU





CFD of drying kiln, Zejda & Tippner 2003, MENDELU

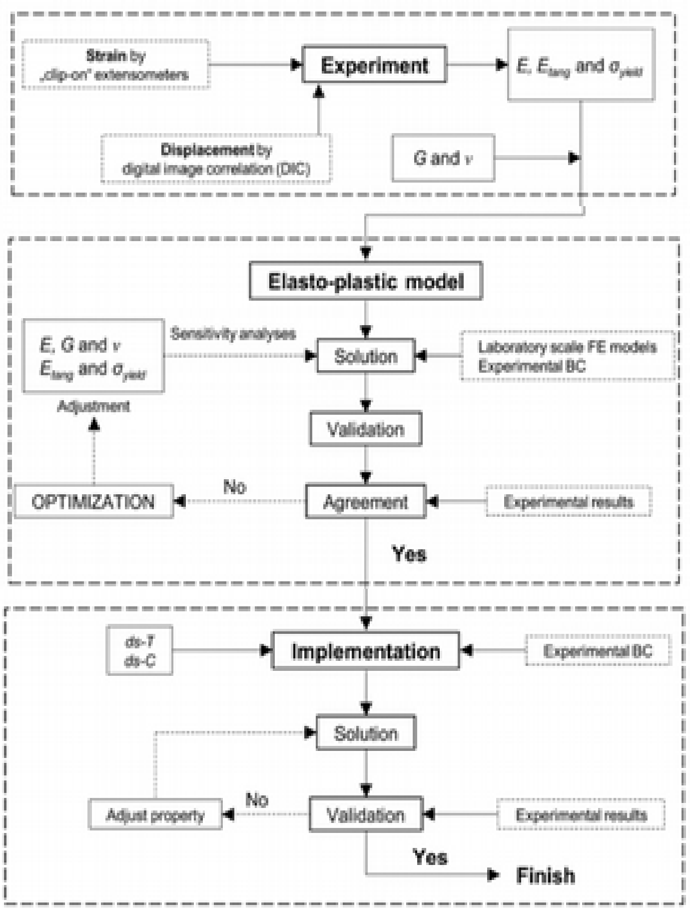
FEA of CLT, Sebera et al. 2012, MENDELU

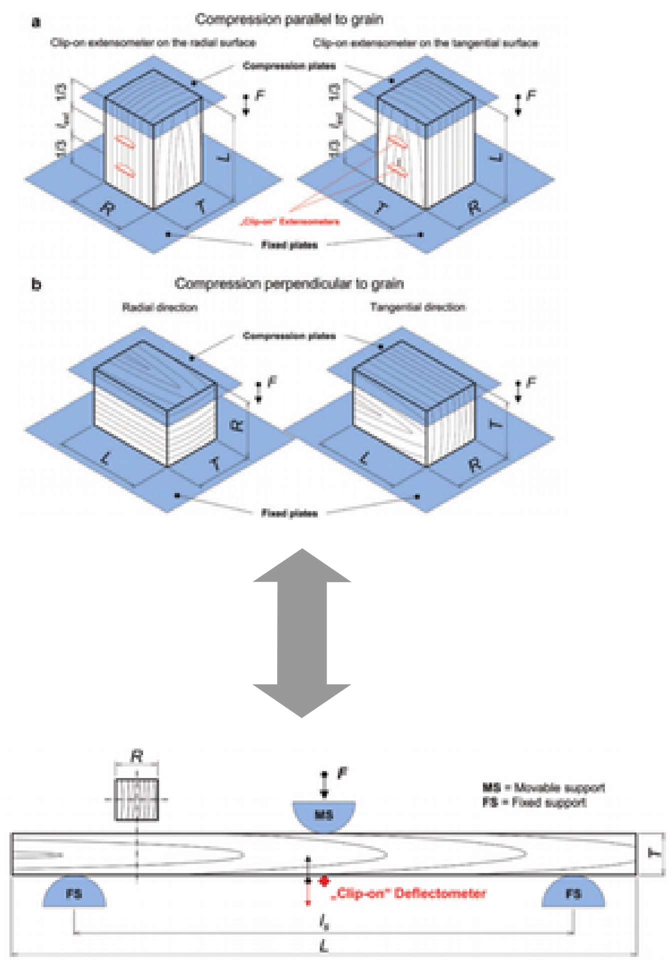


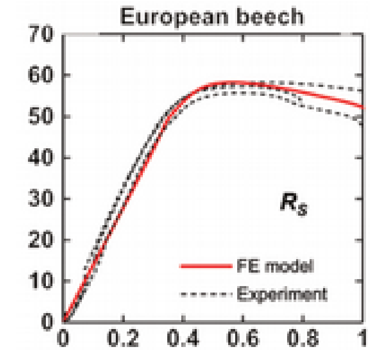
- **Equipment:** FEM SW – **ANSYS** package (research licences & teaching licences for ANSYS APDL, Workbench, Autodyn, CFX etc.), **Comsol Multiphysics**, FlexPDE, ELMER, **HPC computacional linux servers**, Win and Linux workstations

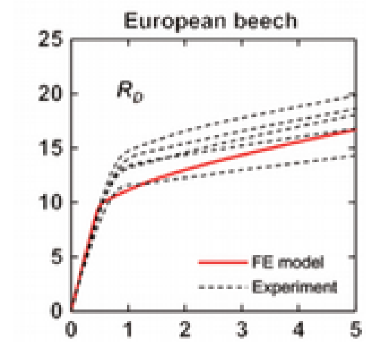
Determination of elasto-plastic material characteristics

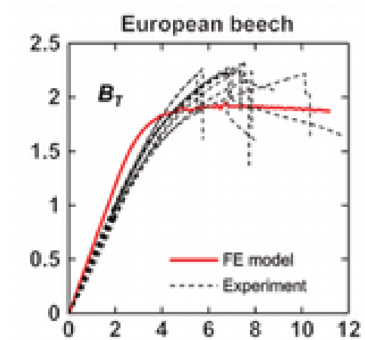
- Norway spruce and European beech - Milch et al. 2016, Holzforschung 70(11)
- English oak, WBC (MDF, ...)





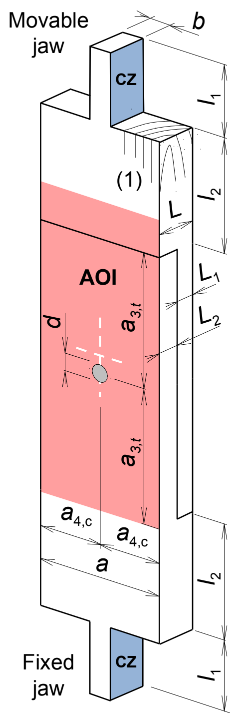


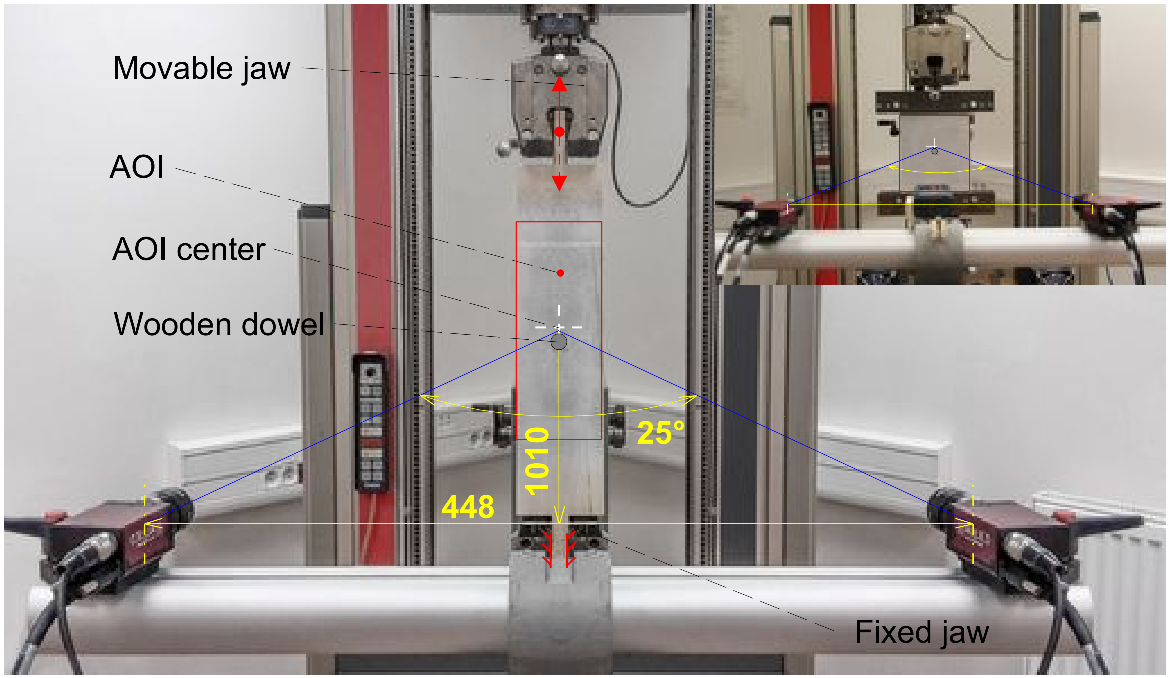


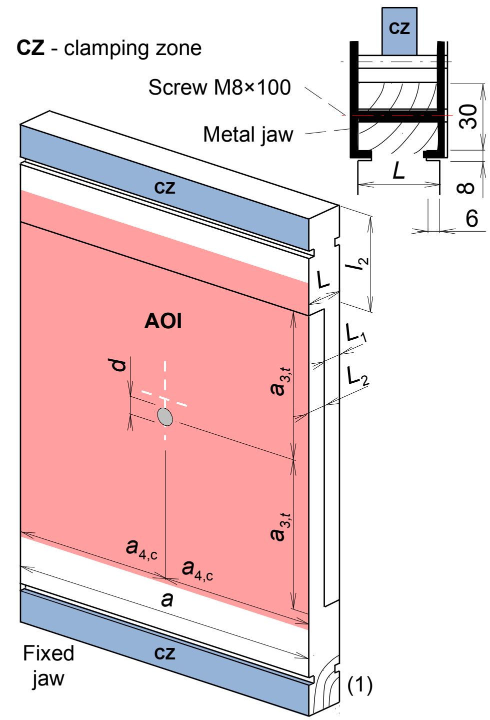


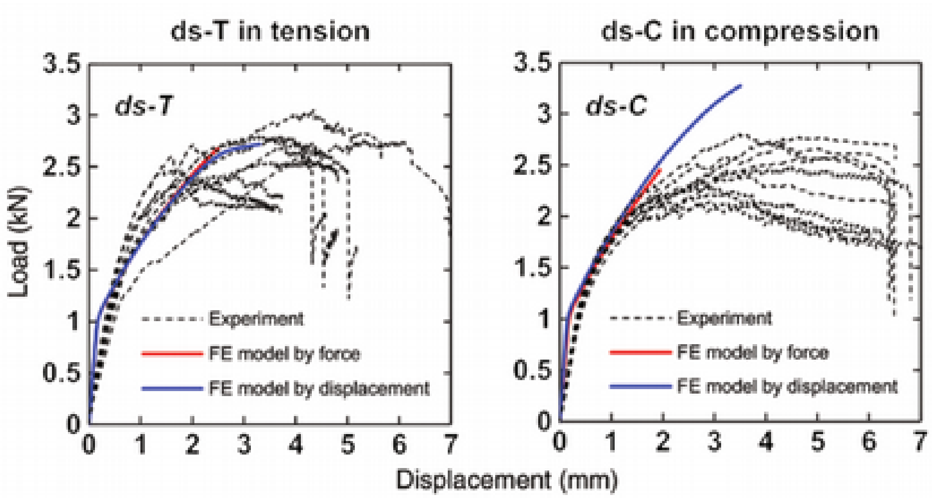
Expermental > Bi-linear model for uni-axial loading > verification in bending

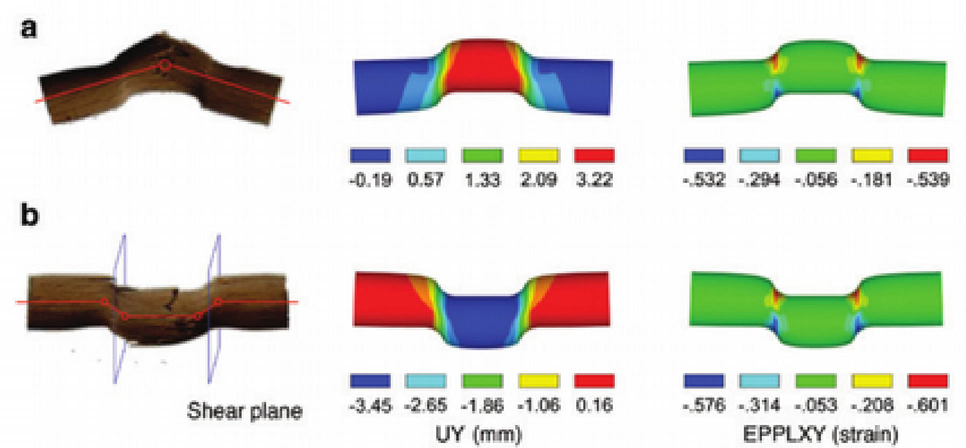
Application of Elasto-Plastic Model in FEA of Joints





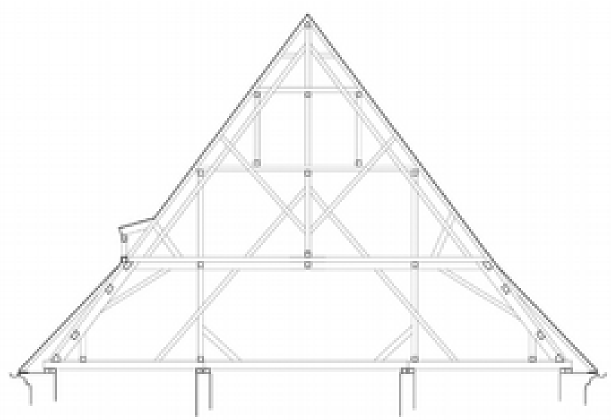


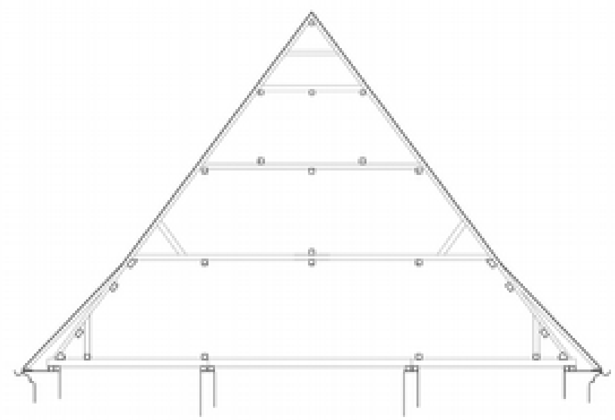




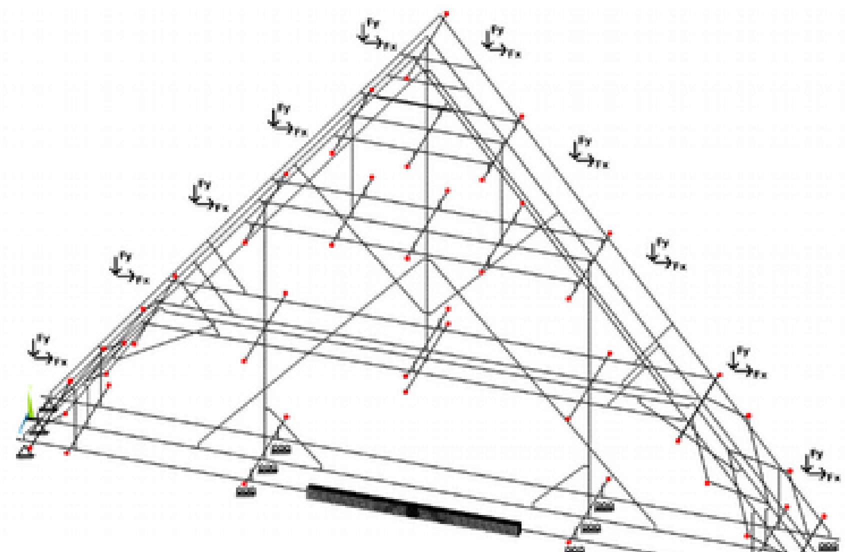
Optimization of All-wooden Joints, structure analysis

Tippner J. et al., 2014, Intern. Conference on Structural Analysis of Historical Constructions

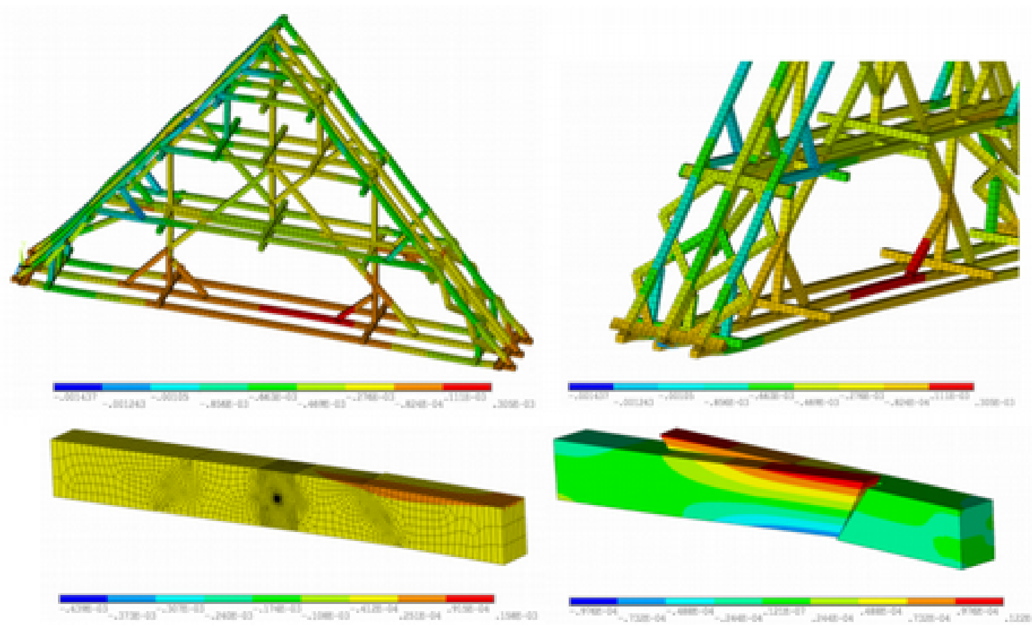




FINITE-ELEMENT ANALYSIS OF A HISTORICAL TRUSS RECONSTRUCTED WITH A TRADITIONAL ALL-WOODEN JOINTS

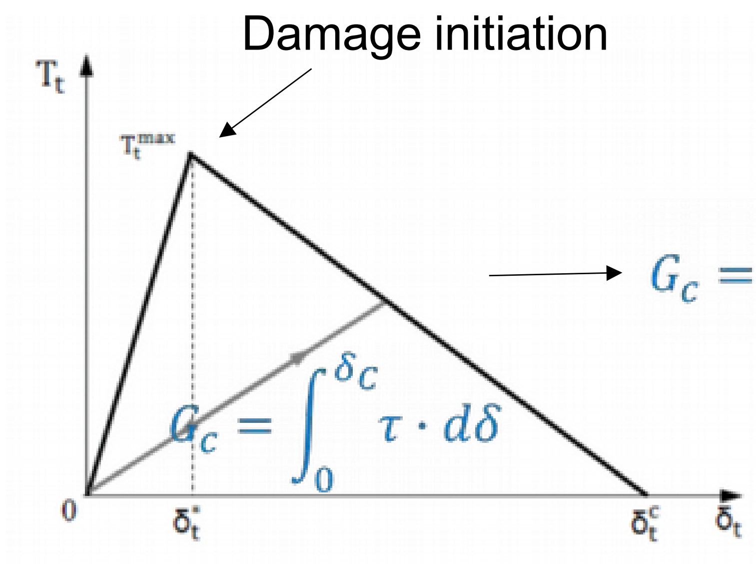


Solid-Beam substructuring

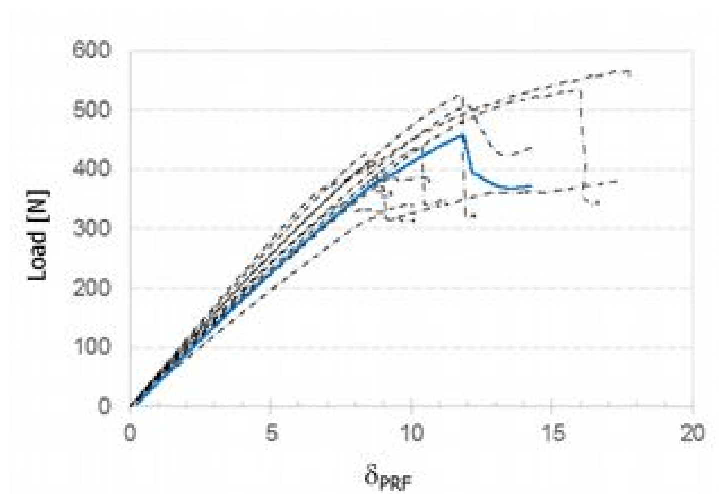


Fracture characterization of adhesively bonded joints

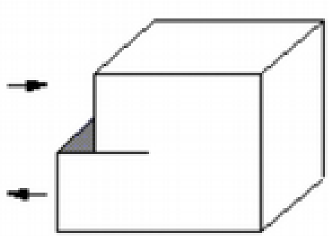
Děcký, D., MENDELU, 2017 - 2019



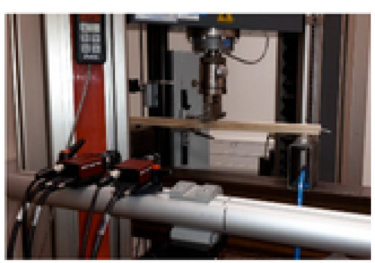
$$G_c = \frac{P^2 a_e^2}{16 B^2 h^3 E_f}$$



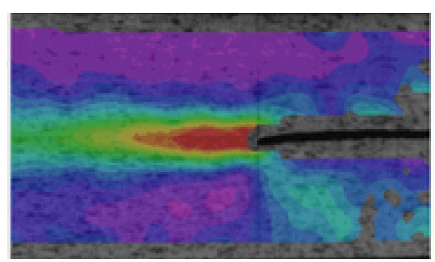
- cohesive zone (**LEFM**), technology via FEM - gradually degrading material elasticity between bonded surfaces
- interface‘s material behavior characterized – stress (σ,τ) and separation distances
- bonded contact – linear traction separation material law
- **mode II: 3-E**nd **N**otched **F**lexure test of bonded joints (via equivalent crack length procedure)



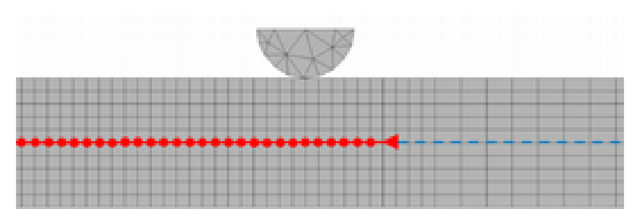
Shearing mode (K_{II})



3-ENF test with DIC



DIC analysis for MM



FE Model with predefined crack-path (Conact-pair based)

Modeling of Wood Desintegration (HARDIS 2017-2020)

1. Orthotropic elasticity

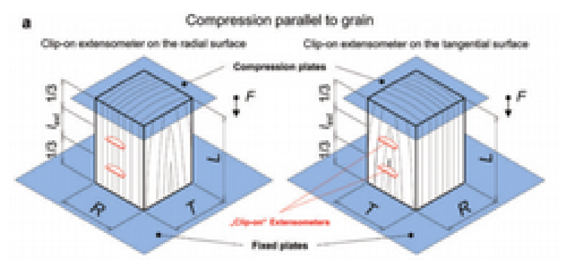
$$
[D]^{-1}=\begin{bmatrix}
\frac{1}{E_x} & \frac{-\mu_{xy}}{E_x} & \frac{\mu_{xz}}{E_x} & 0 & 0 & 0 \\
\frac{-\mu_{yx}}{E_y} & \frac{1}{E_y} & \frac{-\mu_{yz}}{E_y} & 0 & 0 & 0 \\
\frac{-\mu_{zx}}{E_z} & \frac{-\mu_{zy}}{E_z} & \frac{1}{E_z} & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{1}{G_{xy}} & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{1}{G_{yz}} & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{1}{G_{xz}}
\end{bmatrix}
$$

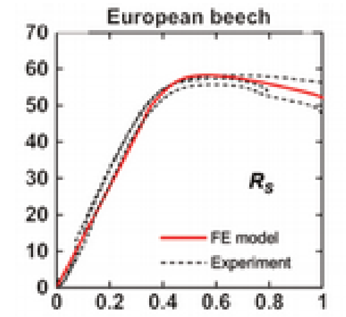
2. Orthotropic plasticity (Hill yield function)

$$
f(\boldsymbol{\sigma},\bar{\varepsilon}^p)=\left[\mathrm{F}(\sigma_{RR}-\sigma_{TT})^2+\mathrm{G}(\sigma_{TT}-\sigma_{LL})^2+\mathrm{H}(\sigma_{LL}-\sigma_{RR})^2+2\mathrm{L}\sigma_{RT}^2+2\mathrm{M}\sigma_{TL}^2+2\mathrm{N}\sigma_{LR}^2\right]^{\frac{1}{2}}-\sigma_y(\bar{\varepsilon}^p)
$$

3. Damage criterion

$$
D=\max\left(\left|\frac{\sigma_{LL}}{\sigma_{LL}^f}\right|,\left|\frac{\sigma_{RR}}{\sigma_{RR}^f}\right|,\left|\frac{\sigma_{TT}}{\sigma_{TT}^f}\right|,\left|\frac{\sigma_{LR}}{\sigma_{LR}^f}\right|,\left|\frac{\sigma_{LT}}{\sigma_{LT}^f}\right|,\left|\frac{\sigma_{RT}}{\sigma_{RT}^f}\right|\right) \quad \textit{if} \quad D\geq 1 \quad \textit{then} \quad \textit{element deletion occur}\,(\textit{failure})
$$





4. Example of material parameters:

$D_{LLLL}=17850$ MPa; $D_{RRRR}=472$ MPa; $D_{TTTT}=388$ MPa; $D_{LLRR}=14$ MPa; $D_{LLTT}=10$ MPa; $D_{RRTT}=216$ MPa; $D_{LRLR}=573$ MPa; $D_{LTLT}=474$ MPa; $D_{LLTT}=53$ MPa;

$\mathrm{F}=52.62$; $\mathrm{G}=-4.99$; $\mathrm{H}=5.99$; $\mathrm{L}=26.74$; $\mathrm{M}=124.92$; $\mathrm{N}=26.74$ $\quad$ $\sigma_y^0=49$ MPa; $E_p=20$ MPa

$\sigma_{LL}^f=53$ MPa; $\sigma_{RR}^f=10.4$ MPa; $\sigma_{TT}^f=11.1$ MPa; $\sigma_{LR}^f=10.7$ MPa; $\sigma_{RT}^f=10.7$ MPa; $\sigma_{LT}^f=7.1$ MPa;

Mendel University in Brno

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Evropský fond pro regionální rozvoj

WOOD K PLUS

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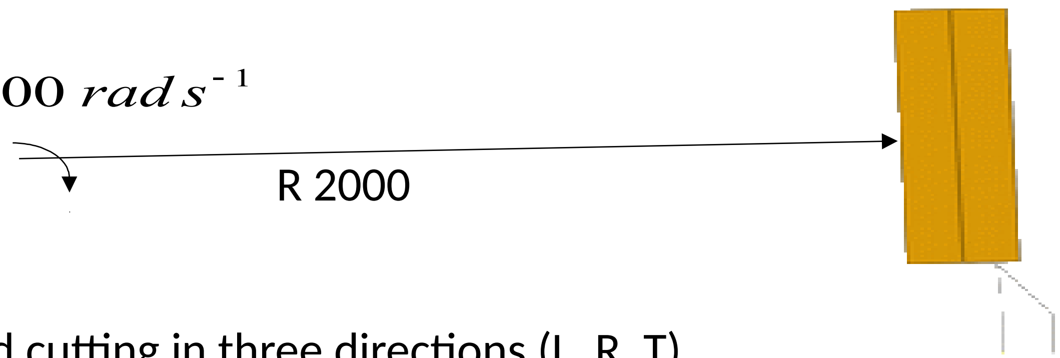
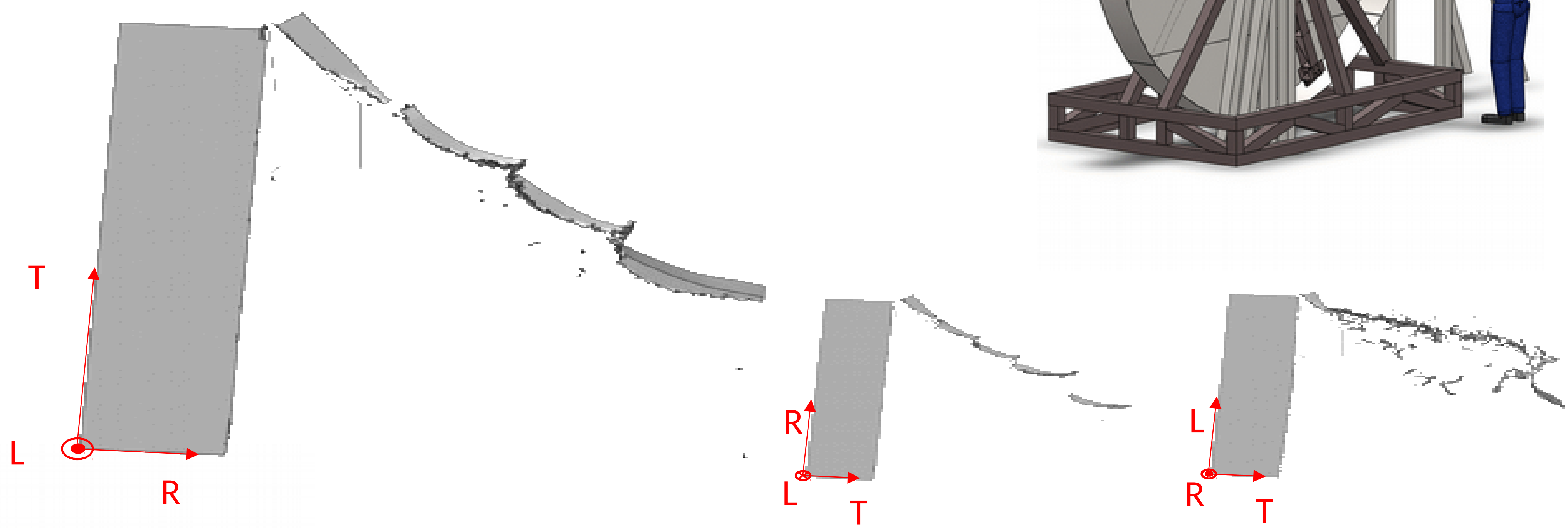
Modeling of Wood Desintegration (HARDIS 2017-2020)

Rotating specimen, fixed rigid knife (explicit dynamics LS-DYNA)

$$\omega = 100 \; rad\, s^{-1}$$

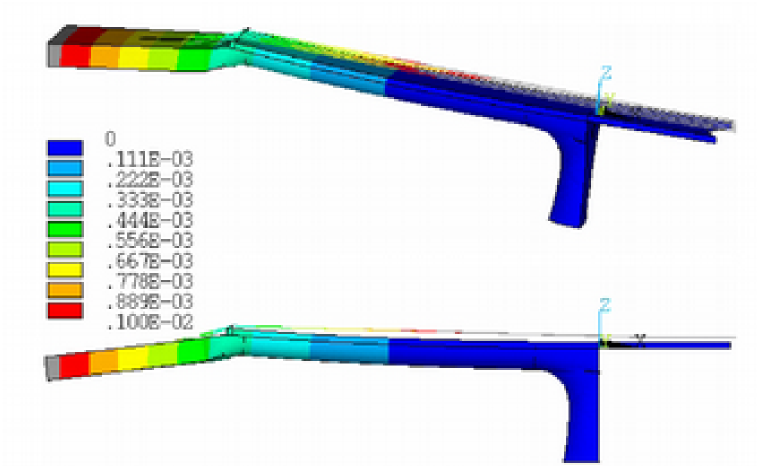


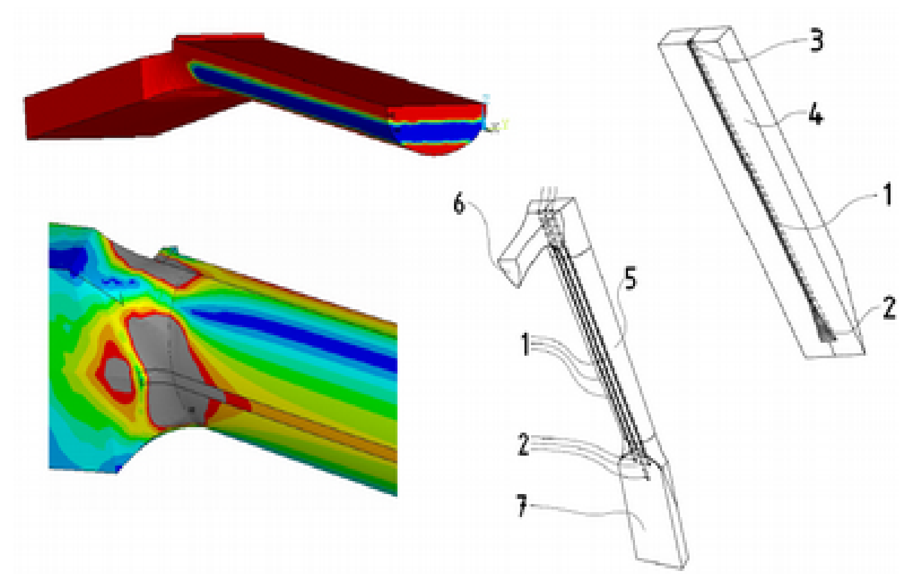
Wood cutting in three directions (L, R, T)

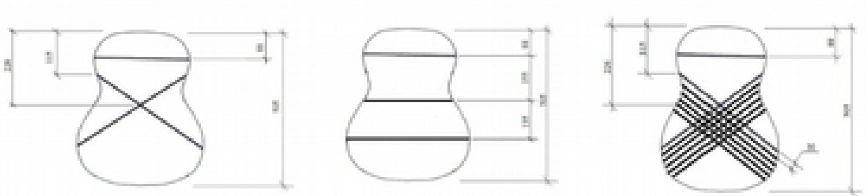


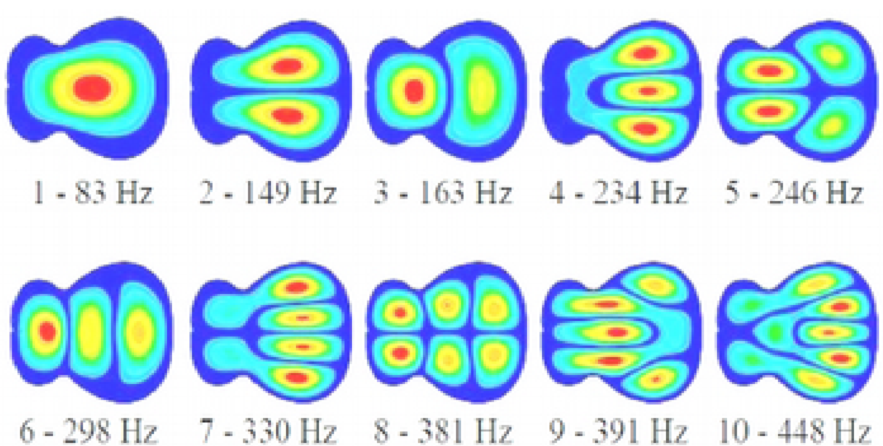
Static and Dynamics of Guitar

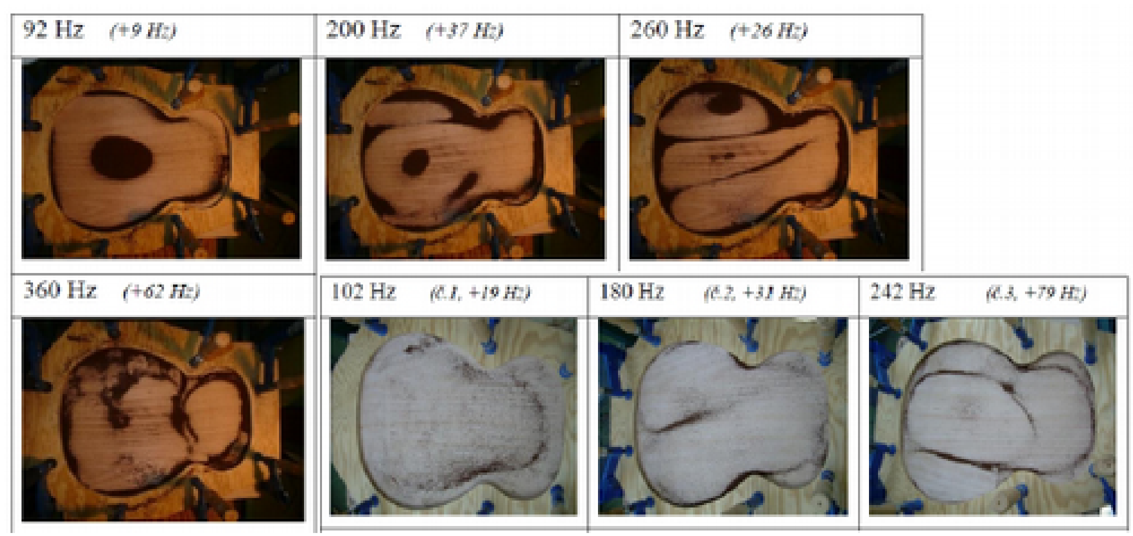
Carbon fiber reinforcement of guitar (topological optimization > structural analysis)







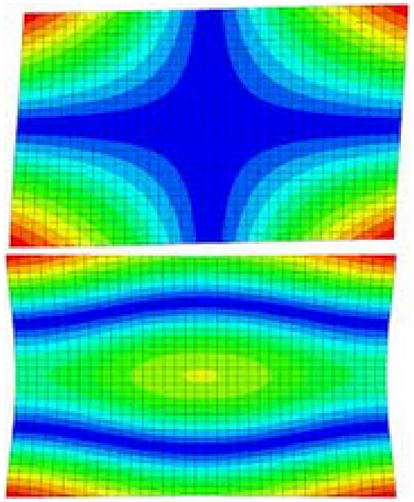




Location of ribs (wooden or carbon fiber rods) based on modal analysis

Physical background of Dynamic FEAs

Types of dynamic analyzes = forms of eq. of motion:



1. undamped modal analysis **[K].*u* + [M].*u*'' = 0**

computation of natural frequencies and mode shapes

2. damped modal analysis **[K].*u* + [M].*u*'' + [C].*u′* = 0**

3. harmonic analysis **[K].*u* + [M].*u*'' + [C].*u′* = *f* (*f*)**

right side: all forces harmonically changed, true amplitudes in the case of periodical vibrations

4. „full“ transient analysis **[K].*u* + [M].*u*'' + [C].*u′* = *f***

loads are generally described in time – allows nonlinearities

Example of 3D Stress-Strain FEA

1. Pre-processing > 2. Solution > 3. Post-processing

1. Geometric model (building or CAD import)

2. Discretization of region (replacement of infinitesimal volume by finite count of elements with finite dimensions, connected via nodes) and declaring physics (field, material, IC, BC)

3. Now we have for each discrete **point: 3 equations** – field of displacements in all directions (x,y,z) and we are looking for **solution of field of strains** (6 equtaions) and field of **stresses** (next 6 eq.)

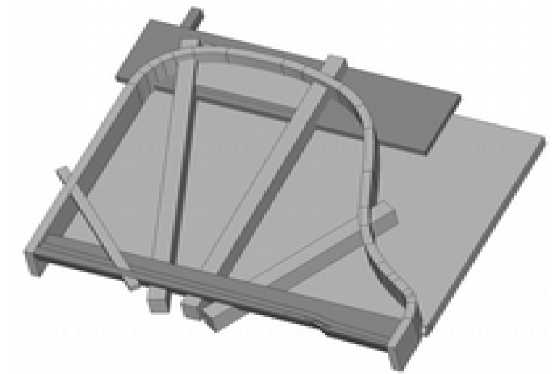
4. Replacement of displacement functions by polynomials and new deriving of displacement functions

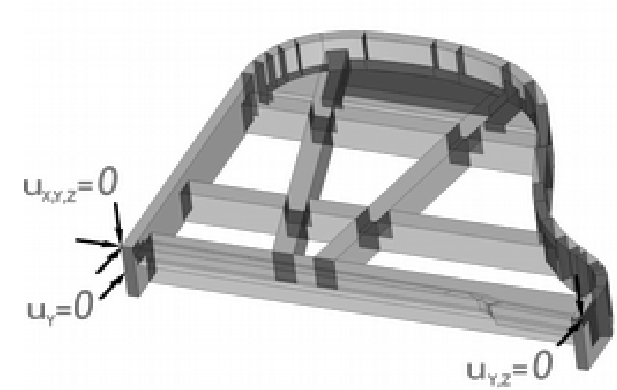
5. Implementation of boundary conditions (displacements, forces)

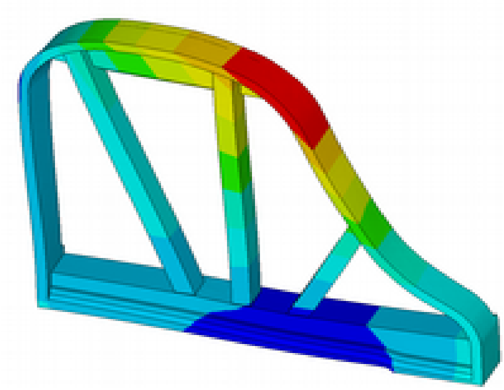
6. Computation of system of algebraic equations - displacements

7. Computation of strains and stresses

8. Reviewing numerical outputs, graphical illustration of results



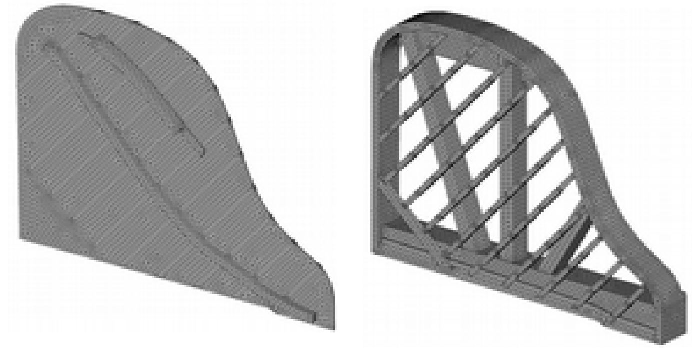




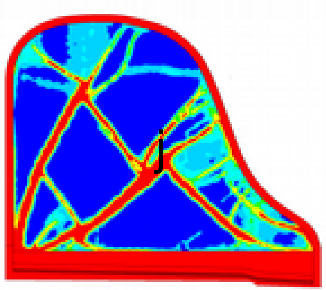
FEA in Wood Science & Technology – Grand Piano

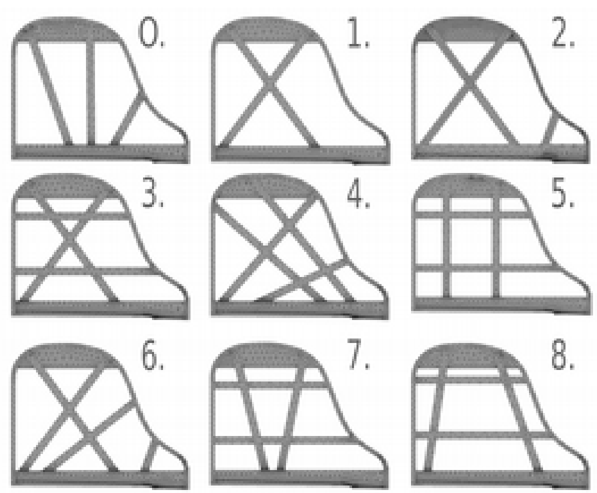
The numerical simulation of behaviour of the **piano soundboard, ribs, bridges and wooden frame** (FEM) in ANSYS.

FE model of planks - soundboard, ribs, bridges, frame

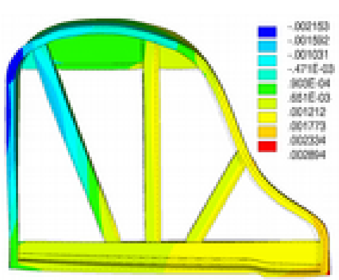


Topological optimization of static loading



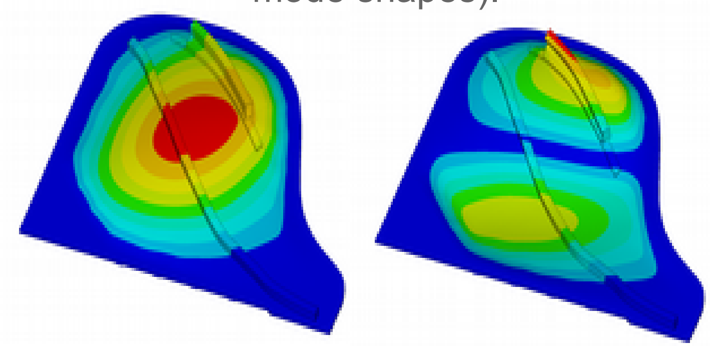


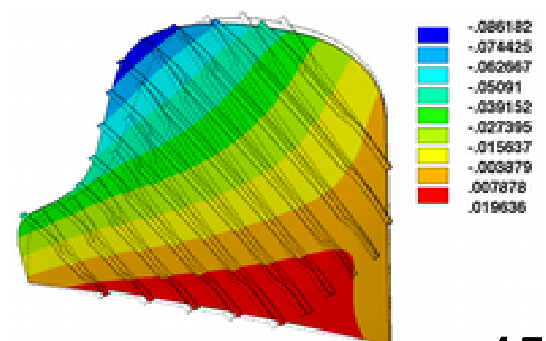
Comparison of several types of the frame



Static loading of frame

Modal analysis of soundboard (freqs & mode shapes).



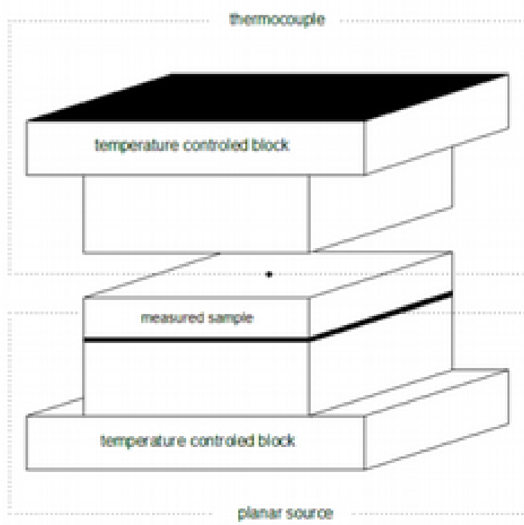


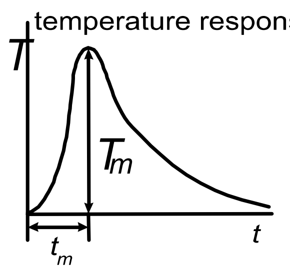
Coupled analysis of straining

Validation of Material Model for Thermal Analysis

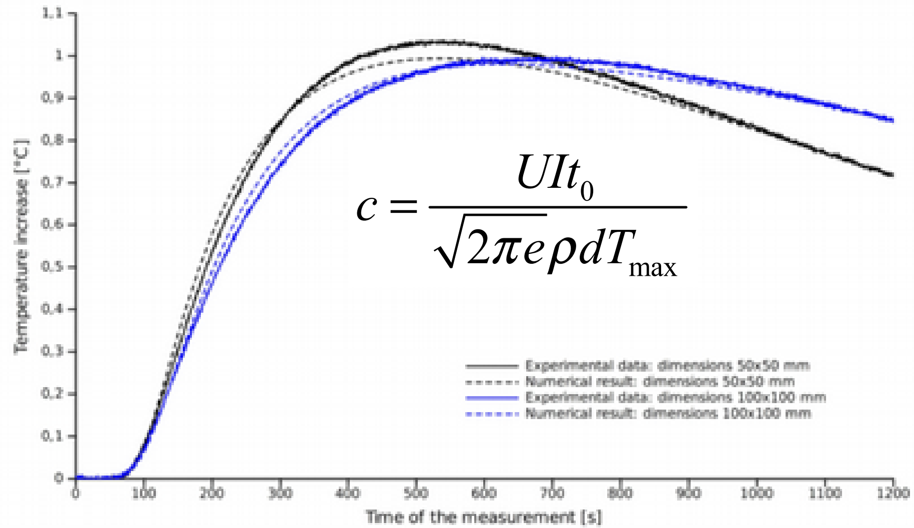
Troppová & Tippner (2015): The influence of specific parameters on thermal properties of MDF by pulse transient method.

Open chamber of RT-Lab device

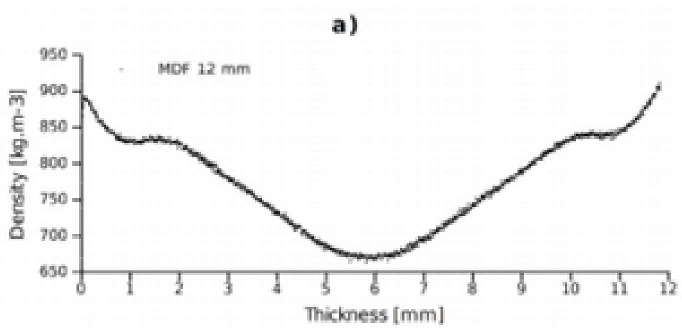


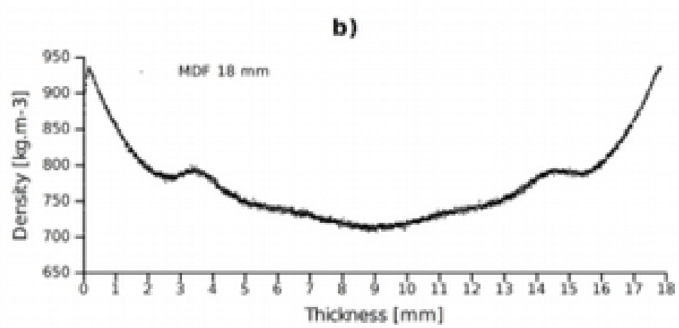


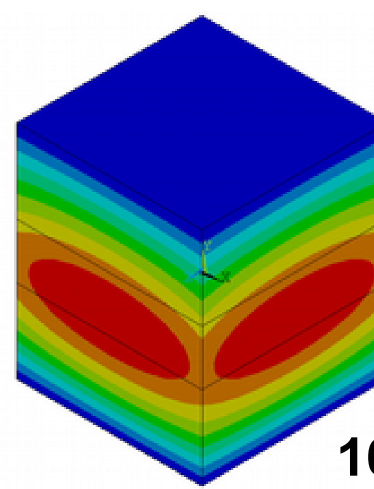
Temperature response of MDF samples with dimensions 50x50 mm and 100x100 mm



$$c = \frac{UIt_0}{\sqrt{2\pi e}\rho d T_{\max}}$$

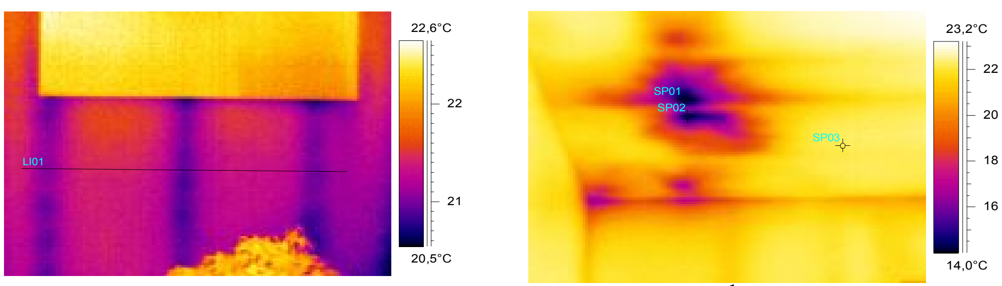




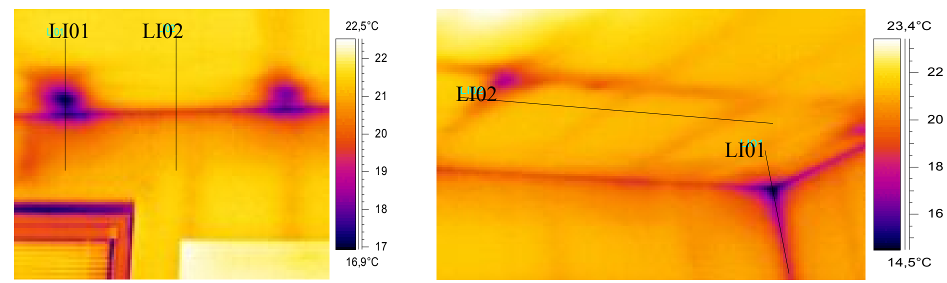


Application: thermal bridges in wooden house

Troppová, Klepárník, Tippner (2015): Thermal bridges in a prefabricated wooden house: experimental and numerical characterization.

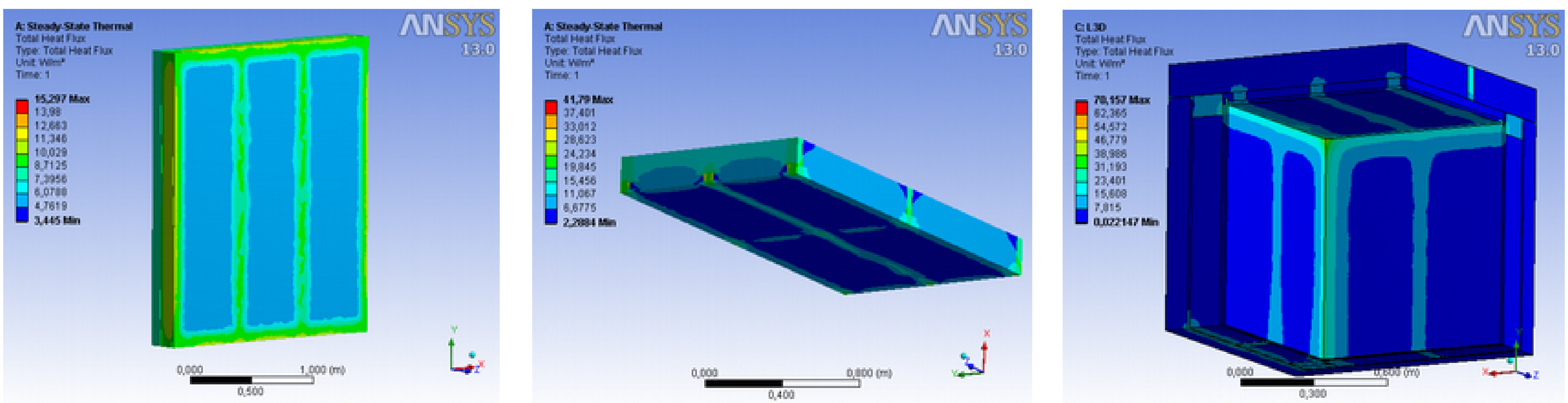


a b



a b

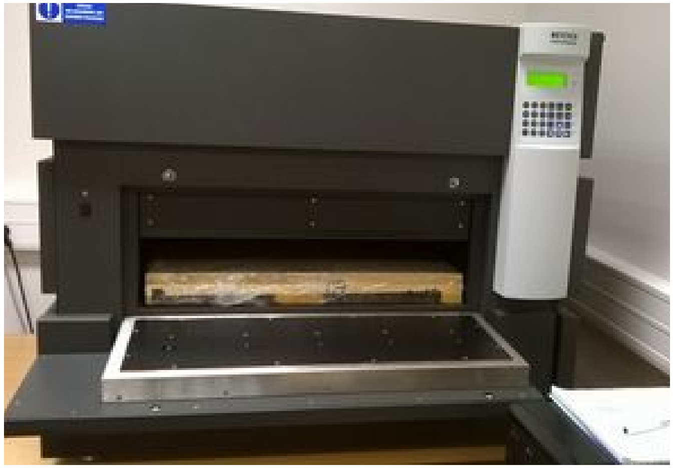
2 methods: infrared thermography was used to monitor thermal bridges, numerical simulations of parts were created using ANSYS.

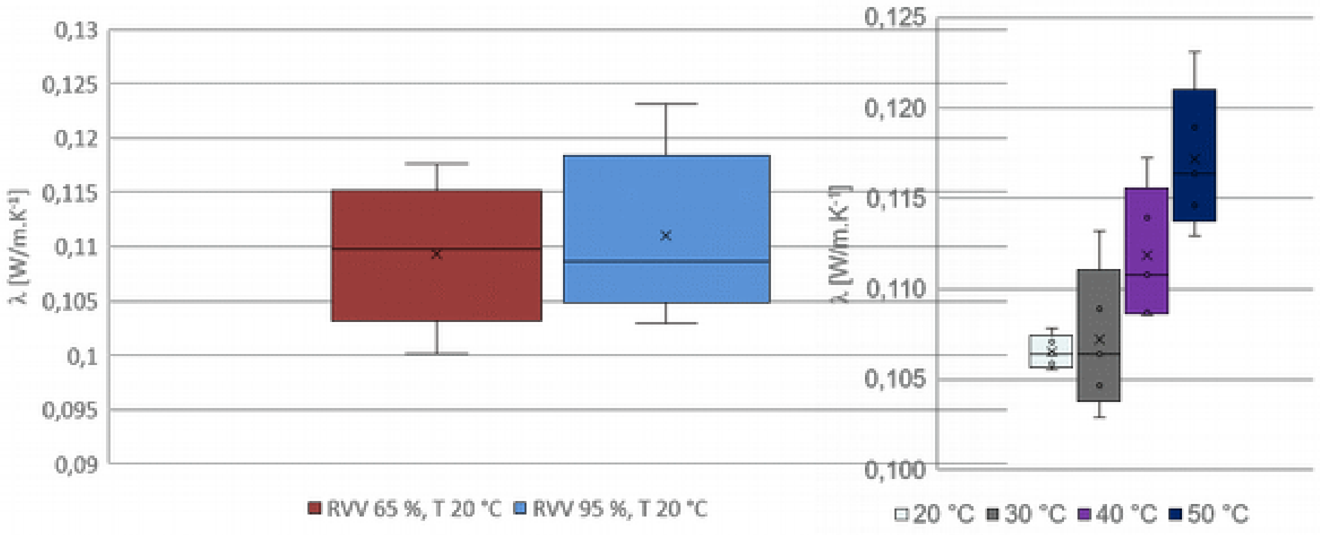


a b

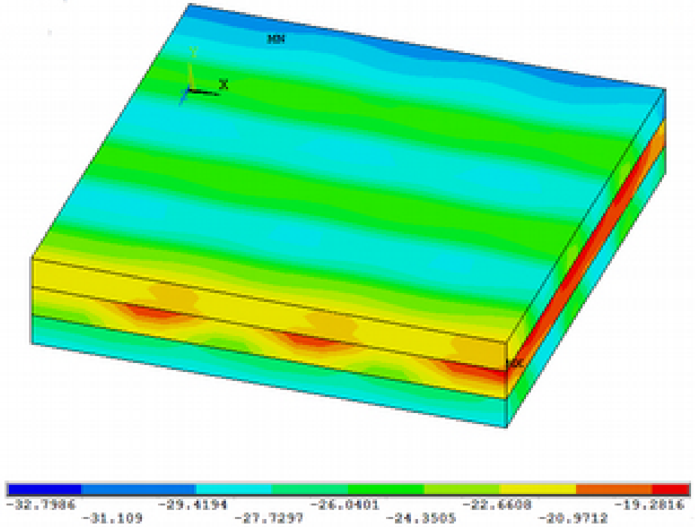
significant influence of thermal bridges in wooden constructions, the calculated ψ values of the structural connections differ from the standard value in EN ISO 14683

CLT – structure, defects, temperature, MC





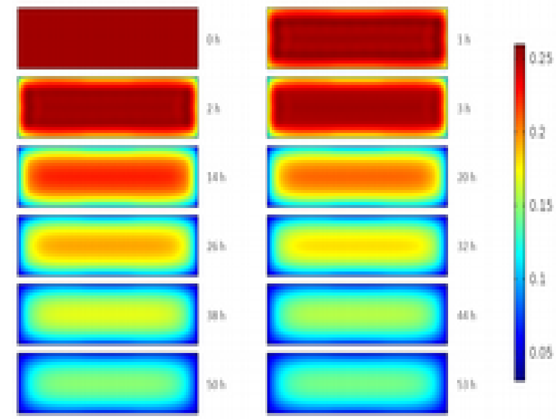
- stationary measurement by „lambdameter“ under different temperatures & MC
- steady state numerical simulations using ANSYS (lamela orientation, cracks)



Numerical simulations of heat and mass transfer in wood

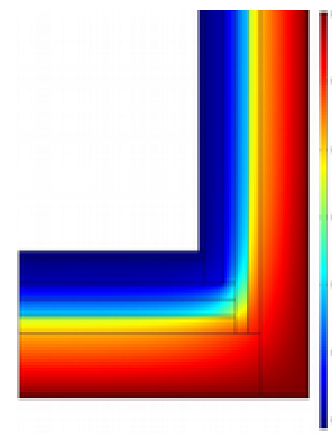
Trcala, M., Suchomelová, P., Tippner, J. MENDELU, 2006 - 2018.

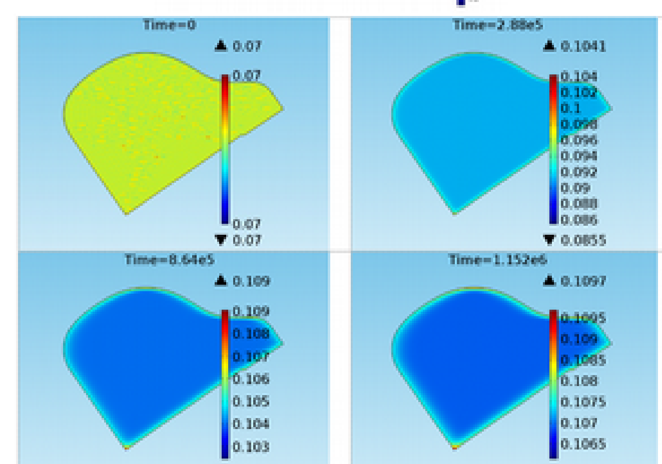
Nonlinear coupled computations of **temperature, mass** and **stress-strain** fields



Application in „real“ tasks:

- *Processing of wood*: **kiln-drying** processes optimization
- *Structural engineering*: swelling and shrinkage of **wooden structures**, water diffusion (and condensation)
- *Properties of wooden products*: minimization of water **sorption in resonance boards**





COMSOL MULTIPHYSICS

ANSYS

MATLAB

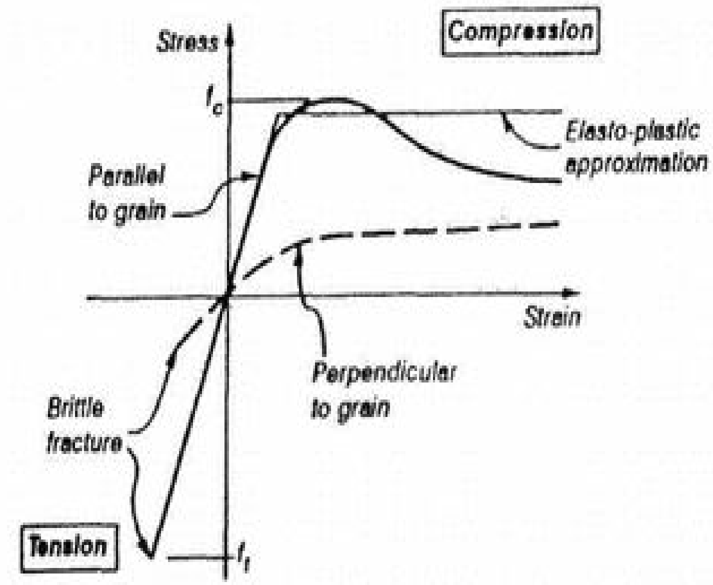
Background of Thermal-Stress-Strain FEA

Strains $\{\varepsilon\}$ should be divided to **thermal** strains $\{\varepsilon_t\}$, initial strains $\{\varepsilon_0\}$ and **elastic** strains $\{\varepsilon_{el}\}$:

$$\{\varepsilon\}=\{\varepsilon_{el}\}+\{\varepsilon_t\}+\{\varepsilon_0\}$$

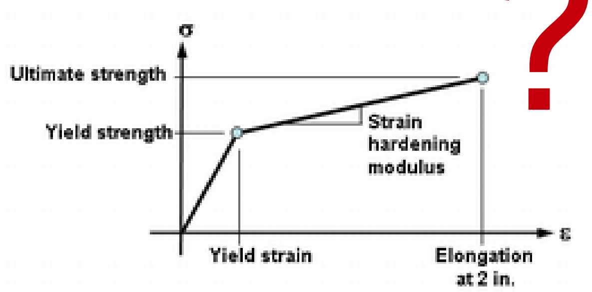
Stress-Strain relationship for linear elasticity (incl. initial **internal stresses and thermal stresses**):

$$\{\sigma\}=[D]\{\varepsilon_{el}\}+\{\sigma_0\}=[D](\{\varepsilon\}-\{\varepsilon_t\}-\{\varepsilon_0\})$$



Matrix of elasticity [D], resp. **compliance matrix** $[D]^{-1}$ are differently defined for isotropic, orthotropic and anisotropic materials. For **isotropic materials** is $[D]^{-1}$ defined:

$$[D]^{-1}=\frac{1}{E}\begin{bmatrix} 1 & -\mu & -\mu & 0 & 0 & 0 \\ -\mu & 1 & -\mu & 0 & 0 & 0 \\ -\mu & -\mu & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2(1+\mu) & 0 & 0 \\ 0 & 0 & 0 & 0 & 2(1+\mu) & 0 \\ 0 & 0 & 0 & 0 & 0 & 2(1+\mu) \end{bmatrix}$$



?

Physical background of Thermal-Stress-Strain FEA

Next for **orthotropic** material is $[D]^{-1}$:

where E is Young modulus of elasticity
and μ is Poisson's ratio.

$$[D]^{-1}=\begin{bmatrix} \frac{1}{E_x} & \frac{-\mu_{xy}}{E_x} & \frac{\mu_{xz}}{E_x} & 0 & 0 & 0 \\ \frac{-\mu_{yx}}{E_y} & \frac{1}{E_y} & \frac{-\mu_{yz}}{E_y} & 0 & 0 & 0 \\ \frac{-\mu_{zx}}{E_z} & \frac{-\mu_{zy}}{E_z} & \frac{1}{E_z} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{xy}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{yz}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{xz}} \end{bmatrix}$$

Thermal strains are defined with temperature, refernece tempereture and **coefficient of thermoexpansion** (analog. hygroexpansion):

$$\varepsilon_t=\alpha_T(T-T_{ref})$$

$$\varepsilon_w=\beta_H\Delta w$$

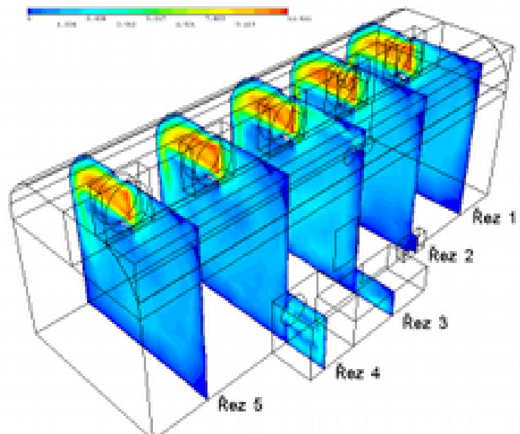
Coupling of the thermal (moisture) field and stress field regards to Hooke's law with decomposition of deformations and 2nd law of thermodynamics is able to define by **2 constitutive thermo-elastic equations**:

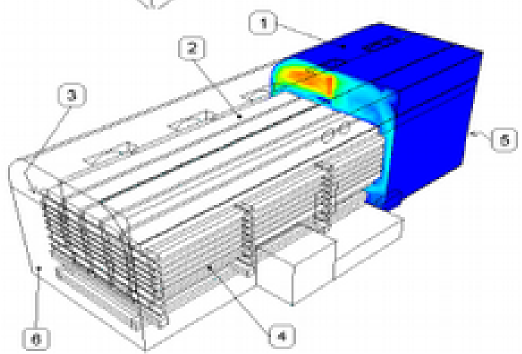
$$\{\sigma\}=[D]\{\epsilon\}-[D]\{\alpha_T\}\Delta T$$

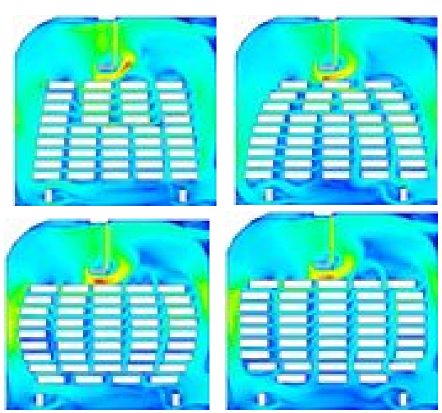
$$\frac{\partial q}{\partial t}=T_0[D]\{\alpha_T\}\frac{\partial\epsilon}{\partial t}+\rho c\frac{\partial(\Delta T)}{\partial t}-[k]\nabla^2 T$$

Examples of CFD in Wood Science

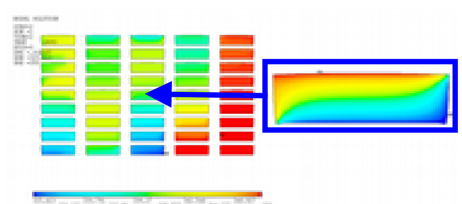
CFD analysis of drying kiln:



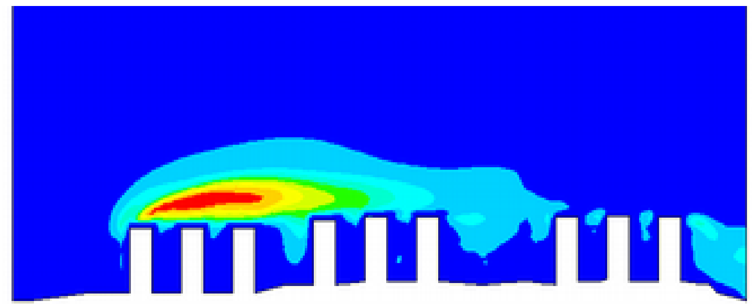




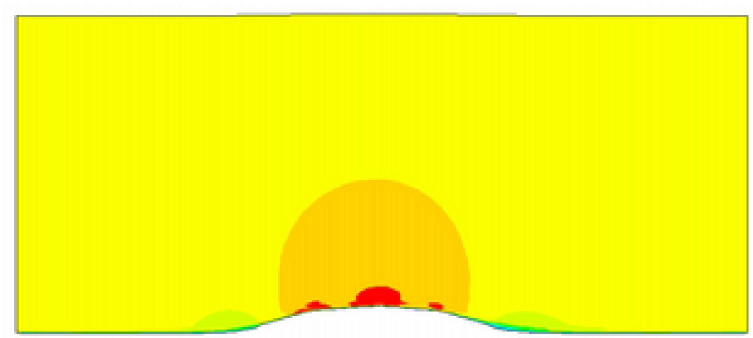
Fluid-Solid Interaction
in thermal analysis

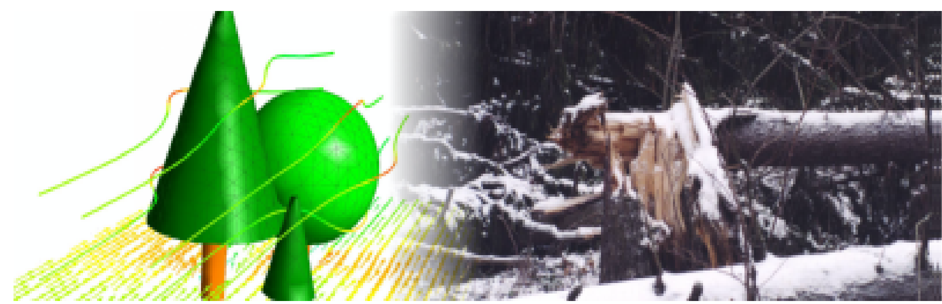


CFD analysis of influence of terrain, canopy, trees



Flotran CFD analysis

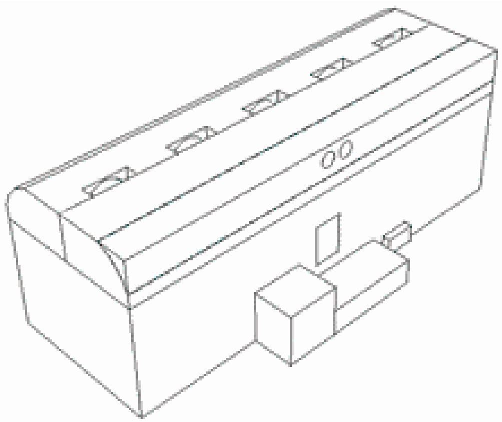
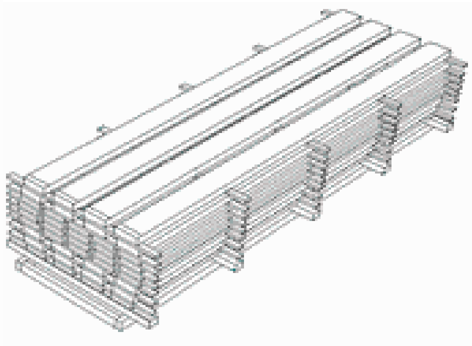
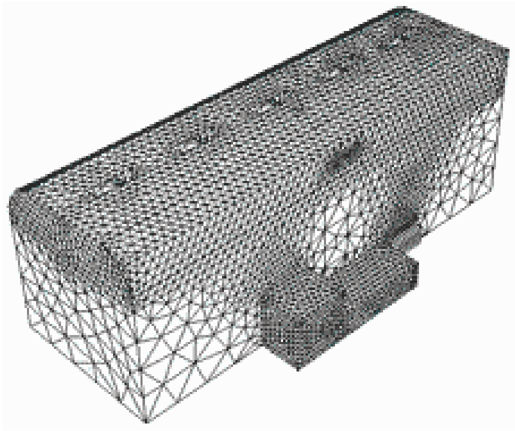
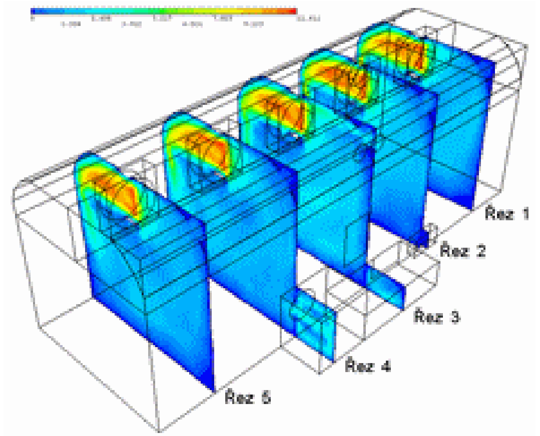




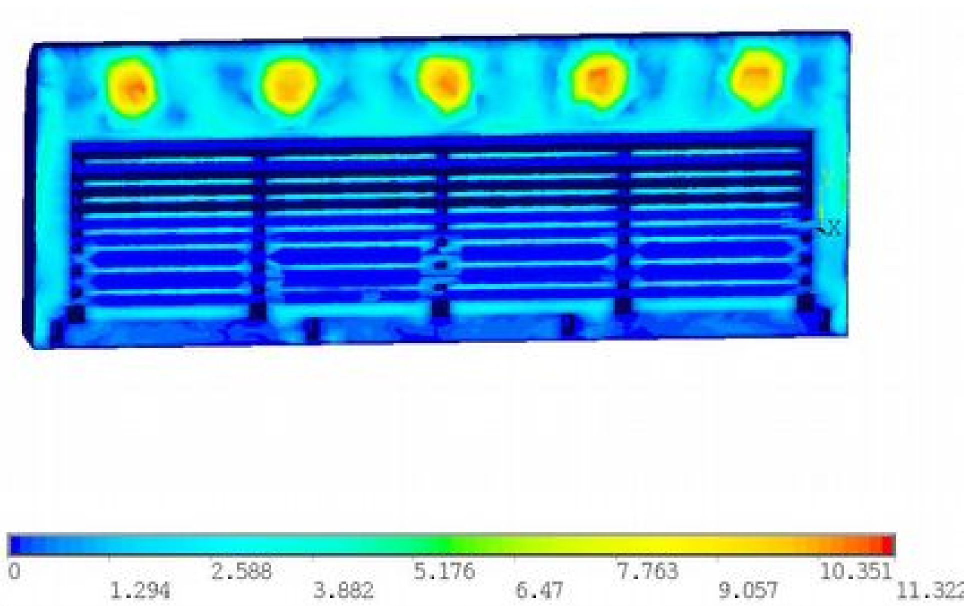
CFX fluid analysis

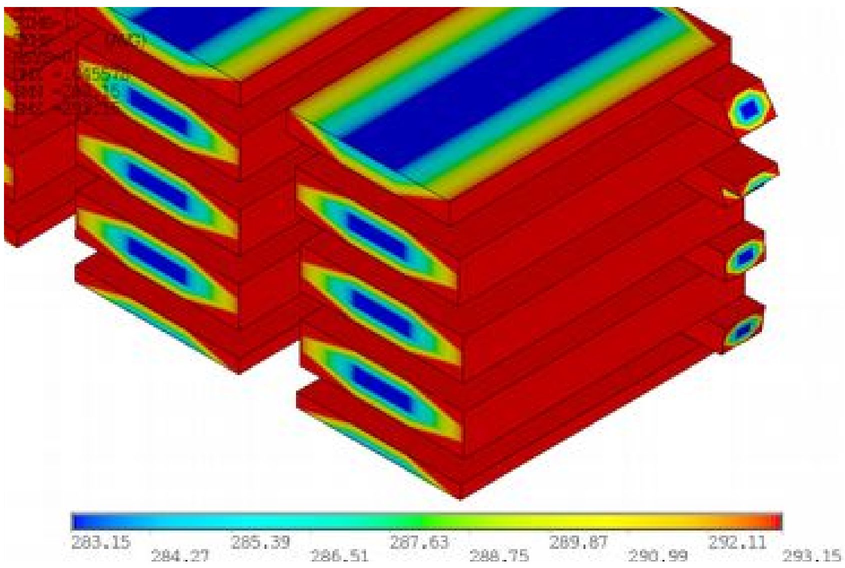
FLOTRAN CFD: drying kiln modeling

Zejda, J., Tippner, J. MENDELU, 2003..

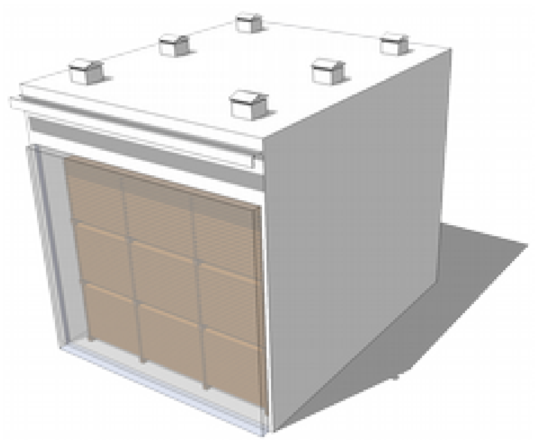
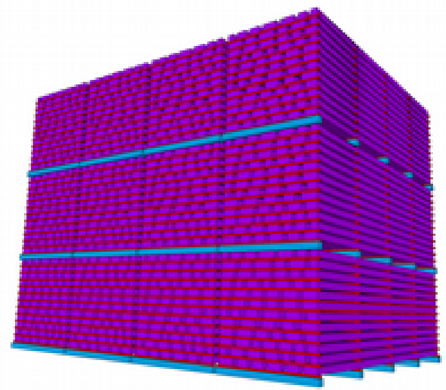
sequentional FSI (Fluid-Solid interaction), laboratory kiln for validation influence of shape of pile

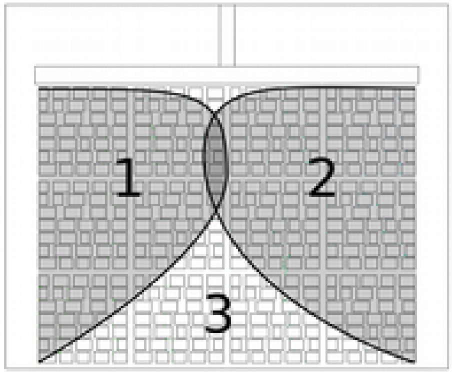




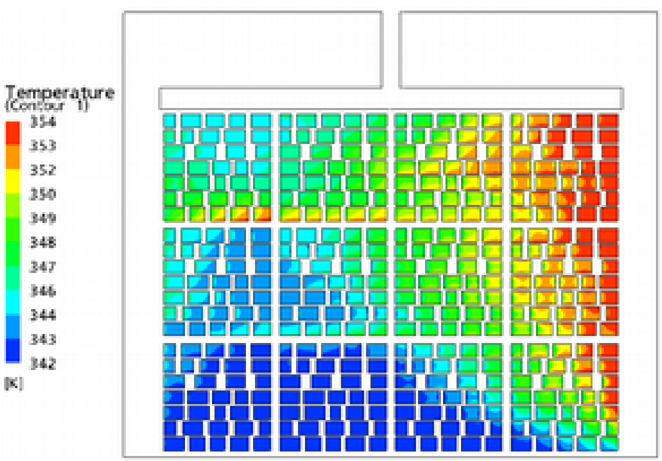
CFX modeling of high-capacity drying kilns

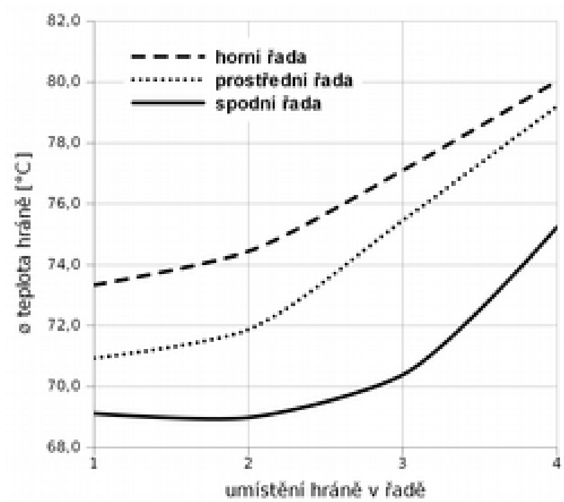
Zejda, J., MENDELU, 2009.

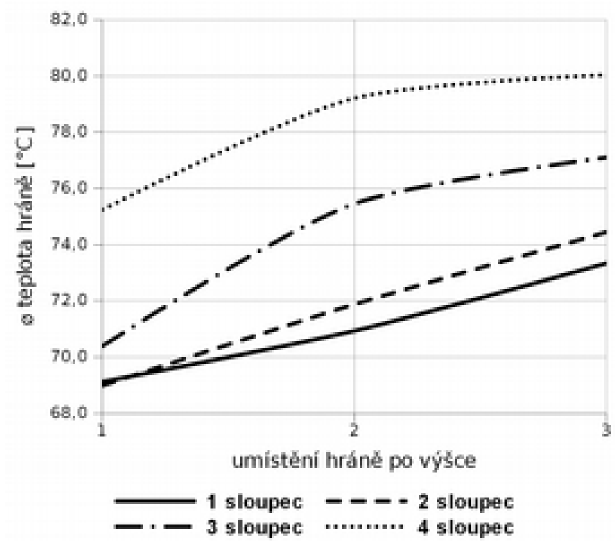





Temperature distributions, CFD based geometry optimization (deflection boards, piles), development of drying schedules.

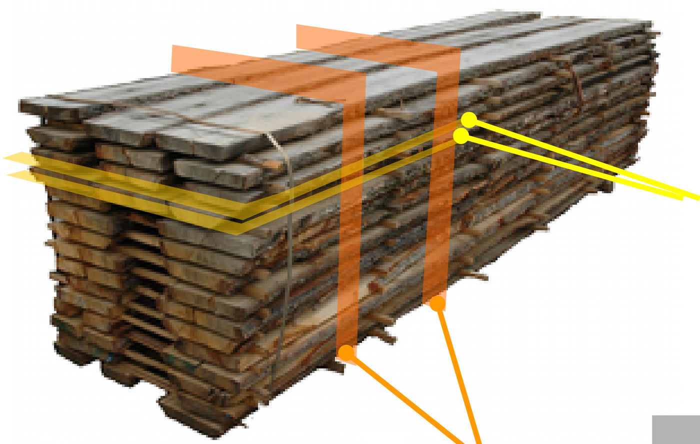


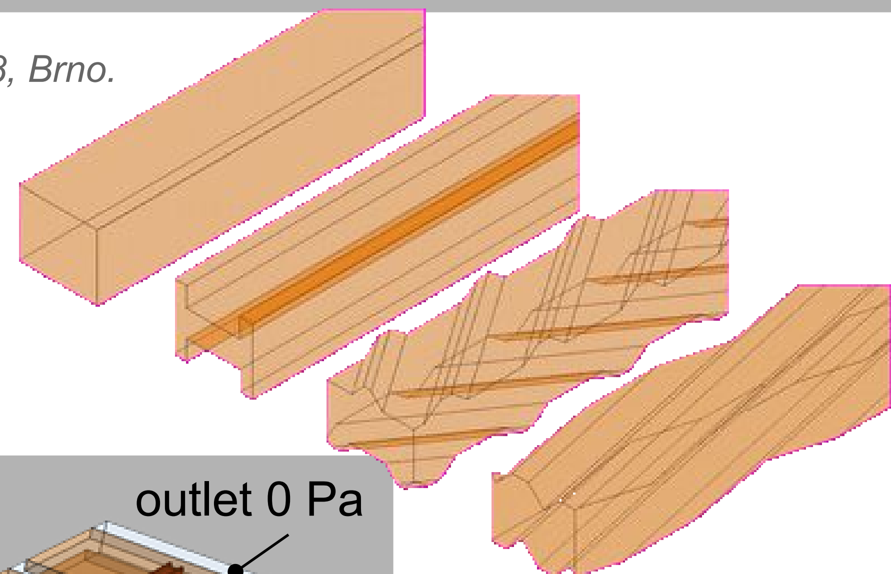


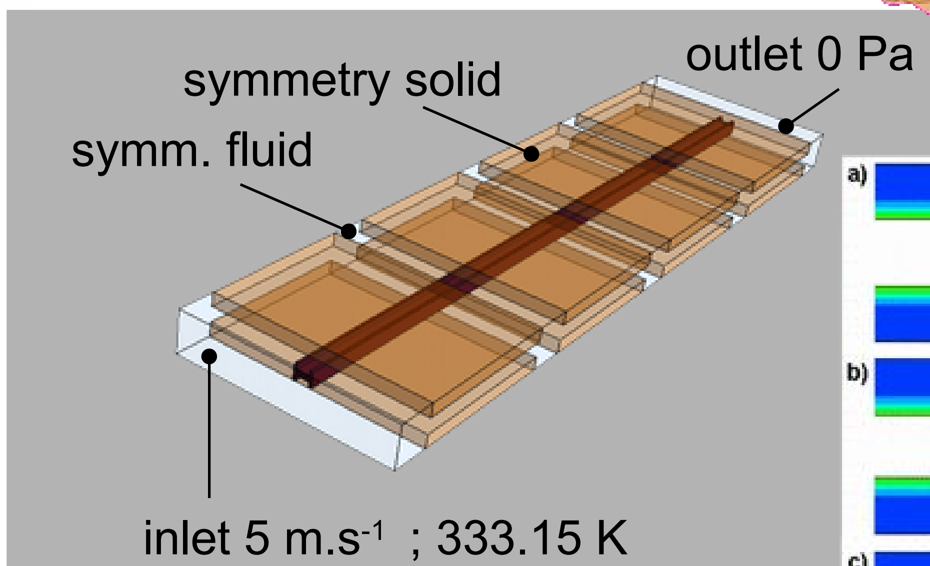


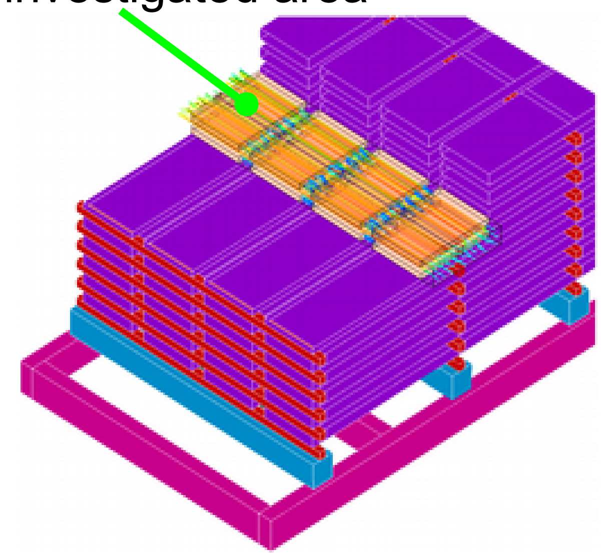
CFX: infl. of stickers on temperature distribution

Zejda, J., MendelNET 2008, Brno.

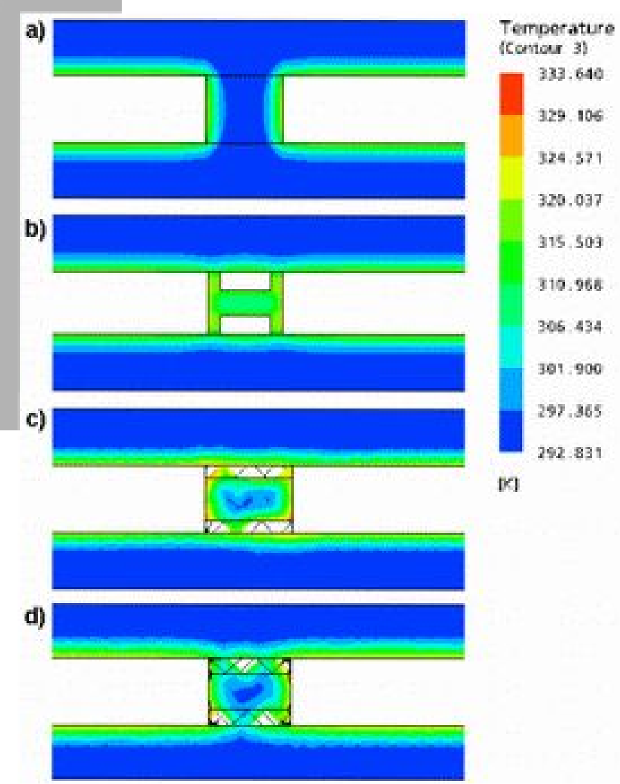






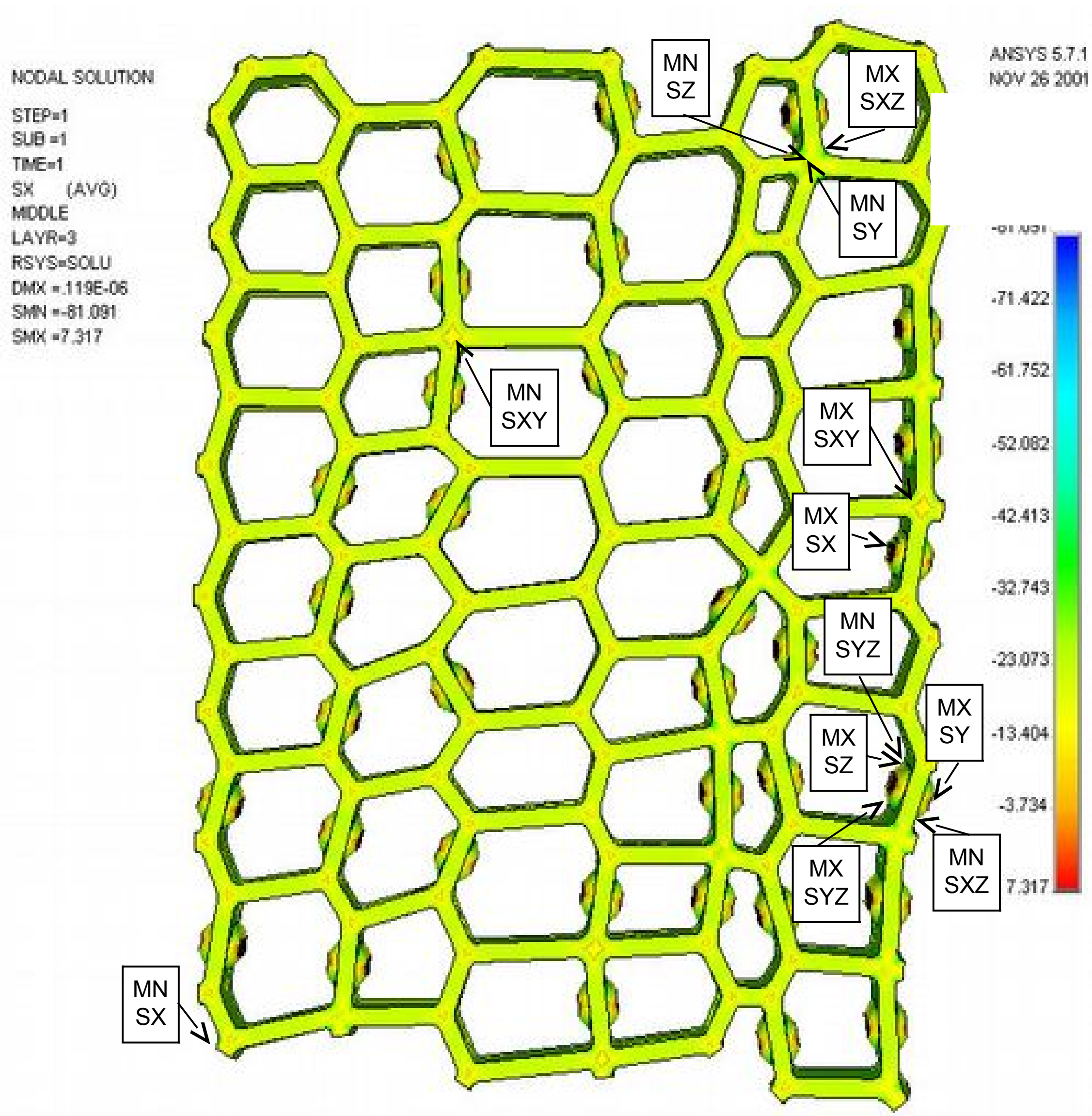


CFX fluid analysis

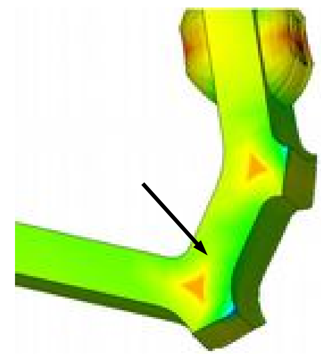


a) rectangular shape influences temperature in boards
b) plastic sticker
c) beech sticker with diagonal channels tuniformly distribution
d) lignostone sticker, antislip form

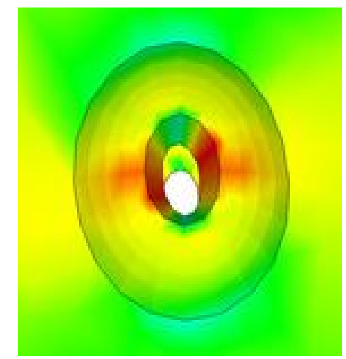
Modeling of Cell Wall - SPRUCE



Javořík, J. MENDELU, 2002



SX - min



SX - max

	FEM Model	Požgaj 1997	Bodig 1993
E_L	12 800	13 650	11 506
E_R	1 052	789	830

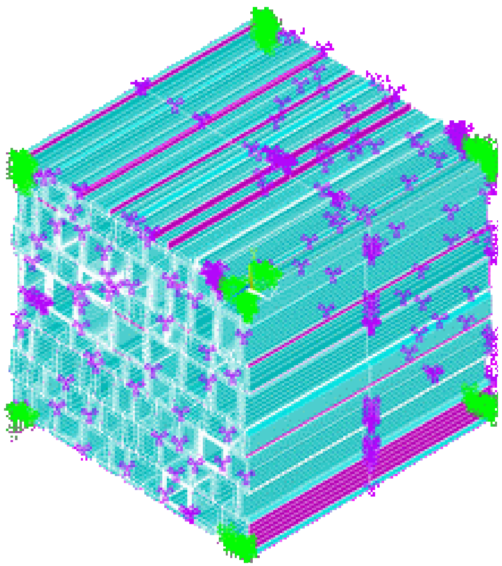
Norway spruce

- able to detect significance of geometry (morphology) parameters between scales

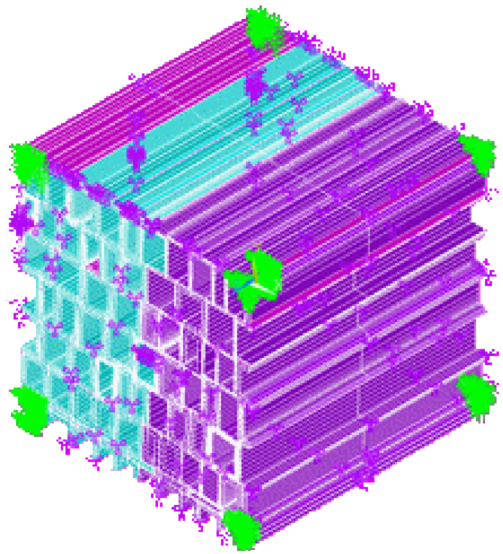
- able to predict "what-if" material changes caused by wood modification

“Superelement” Approach to Wood Modeling

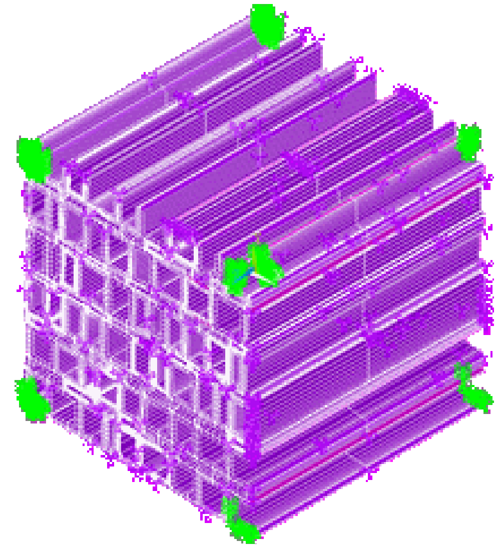
Early wood



Transition zone

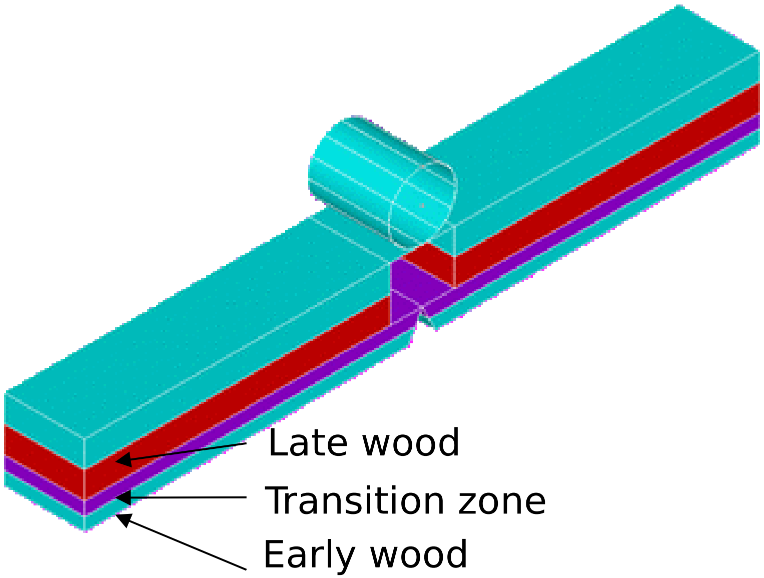


Late wood



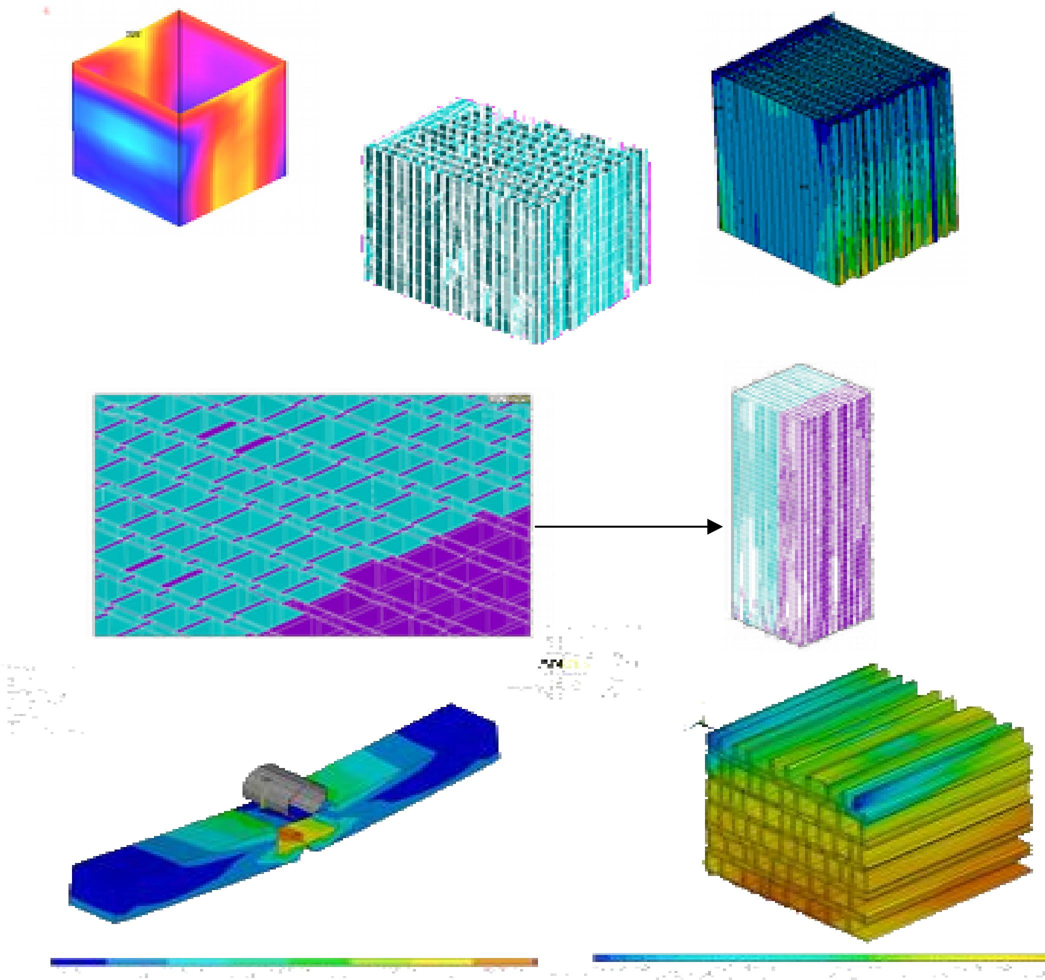
Material constants

	dir./plane	wood			
		early	late	transition zone	
Cnt. of trach.planes		28	22	21	-
Porosity		0.435	0.444	0.549	-
Young module in compression	L	21414.38	20206.35	15420.54	MPa
	R	3319.82	3053.32	1876.42	MPa
	T	2146.67	2651.19	2002.52	MPa
Shear module	RL	574.26	543.01	363.33	MPa
	RT	341.65	394.27	276.91	MPa
	TL	485.89	507.33	377.03	MPa



Anisotropic HOMOGENIZED model of Wood Structure

Konas, P., MENDELU, 2005



FE model of Wood Cell Wall structure (scale: **sub-micro**)

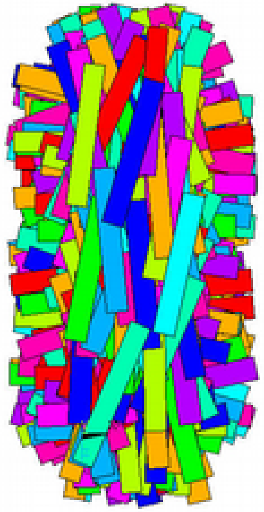
FE model of anatomical structure of wood (scale: **from sub-micro to micro** level)

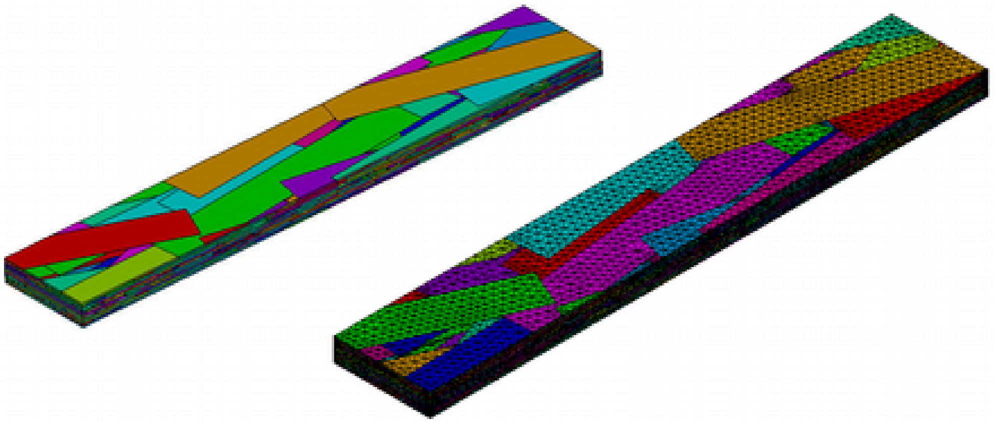
FE homogenized model of wood (scale: **sub-micro to macro**)

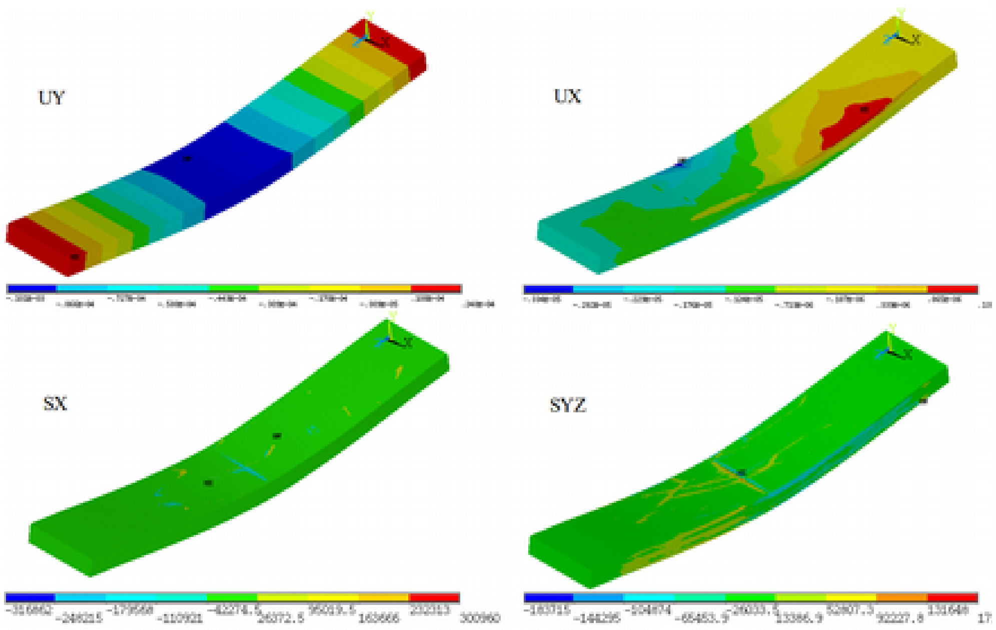
- transformation into isotropic scale (less complicate physical laws and parameters used), still appropriate model for simulation of difficult physical problems

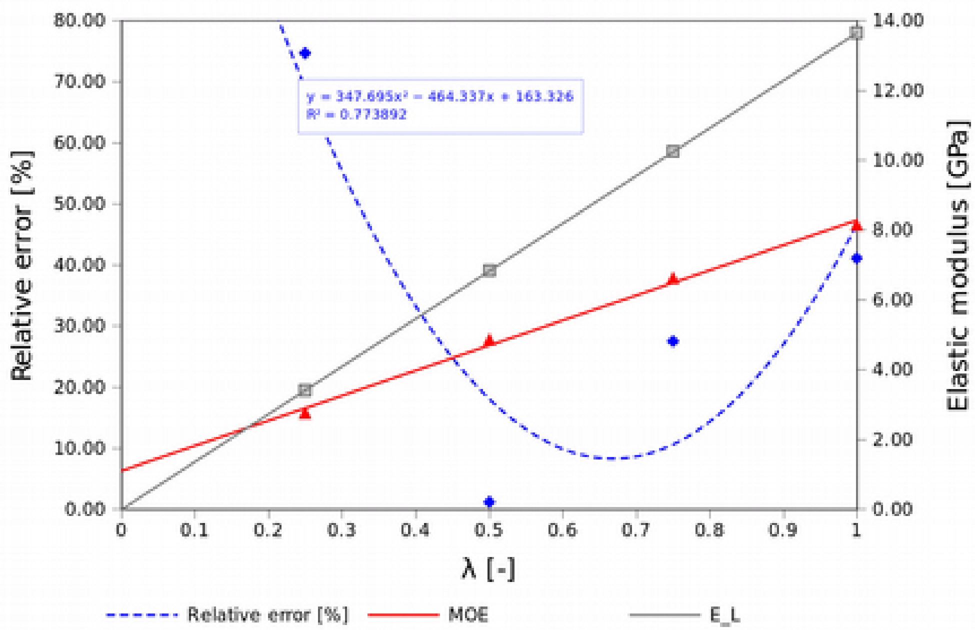
FEA of OSB – deterministic model

Sebera, V. MENDELU, 2016 – Deterministic modeling of composite, „projection“ of material properties into global bending modulus, inflence of orientation of particles.



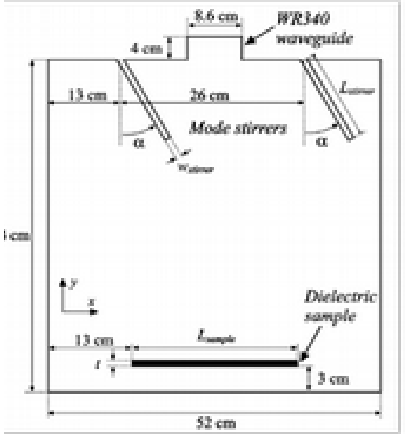


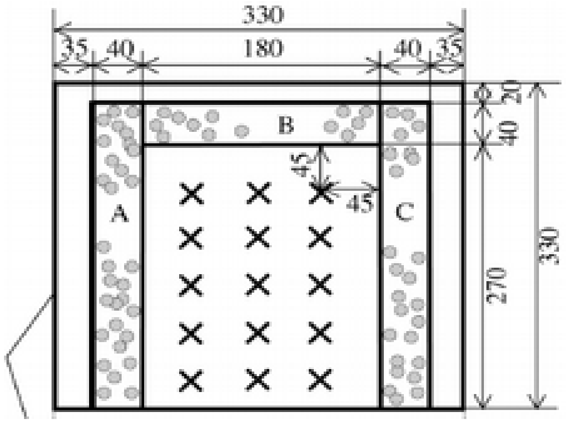




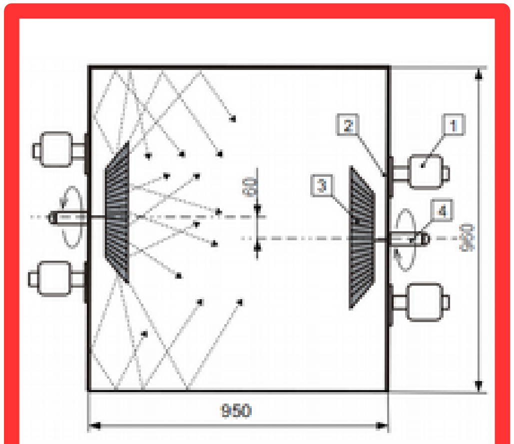
Uniformity of MW field

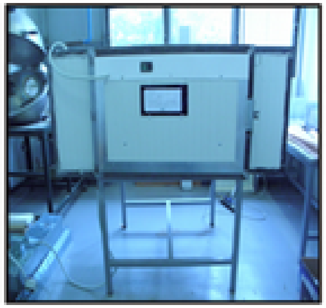
Spencer, P. 1950 : 1st patent for meal warming using MW (USA)





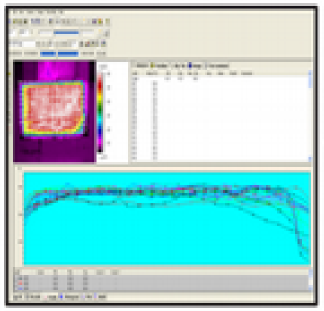
1) rotation/shift or 2) mode stirrers (reflective plates, movable reflective beads, fan-like stirrers)



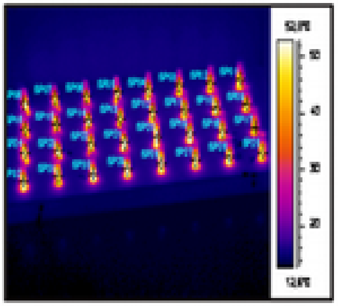


MIA-4K

ThermaCAM™P65



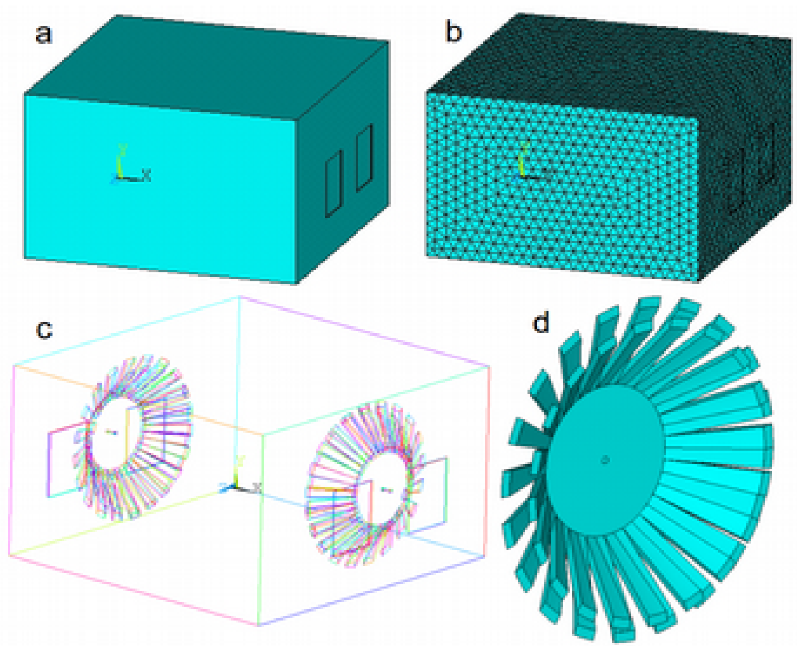
ThermoCAM™Researche™



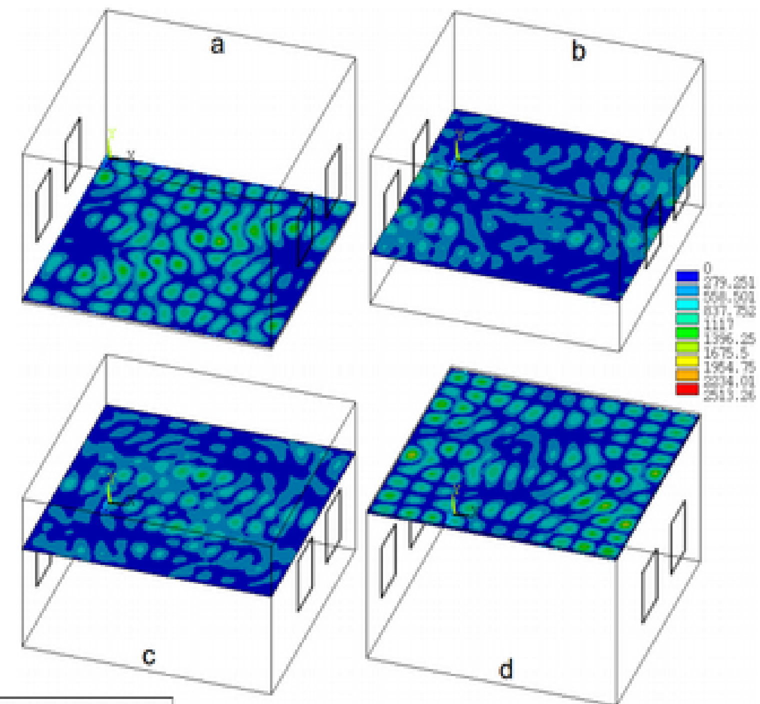
Thermogram

Nasswetrová A. et al. The analysis and optimization of HF electromagnetic field homogeneity by mechanical homogenizers.... Wood Research, 2013.

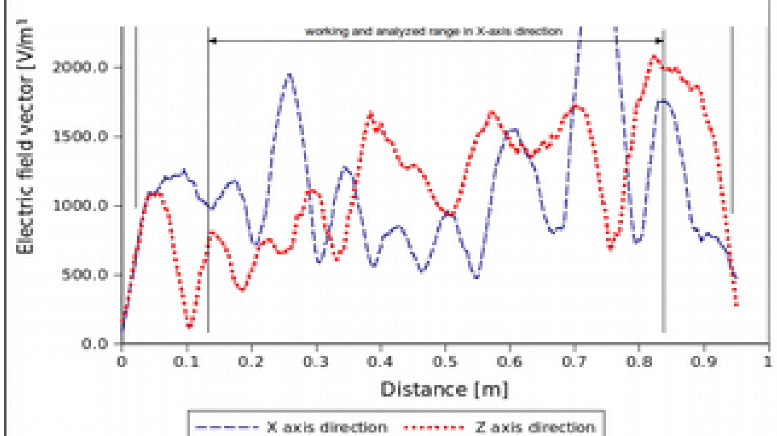
Analysis of mode stirrer: field uniformity in MW wood dryer

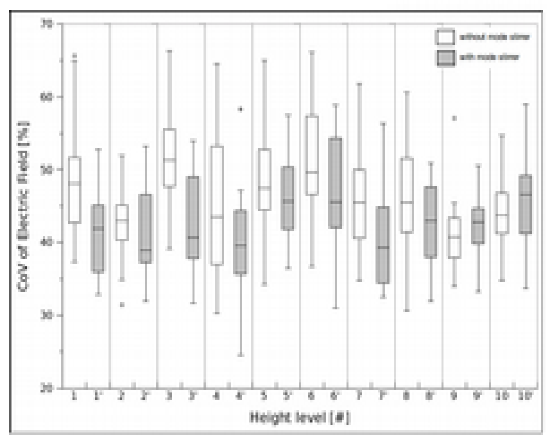


FEM with/without stirrers

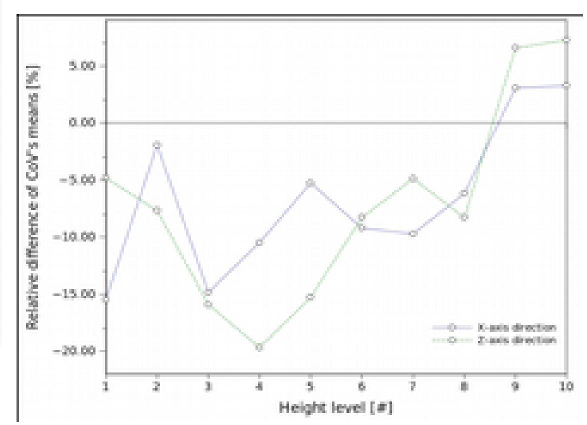


EF distribution along the paths:





analysis of variability



Sebera, V., et al. FEA of mode stirrer impact on electric field uniformity in MW…, Drying Technology 2012.

Probabilistic analysis of semi-destructive device

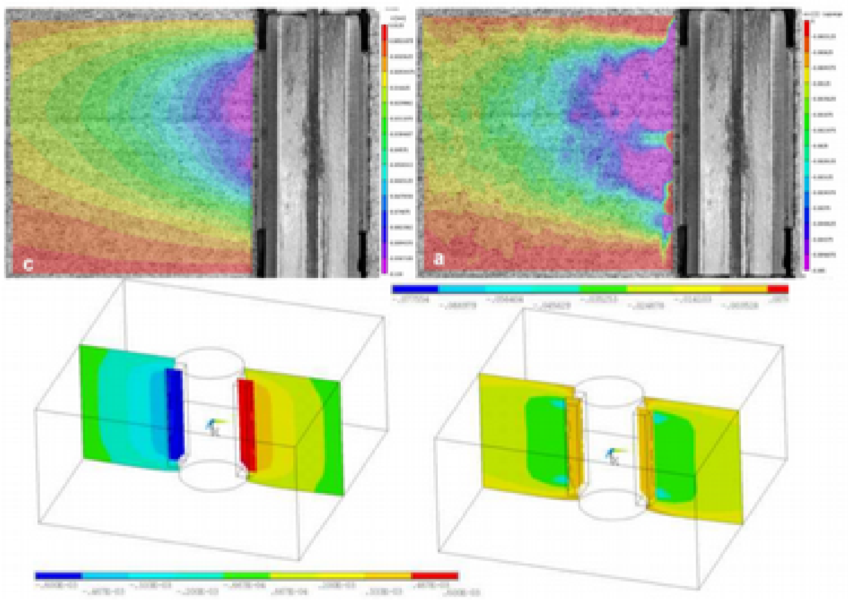
What is sensitivity of developed *in-situ* device to material parameters?

1) **building and validation of** model, (FEM x measurements by DIC),

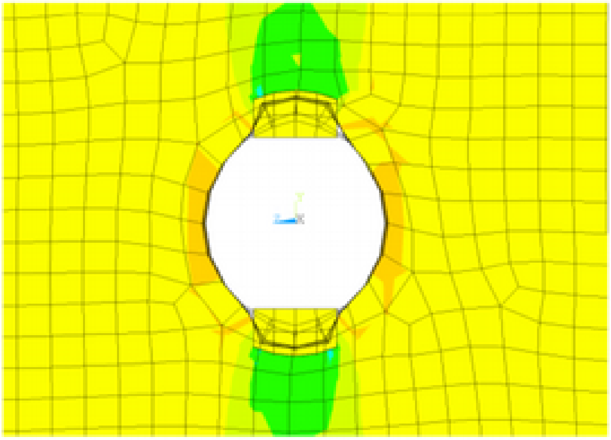
ARCCHIP
ITAM

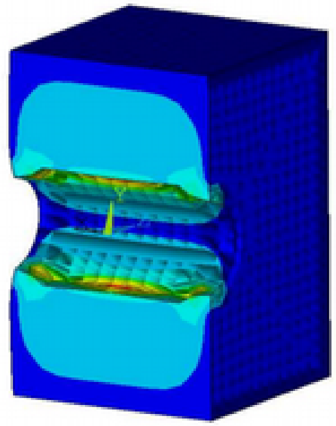
2) using of verified model for probabilistic analyses (**PDS** - hundreds of simulation with *Monte Carlo* generated inputs)

3) describe **correlations between material** properties and measured parameters



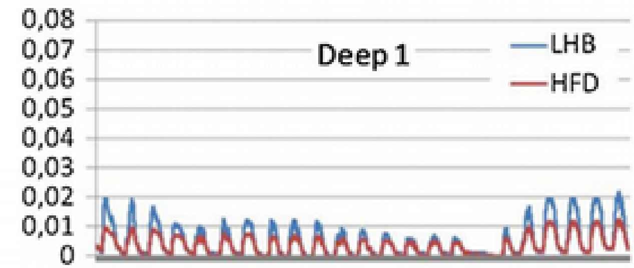
	E_L	E_R	E_T	G_{RT}	G_{LT}	G_{LT}	A_L	A_T	A_R
F_R	**0.959**	0.013	0.048	0.035	0.073	0.014	0.030	0.019	0.027

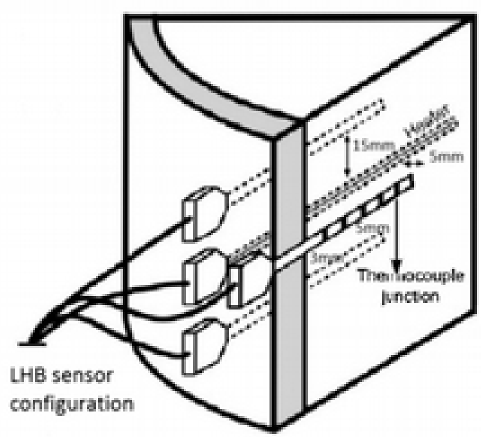


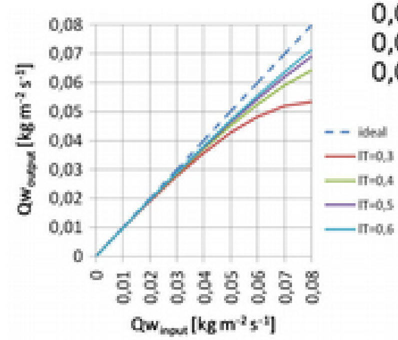


Innovation of Sap Flow Measurement Method

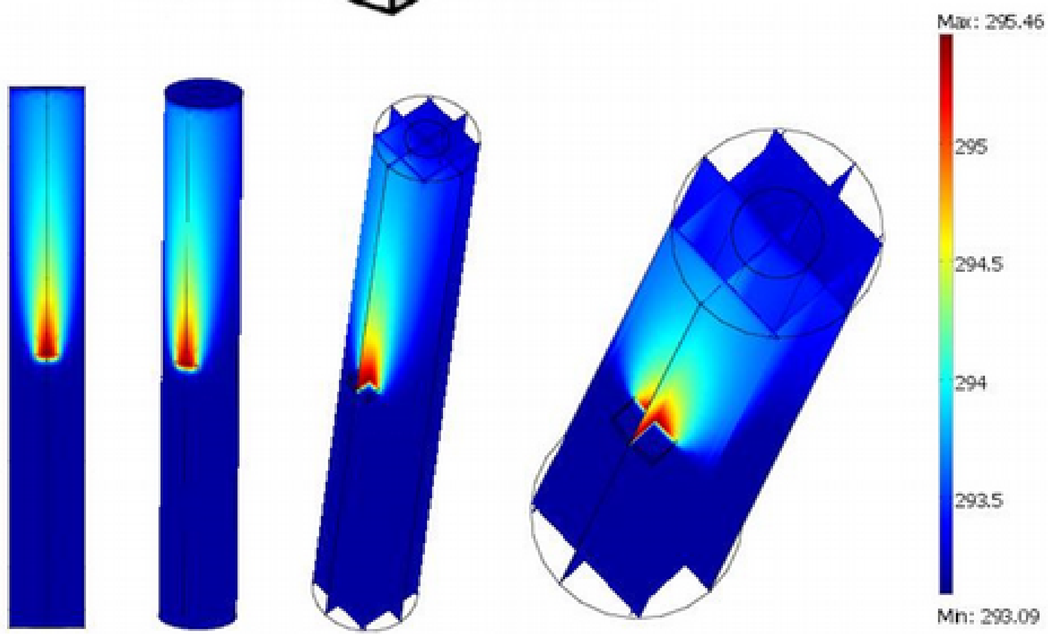
Trcala, M., Čermák J. A new heat balance equation for sap flow calculation...Applied Thermal Engineering, 2016.

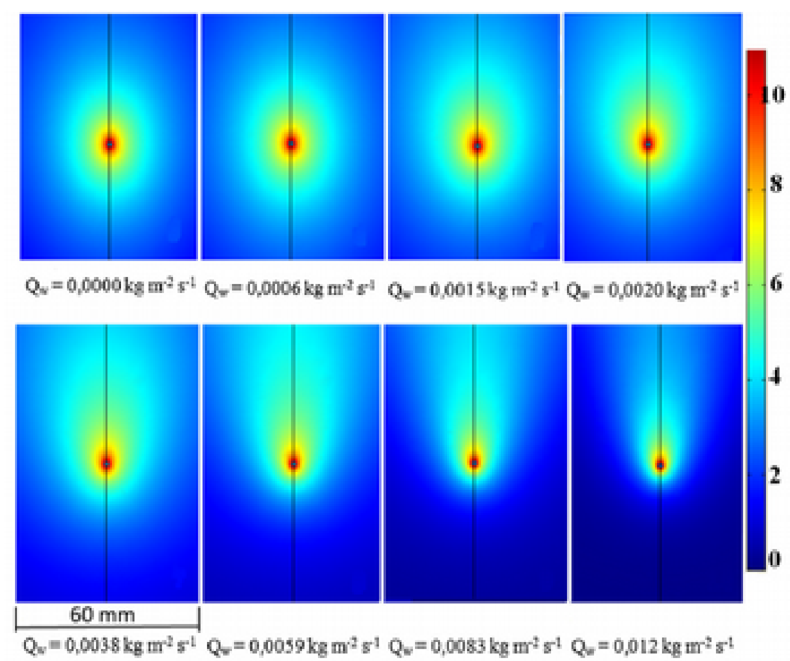






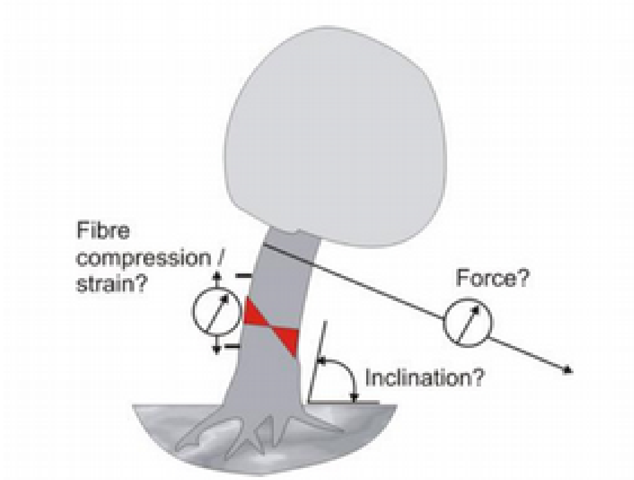
COMSOL MULTIPHYSICS





new formula (LHB) for sap flow calculation was derived from the steady-state 2D PDE (conduction and convection of heat in sapwood using the HFD configuration

Tree biomechanics – static test of tree



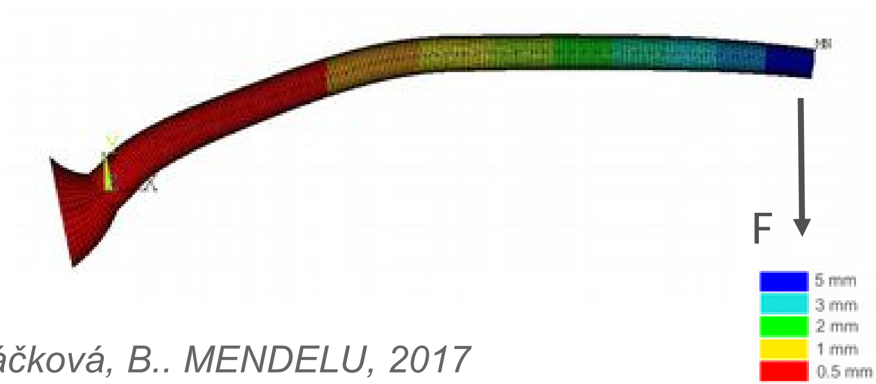
Root plate + stem ⟷ Branch

Root plate + stem ⟷ Tree

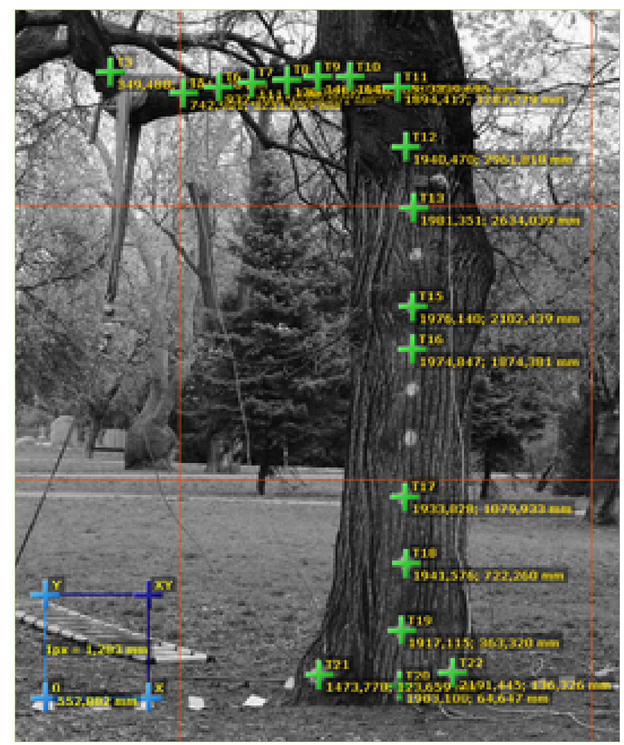
Branch ⟷ Tree

Branch

- 3D structural analyses
- BEAM elements – 187 – tapered
- orthotropic material model (E_L = 8 GPa)
- Force = 2066 N
- Large deformation

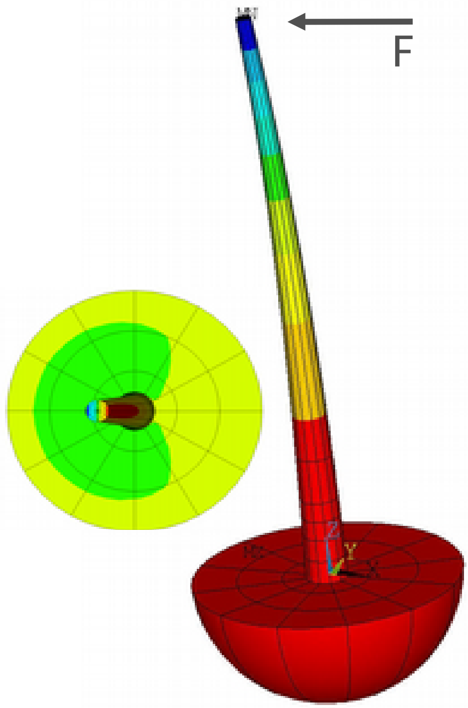


⟷



Vojáčková, B.. MENDELU, 2017

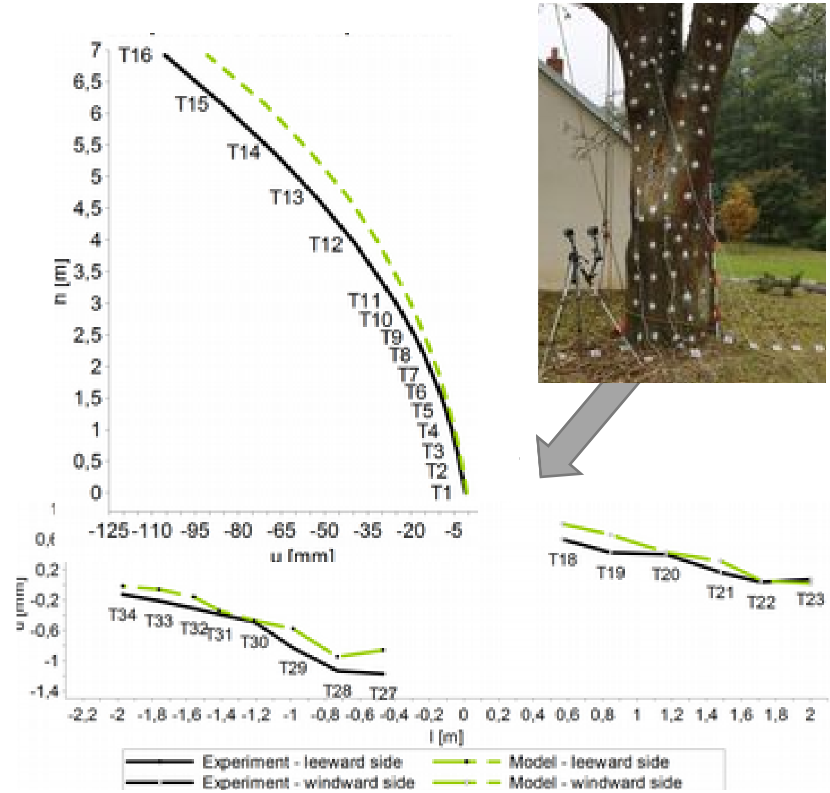
Tree biomechanics – static test of tree



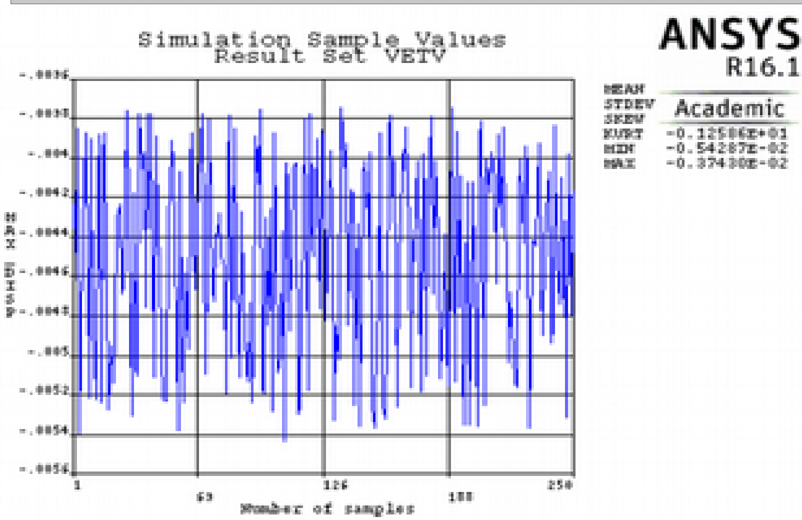
Stem and root plate

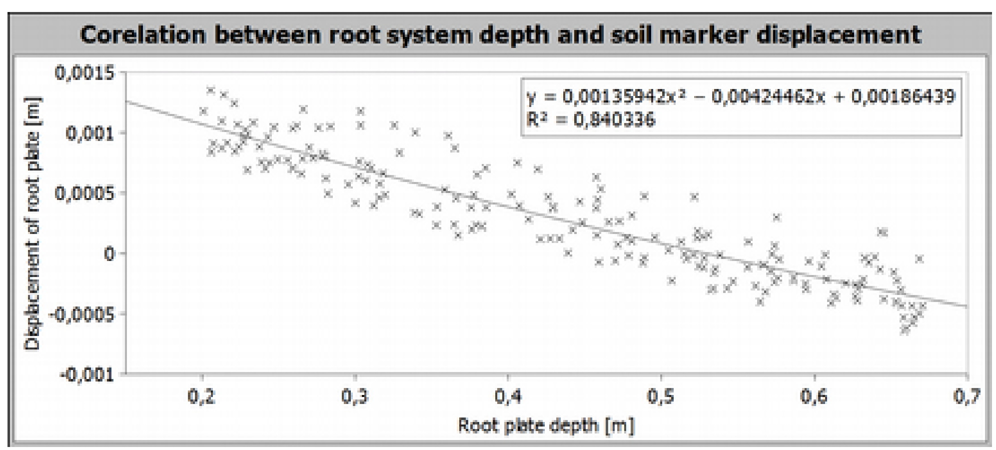
- 3D structural analyses
- SOLID elements – 187 tetrahedrons
- 108 segments – different material
- Stem – orthotropic material model
  (E_{L_base} = 4 GPa, E_{L_stem} = 5.1 GPa)
- Root plate – isotropic material model
  (E_{L_roots} = 2.02 GPa, E_{L_soil} = 0.02 GPa)

Vojáčková, B.. MENDELU, 2017

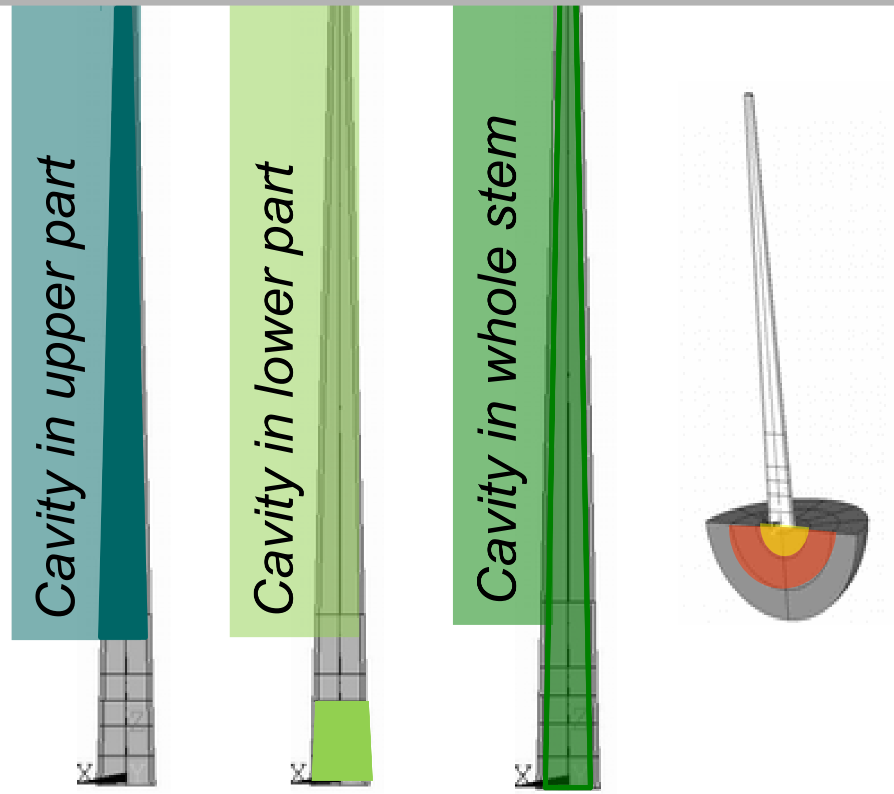


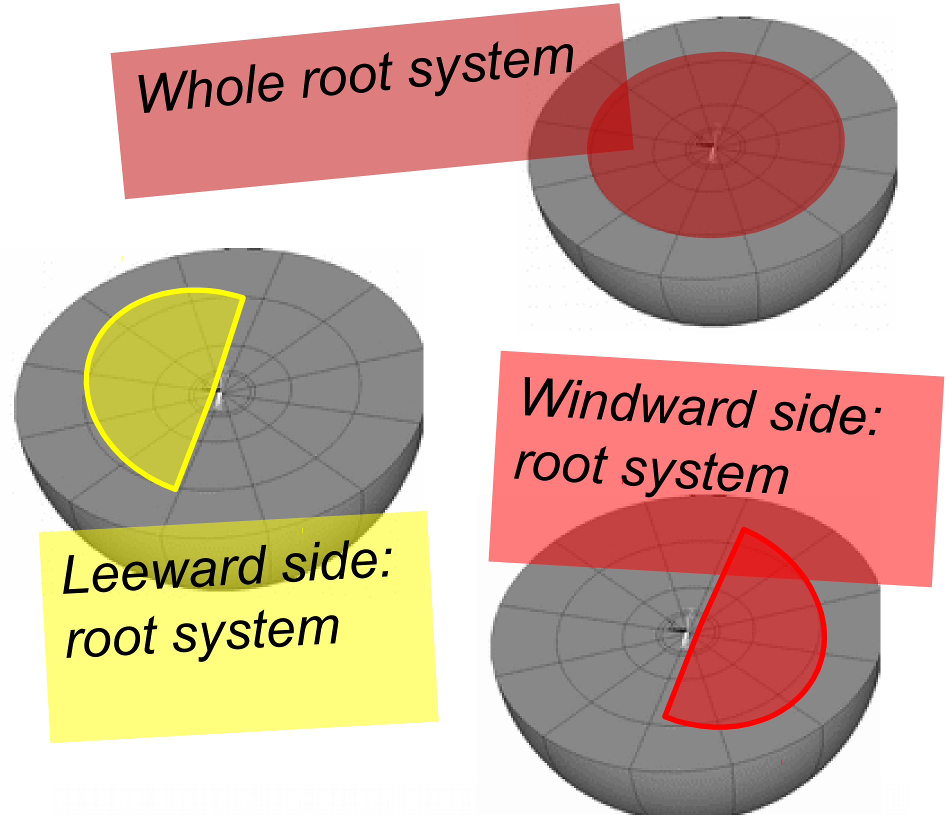
PDS (tapering, stem diam., depth of RS...):

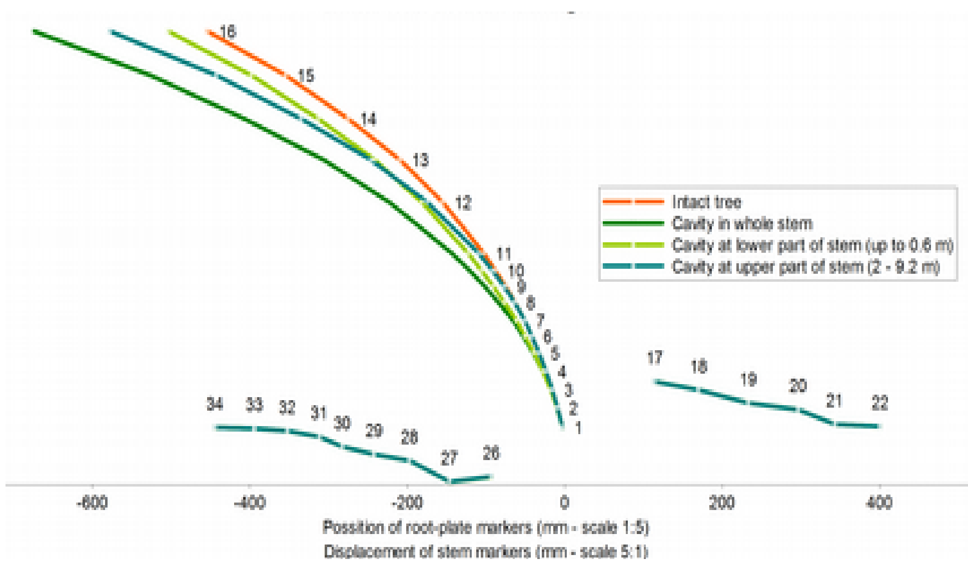


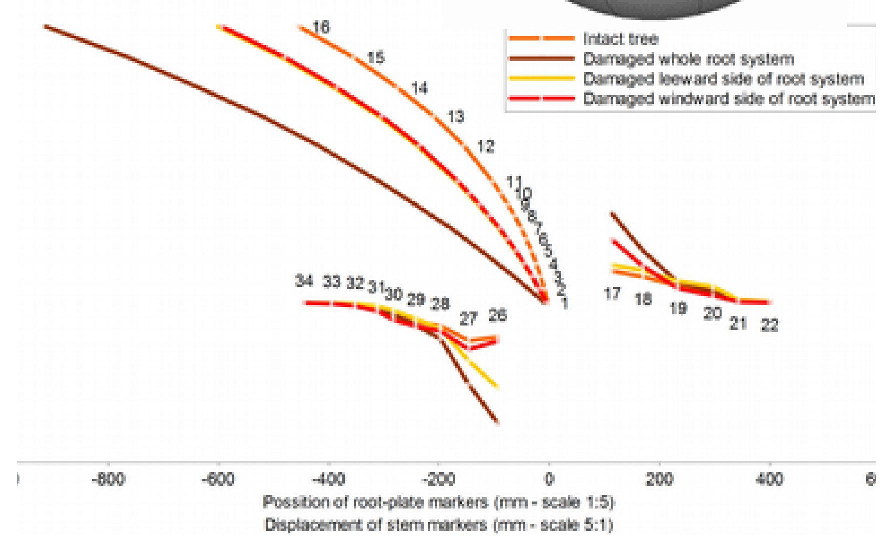


Tree defect simulation (stem, root system)



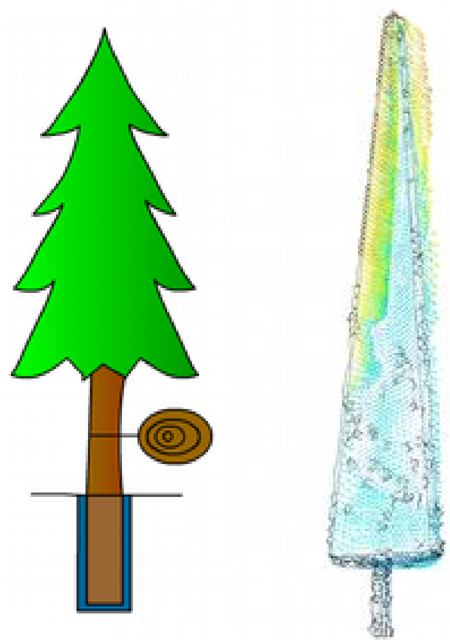






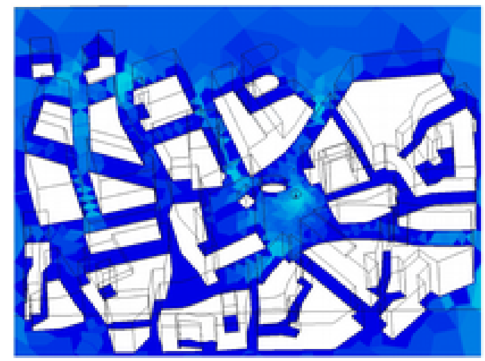
Wind Load Analysis – Christmas Tree

Prague's Christmas tree – synergy of wood anatomy, tree biomechanics, wood mechanics and numerical simulation

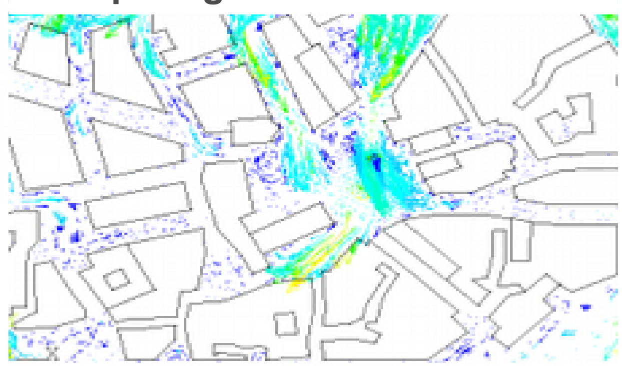


Boundary conditions – "weather"

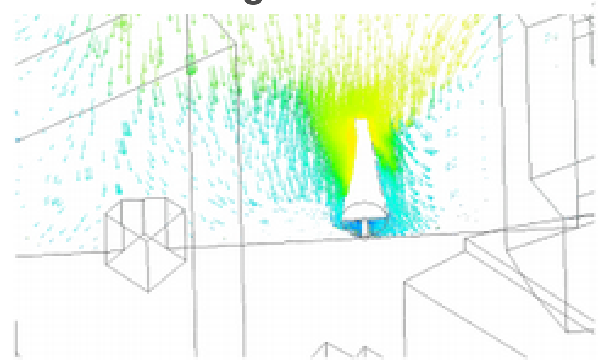
CFD analysis of the square



Computing of wind distribution

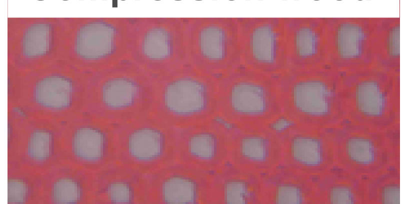


Wind loading on the tree



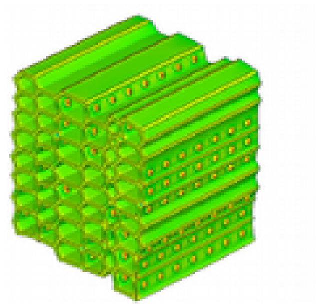
Tree failure mode – torsion

Compression wood

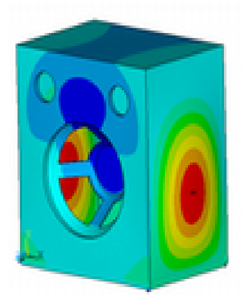


Although anchorage was good enough, a **combination of different mechanical properties of wood** (CW) **and character of loading** caused the fall.

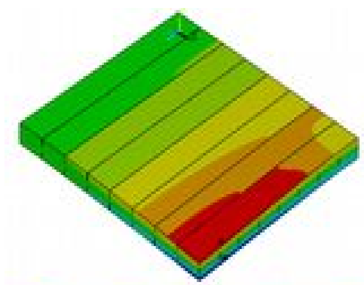
Examples of FEA in Wood Science & Technology



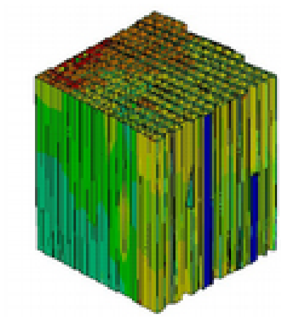
Mechnaics - Wood cell submicrostructure



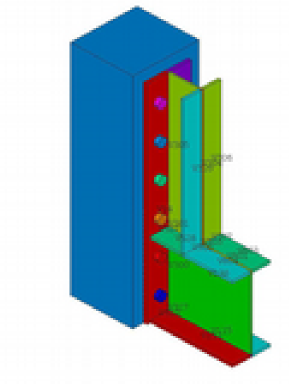
Acoustics - Loudspeaker



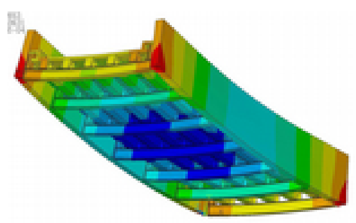
Stress/strain - CLT Panel



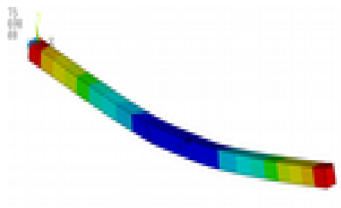
Multiphysics - Wood microstructure



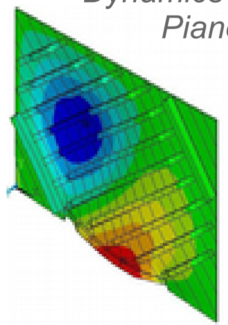
Mechanics of joints

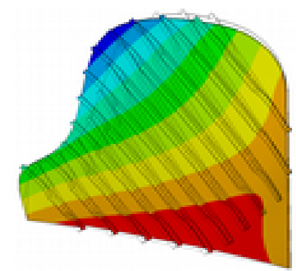


Mechnaics - Bridge

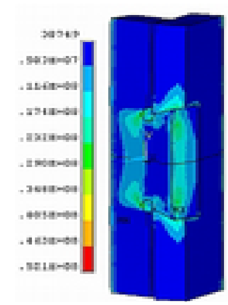


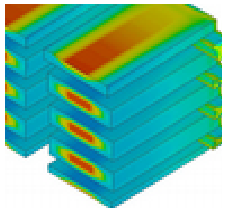
Mechanics – Historical Wood Jointings



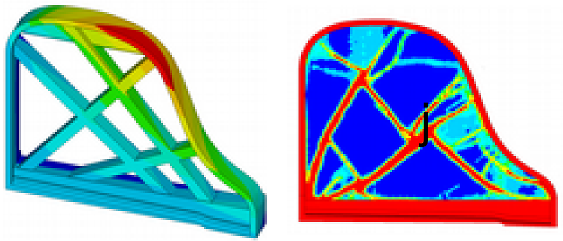


Dynamics / Hygroexpansion Piano soundboard

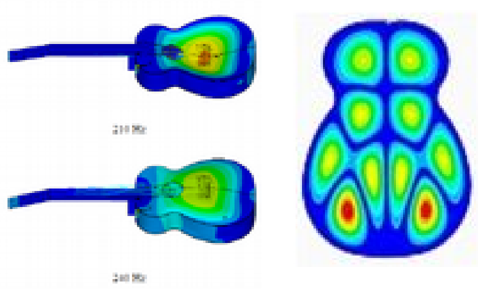




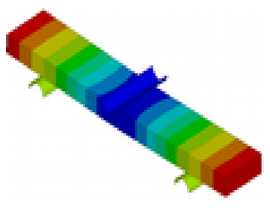
Thermal/Stress - Wood drying



Mechanics/Dynamics - Frame of piano



Dynamics - Guitar



Mechanics – Standard tests