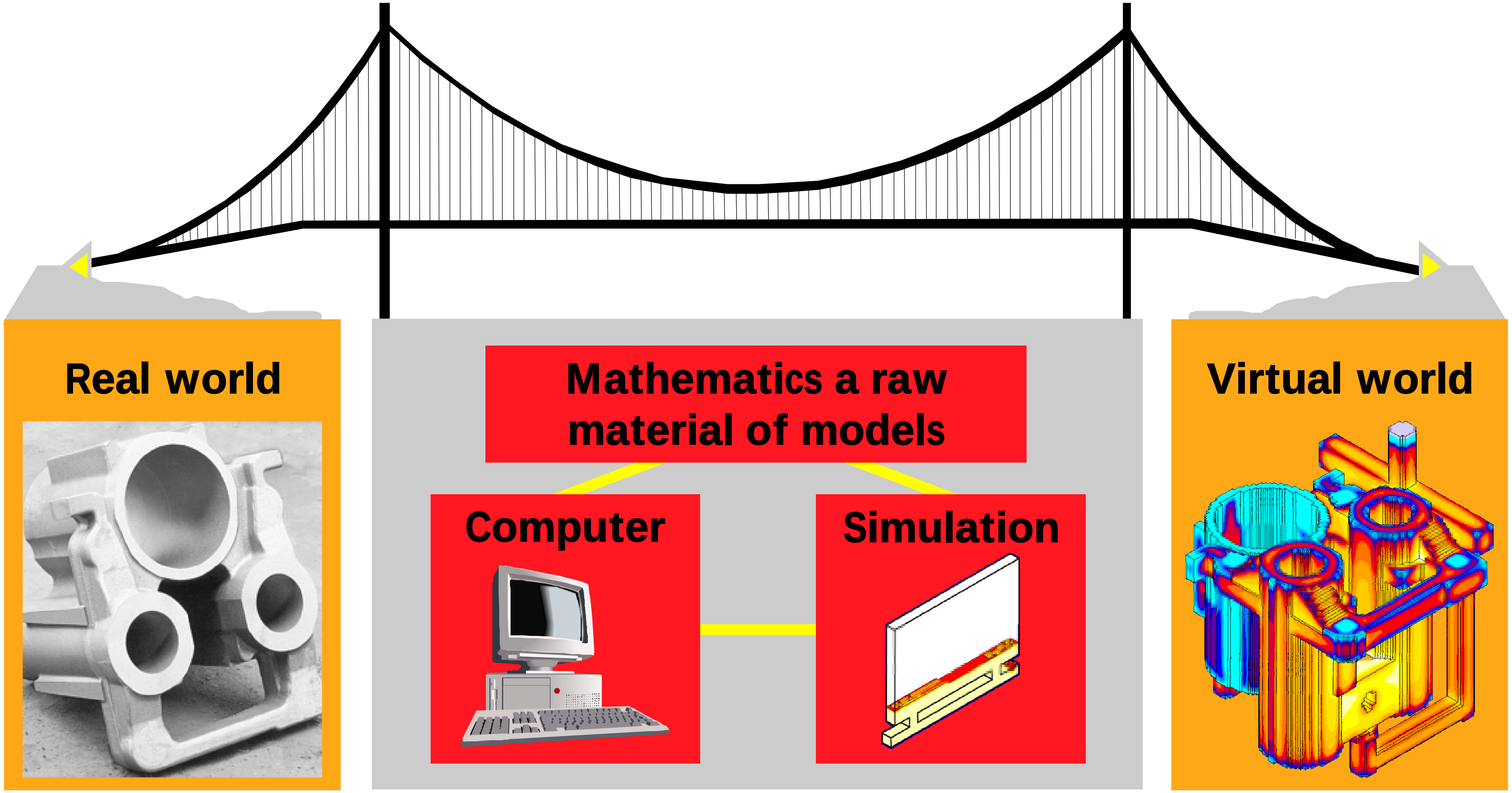
Virtual Textile Design for an Integrated Product Policy

Fraunhofer Institut Techno- und Wirtschaftsmathematik

Andreas Wiegmann, PhD (Univ. of Washington)

Techtextil Frankfurt, 8. April 2003

Mathematics as a key technology



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Scientific Exchange and Mathematical Expertise

TECHNOLOGY

"Classical" disciplines

- Numerics
- Differential equations
- Stochastics
- Optimization

Mathematical Expertise of ITWM

"Border areas"

- Fluid dynamics
- Image processing
- Neural networks
- Inverse problems
- SPH
- System and Control theory
- Queueing theory
- Fluid-Structure Interactions
- Facility location planning

MATHEMATICS

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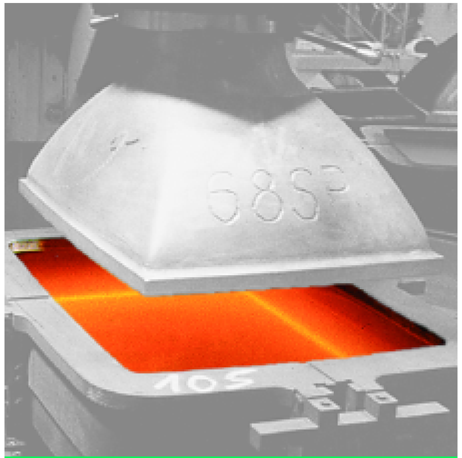
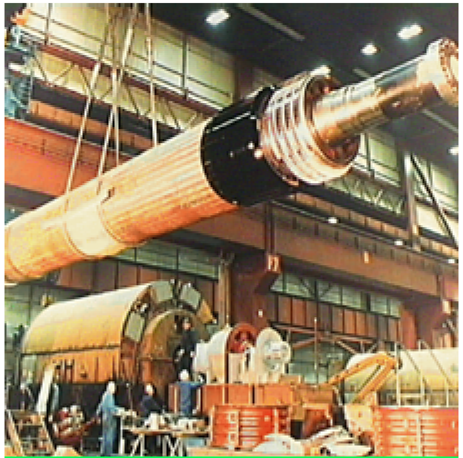
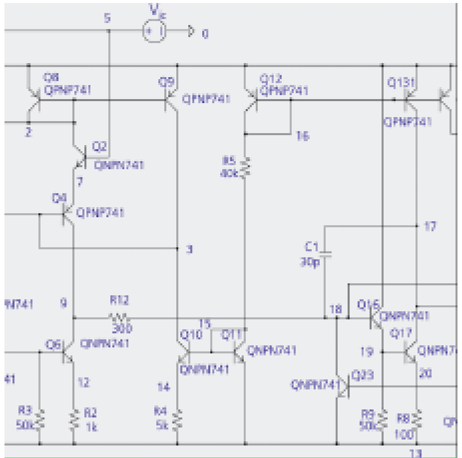
Industrial projects and partners of ITWM



Schott Glas

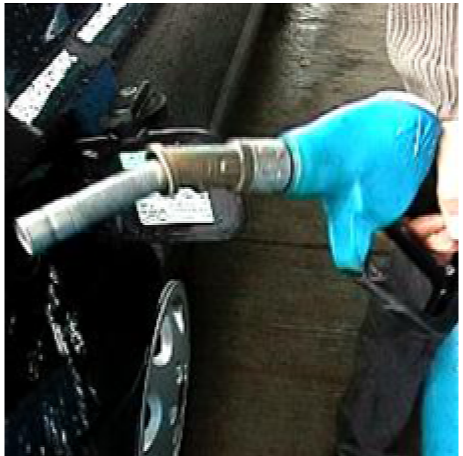


SIEMENS

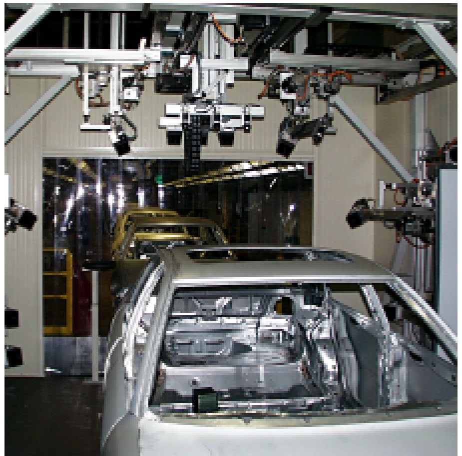


Infineon

SAP



Volkswagen



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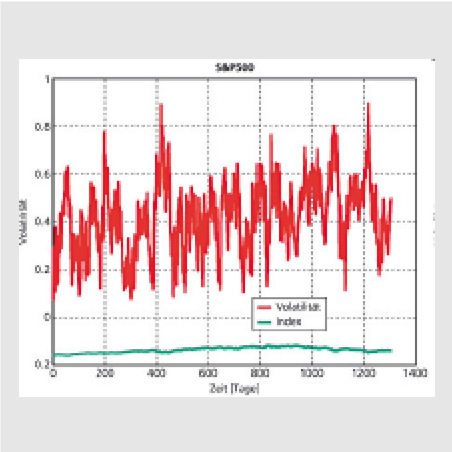
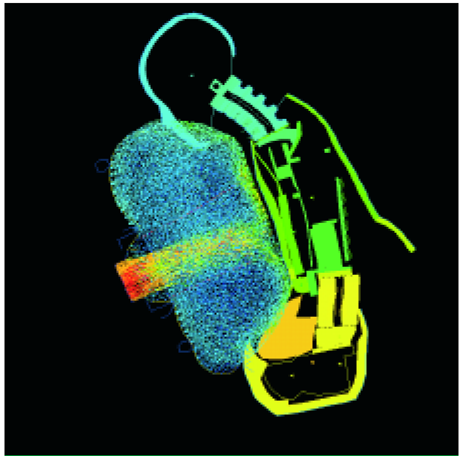
Industrial projects and partners of ITWM



Hypovereinsbank



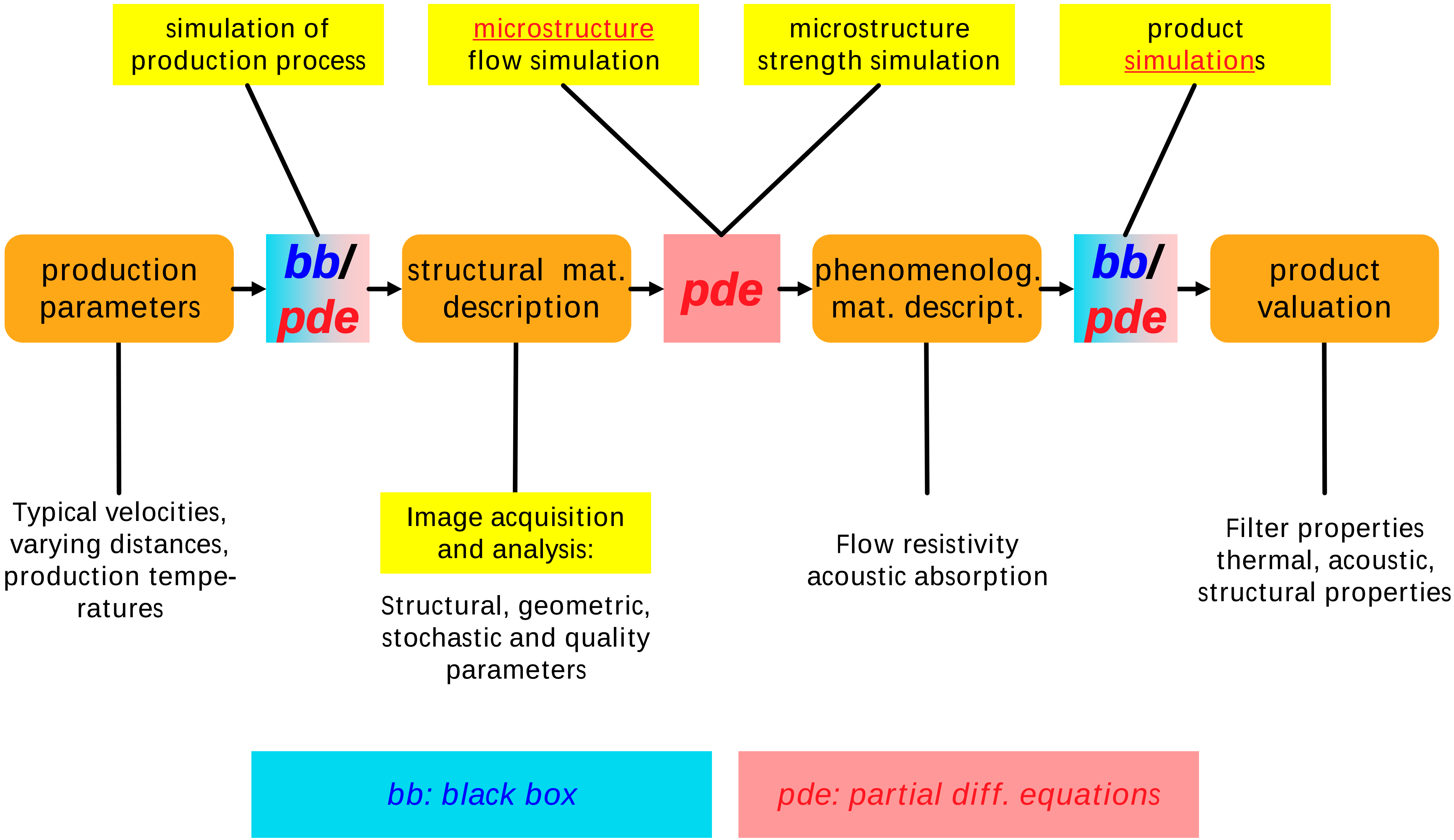
ESI-Group (F)

Statistics 1996 - 2001

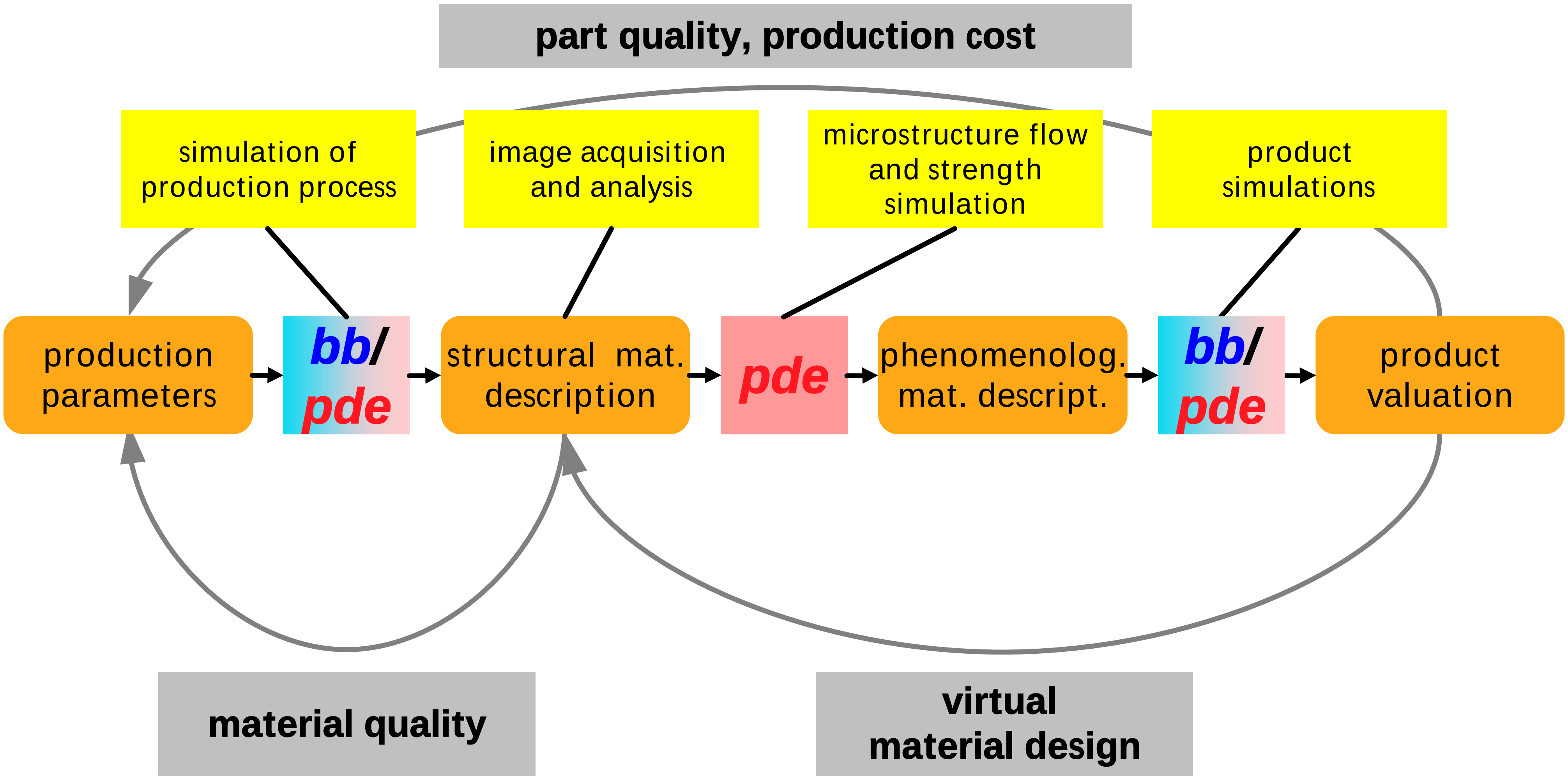
219 industrial projects	→	136 SME-projects	→	86 regional SME-projects
10 million €		5.3 million €		3.2 million €

Only 37 of the 219 industrial projects are without follow-up order !

Virtual Material and Process Design: Production of non-wovens



Optimization problems



ViMPO projects at ITWM

- Extension of virtual material and process optimization from textiles to construction materials, wood, paper, leather, … in the ViMPO toolbox, towards strength, heat transfer, radiative transfer, moisture transfer and acoustic absorption properties
- Use of surface inspection, 3d image acquisition and 3d image analysis methodologies
- Process simulation in the filter, glass and textile production industries
- Use of black box techniques and wherever exact physical descriptions are not known or where online results are required.

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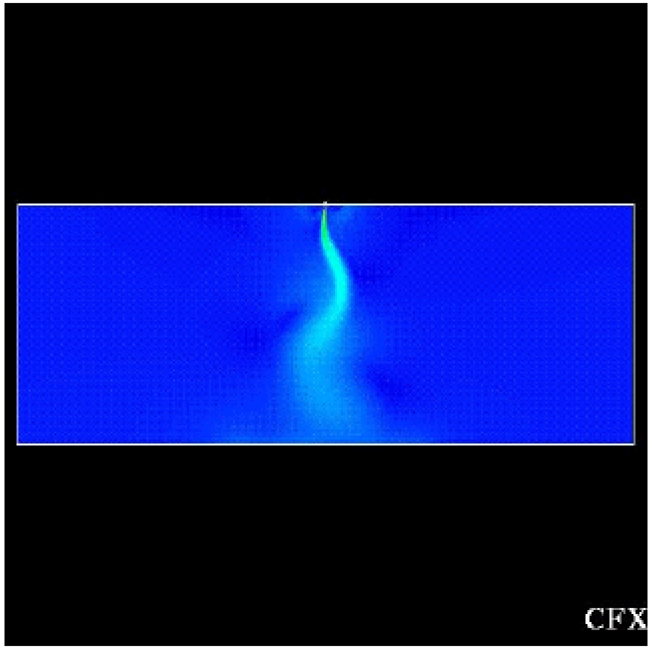
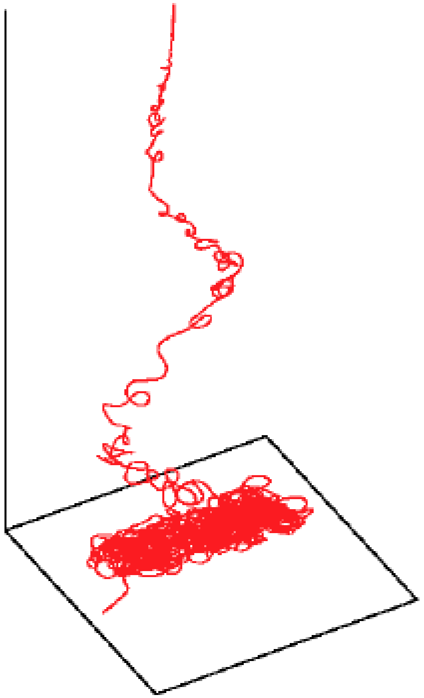
Simulation of production process

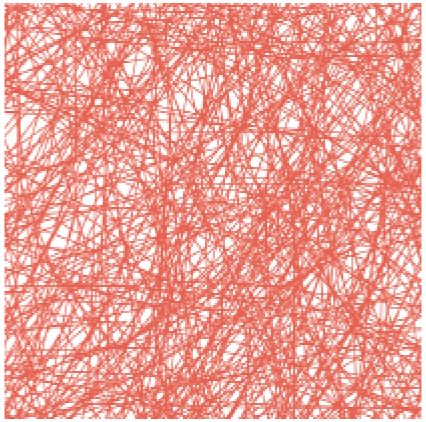
plant



CFD

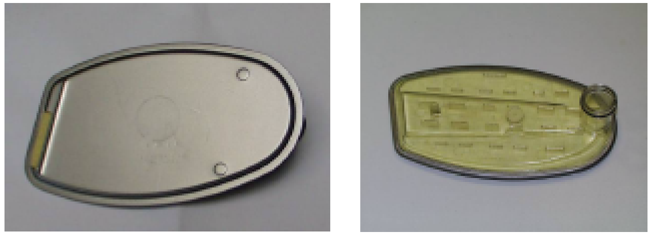


fiber dynamics



virtual nonwovens

Product simulation: Design of suction filters



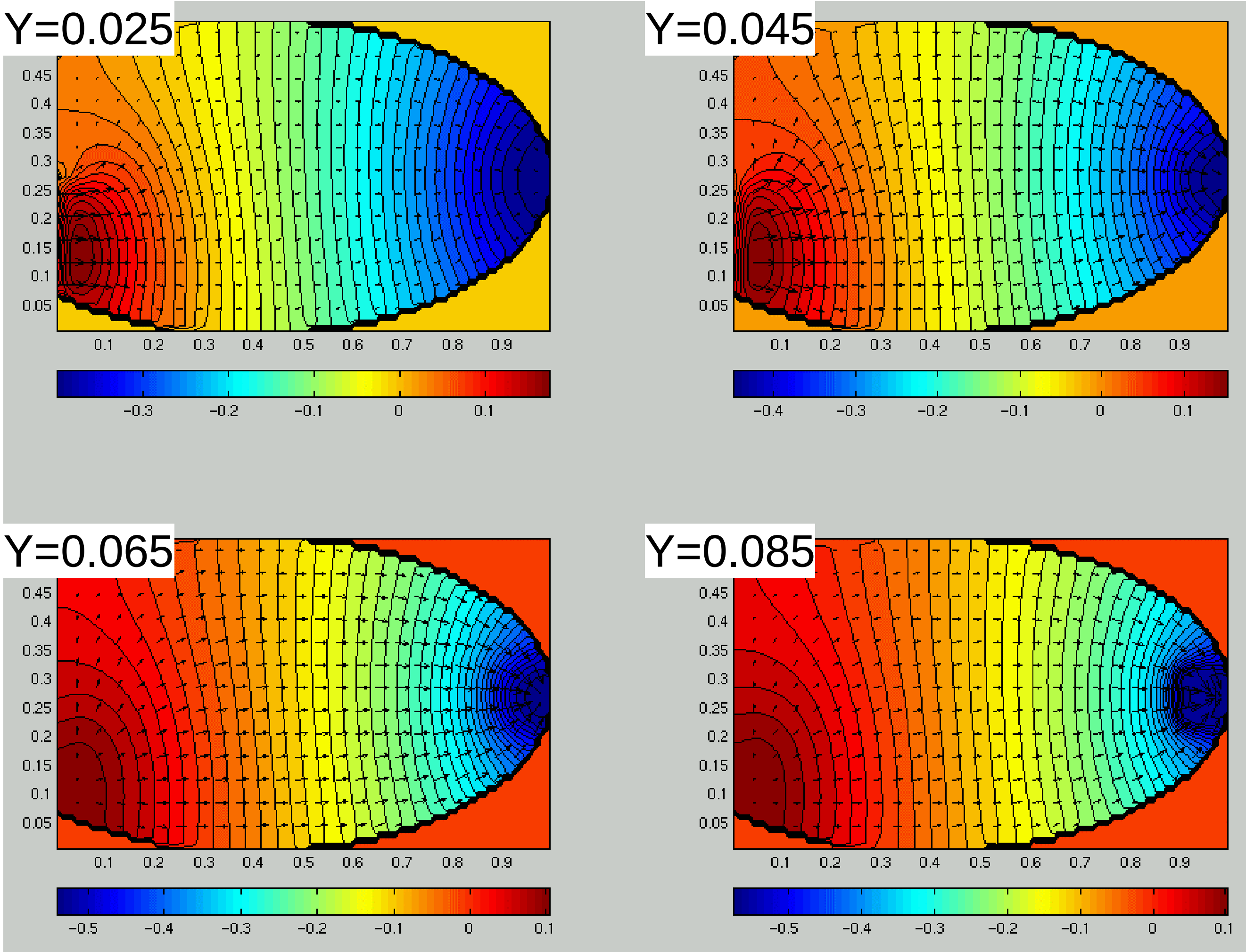
Upper and lower part of casing

Oil enters

Low pressure

Filter media

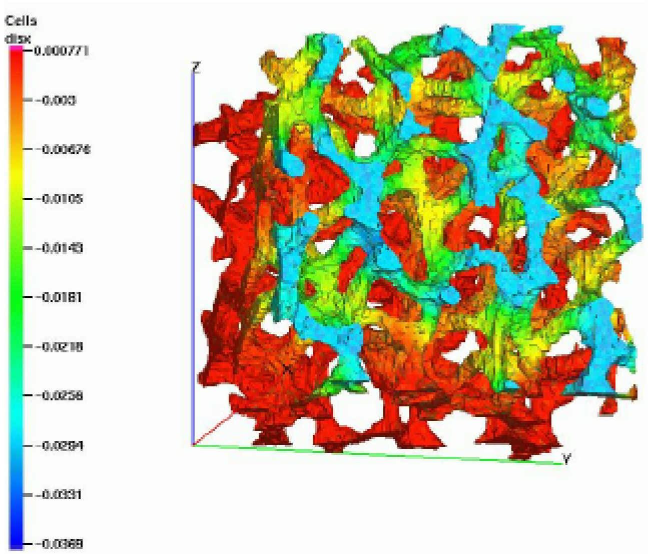
- Pressure and velocity distributions
- Horizontal cuts



Goal: Optimization of the filtration

Homogenization

Calculation of effective mechanical properties and micro-fields like stresses, strains, temperature etc.



Homogenization →

Effective

- stiffness
- relaxation
- strength
- durability
- permeability
- heat conduction
- heat expansion

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Data mining for virtual material design

Physical model

Prototype characteristics

Measured prototype performance

Input(1)
...
Input(N)

Black/Gray Box

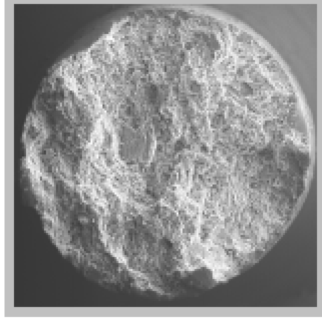
Output(1)
...
Output(M)

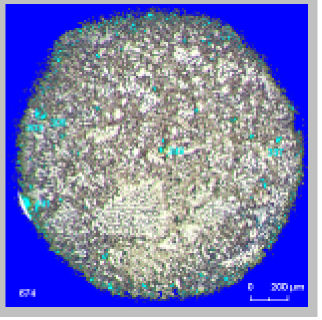
System identification

Knowledge extraction

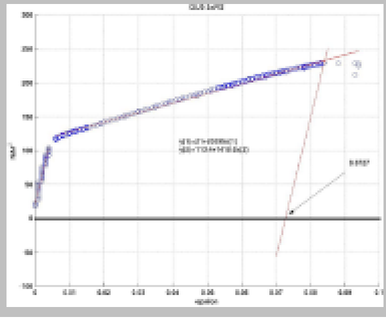
Decision support

- Porosity
- Cavity
- Cracks
- Geometry

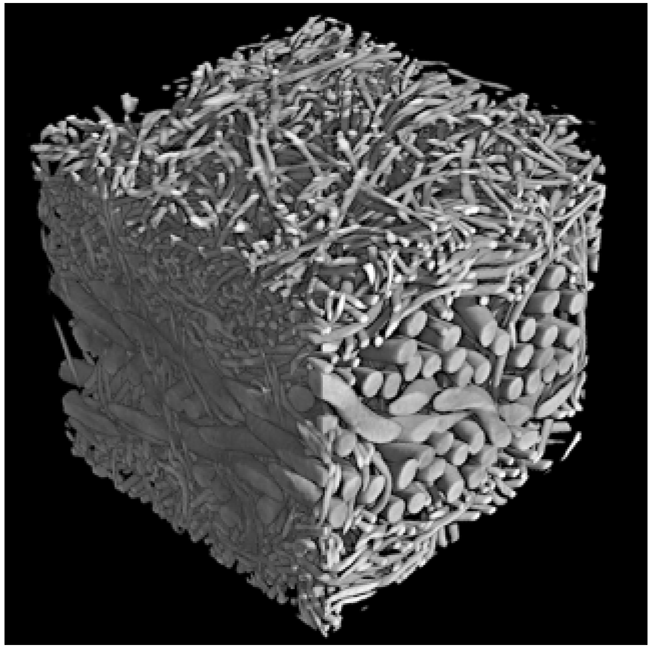


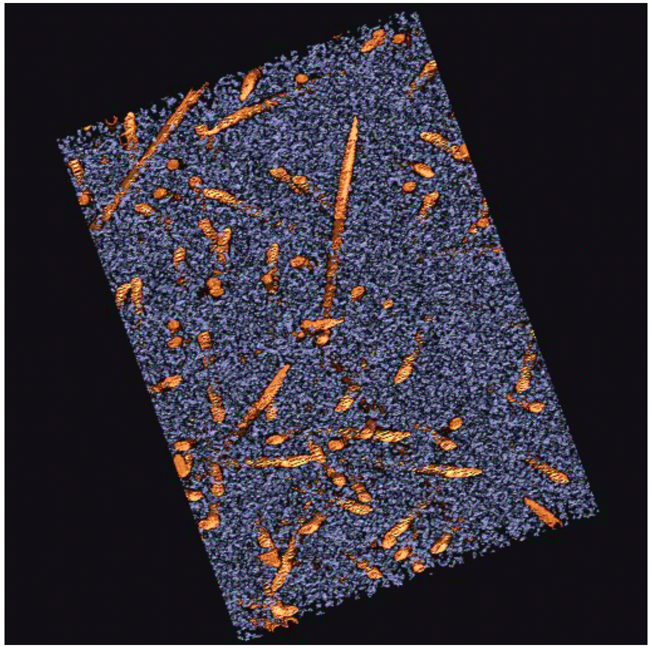


- Crash performance
- Stretch properties
- Fatigue



Tomography of a real and two-phase flow through a virtual fleece





3-d image analysis identifies structural and quality parameters

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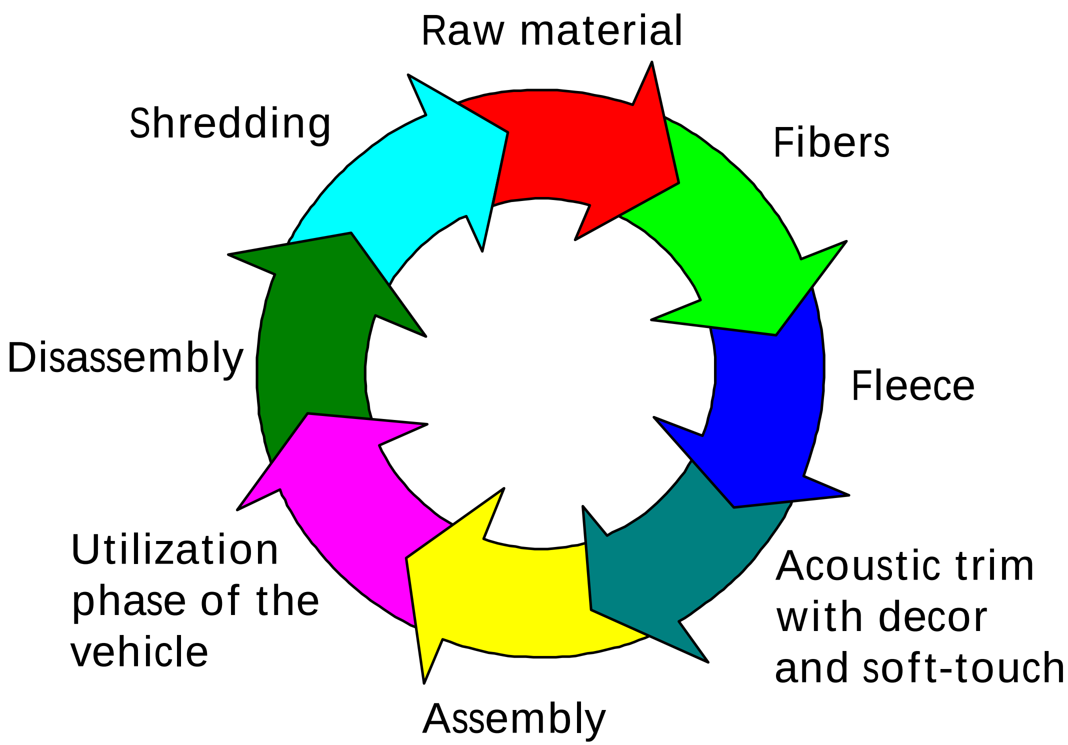
What is an integrated product policy?

Integrated Product Policy (IPP)

The entire life cycle of a product from its production up to its recycling is considered.

The effects on the environment during the entire life of the product are taken into account additionally.



Closed product life cycle

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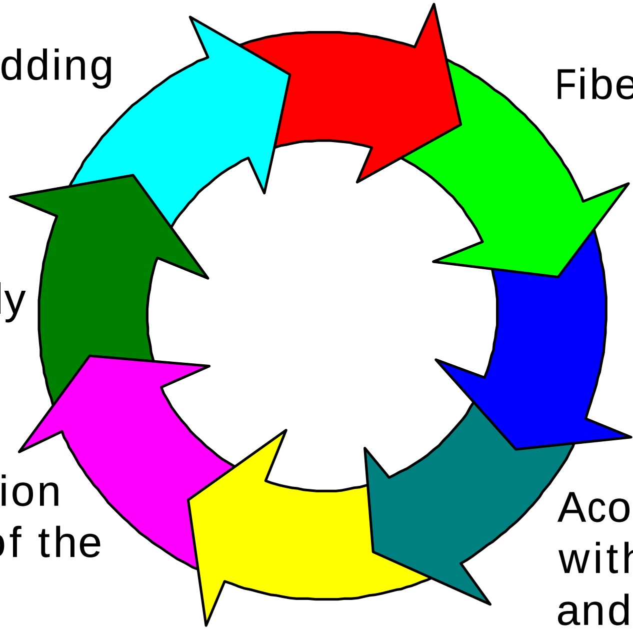
What is our central IPP idea?

Create functionality of car interior trim by virtually optimizing the use of a single material (example: polyester)

The acoustic absorption, stiffness and other properties are considered in the design of the microstructure of the headliner.

Also décor and soft touch layers are made from the same material.

The headliner can be taken out all at once, completely recycled into the original raw material, polyester, and reused to make another headliner.



Closed product life cycle

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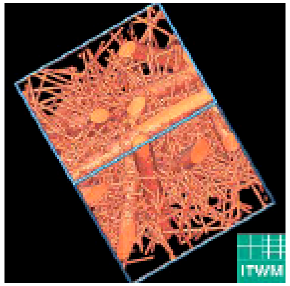
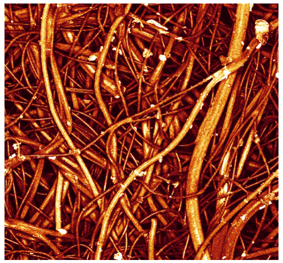
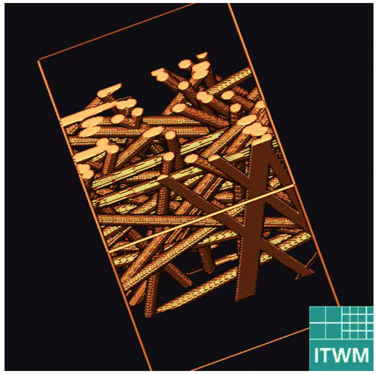
The complete integrated Design cycle

Simulation of the microstructure

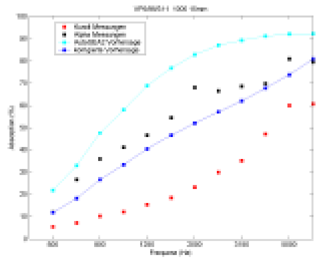


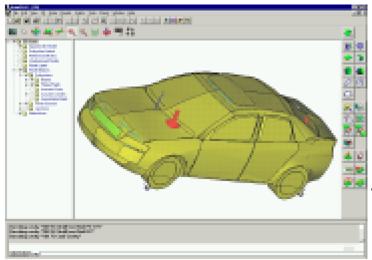


Simulation of Fluid flow



Simulation of the material absorption





Simulation of the acoustical trim

Searching for optimal fleece

Extracting parameters For manufacturing

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Simulations: mathematical background

➢Flow simulation

Given a porosity, fiber radii and fiber directions, calculate the flow resistivity.

(Navier) Stokes equations with periodic and no slip boundary conditions, respectively.

$$m\Delta\vec{v} - grad\,\mathrm{P} = \vec{e} \quad in \;\; \Omega,$$

$$div\,\vec{v} = 0 \quad in \;\; \Omega,$$

$$\vec{v} = 0 \quad on \;\; \Gamma,$$

$$\vec{v}, p \quad periodic \quad on \; \partial\Omega.$$

➢Acoustics simulation

Given the fleece thickness, flow resistivity, and cavity thickness, determine acoustic absorption in the impedance tube.

Delany-Bazley Model for air at 20°C.

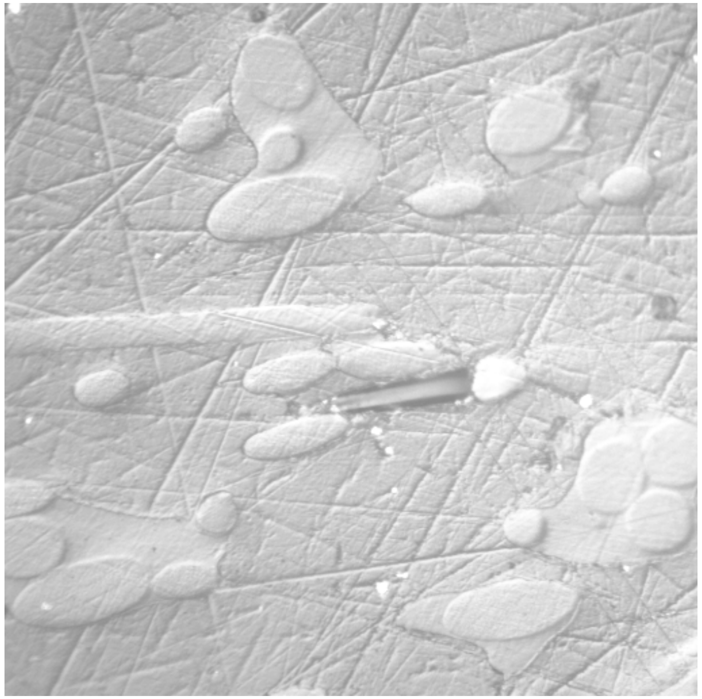
$$A(f) = 1 - \left\| R(f) \right\|^2 \qquad X = \frac{r_o f}{s}\, meter$$

$$R(f) = \frac{Z - Z_o}{Z + Z_o}$$

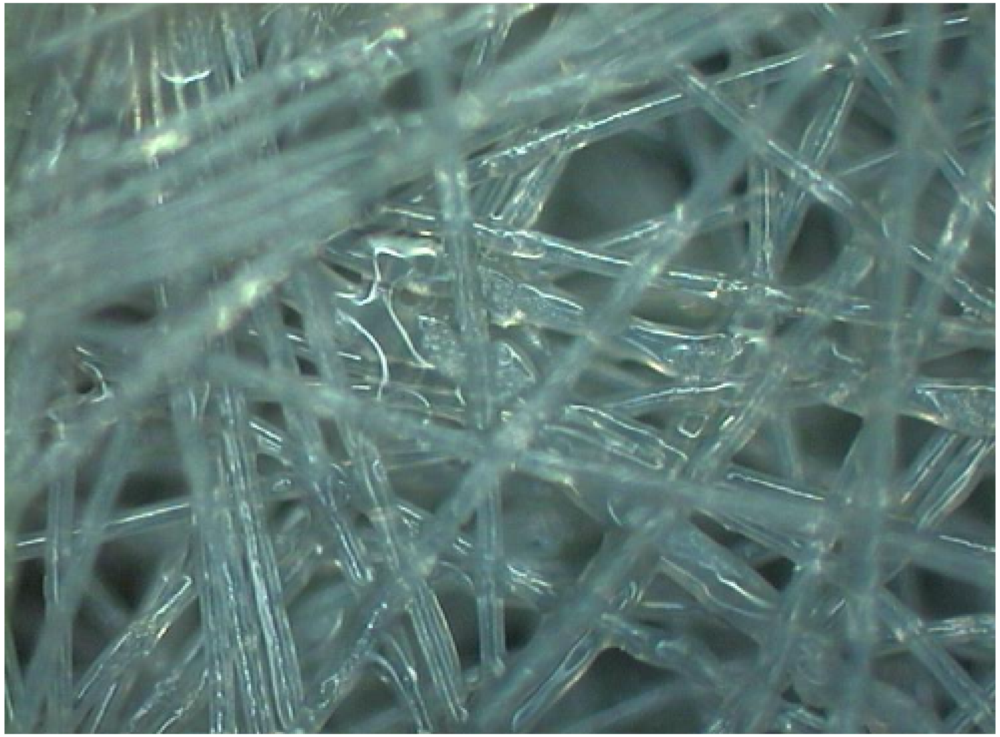
$$Z_c = r_o c_o \frac{0.159 X^{-1} - 1.403 i}{\sqrt{-1.466 + 0.212 i X^{-1}}}$$

$$k = \frac{-i2pf}{c_o}\sqrt{-1.466 + 0.212 i X^{-1}}$$

Nonwovens – random microstructures (2d images)



Cross section: 0.22 mm x 0.22 mm
Embedded in resin, enlargement: 50x
Polyester staple fiber Fleece



Microscopy (1:10):
Spun bonded Fleece

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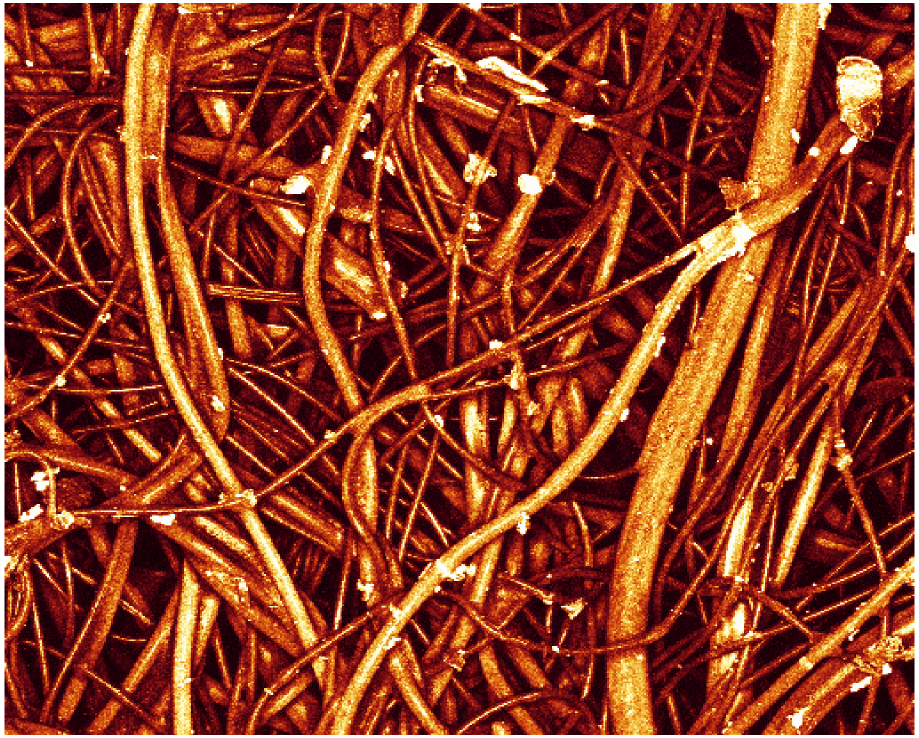
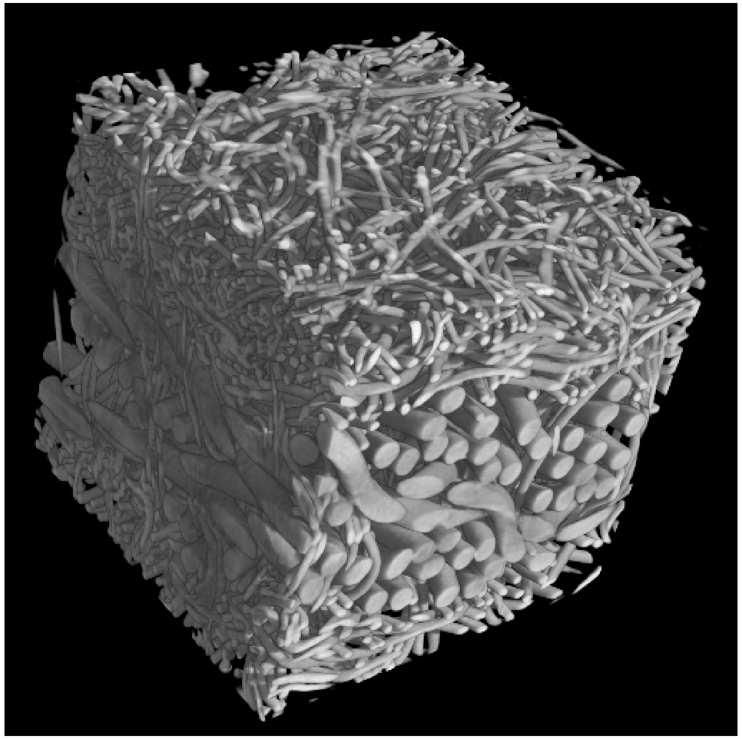
Nonwovens – random microstructures (3d images)



Confocal laser scan:
Polyester staple fiber Fleece



Tomography:
Felt used in paper dehydration

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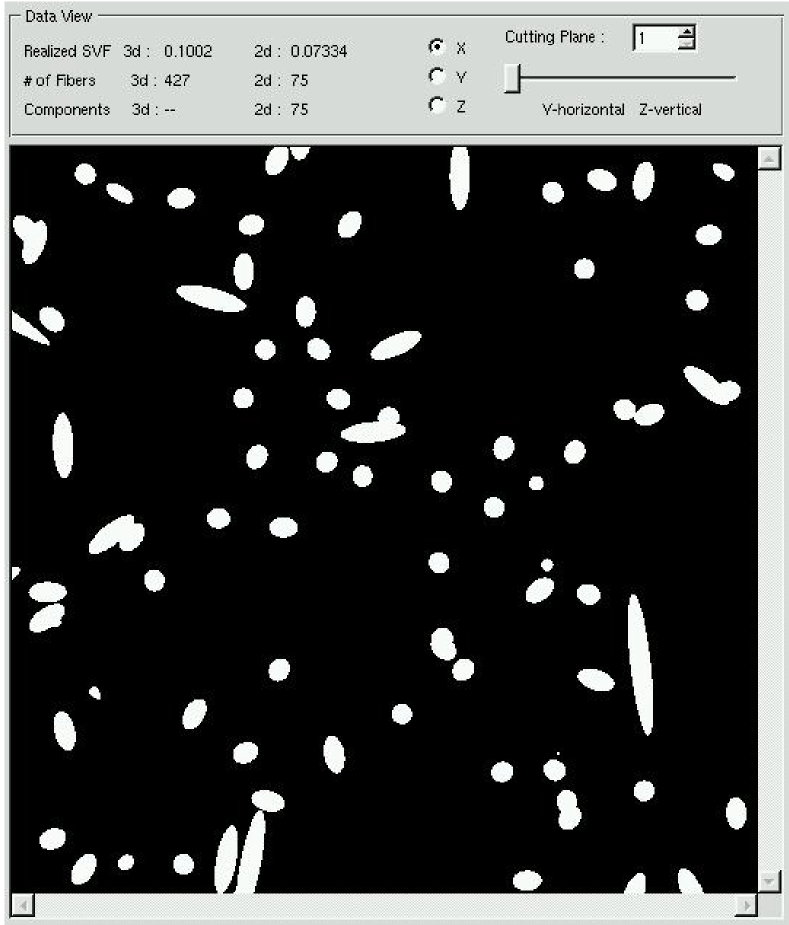
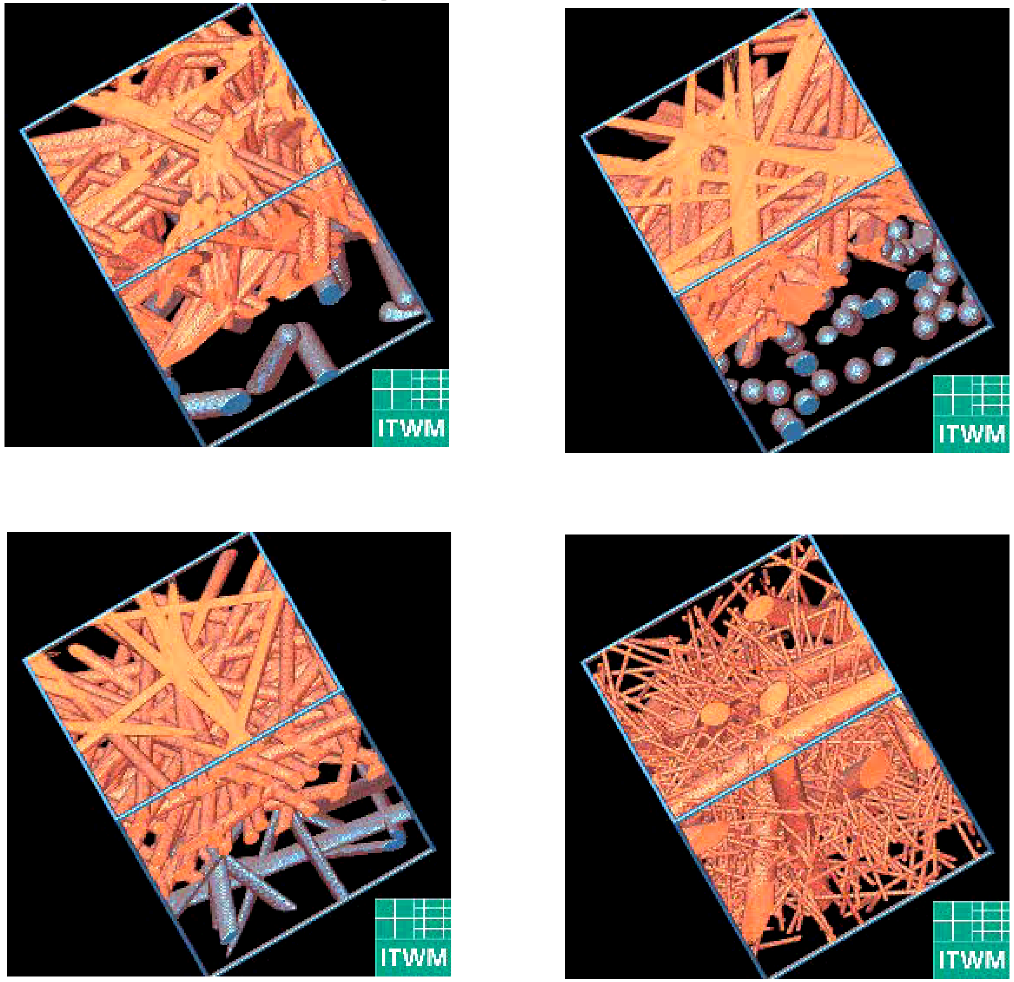
Models of nonwovens, the microstructure generator *GEODICT*





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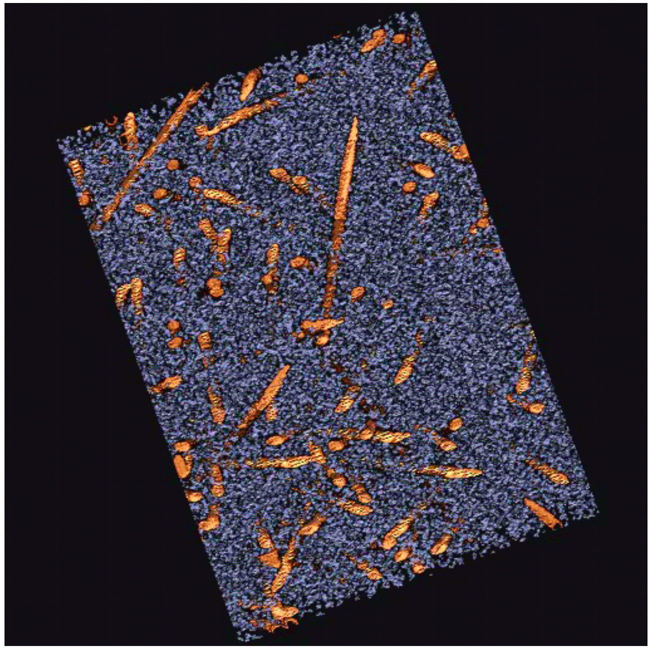
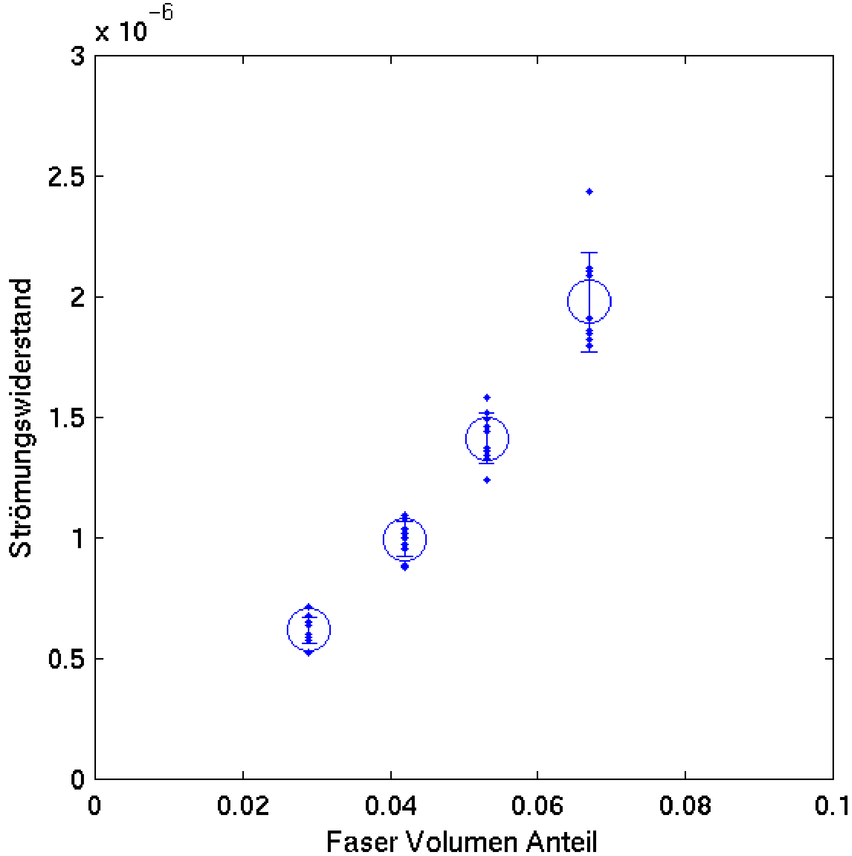
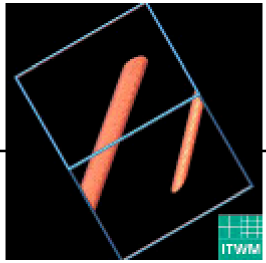
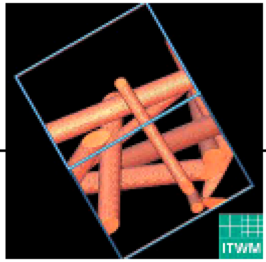
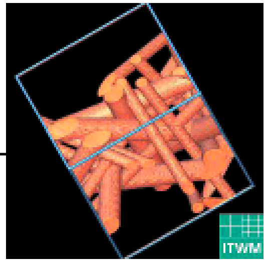
Flow through a virtual fleece and flow resistivity dependent on solid volume fraction











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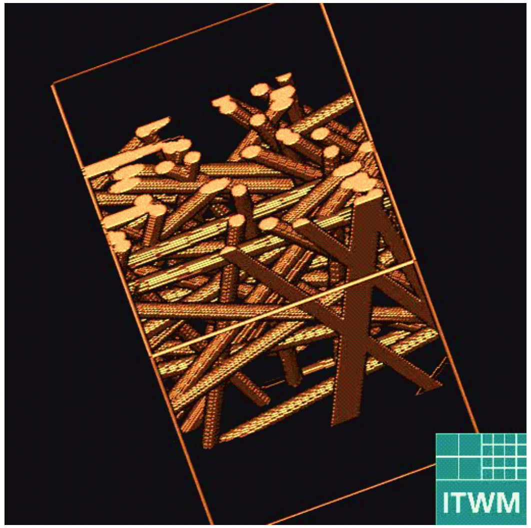
Microstructure simulation

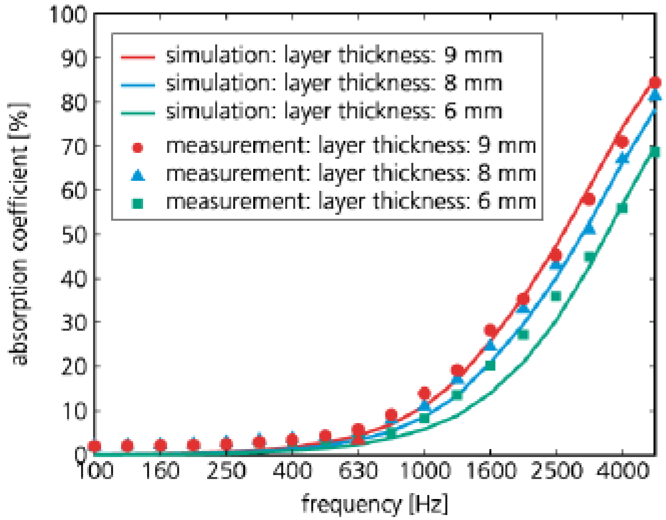
Complementing the microstructure flow simulation by an acoustic model

Flow resistivity is computed



Microstructure simulation

Acoustic Model



Frequency dependent absorption coefficient

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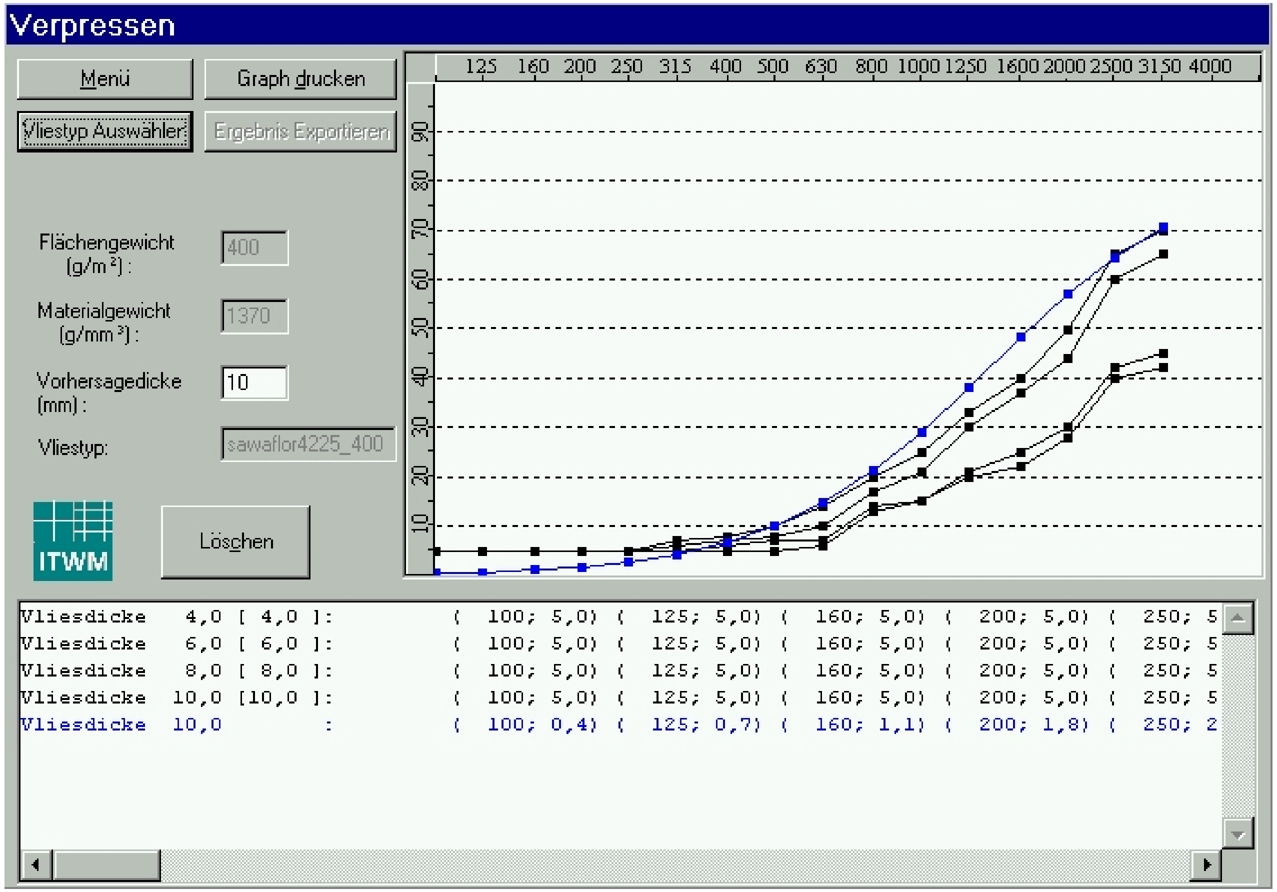
Impedance tube – optimal fleece with acudict II

- Input: acoustic measurements, pressure/velocity pairs
- Stable though multiple measurements
- Prediction of acoustic absorption for different compression rates
- Search for best fit with desired absorption in Fleece data base
- Constraint optimization, best fit for given area weight, certain types of fleece, etc.
- Output: to excel spreadsheet



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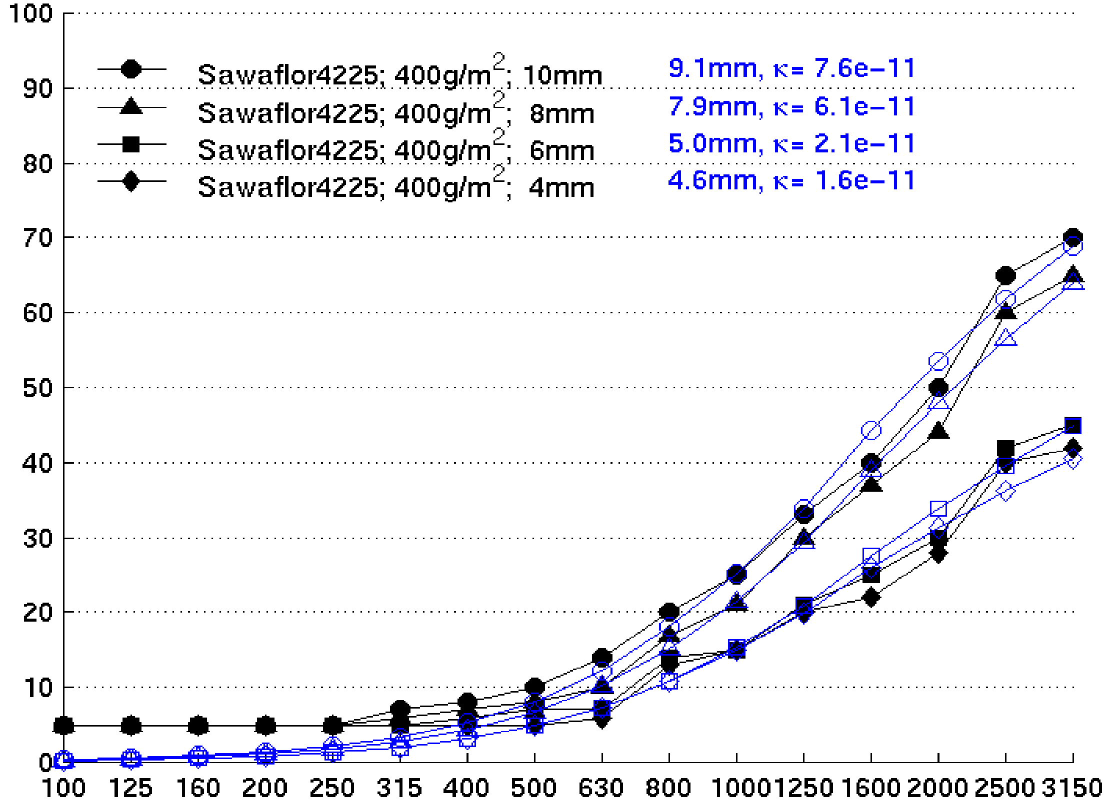
Verification of simulation by measurements



Comparison of measurements (black) and simulations (blue)

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The Sandler success

By using micro structure simulation and Acudict II, ITWM´s partner Sandler

- has replaced previously outsourced acoustic measurements on head liners by in house flow resistivity measurements (4 weeks reduced to about 2 hours).
- can avoid producing intermediately compressed headliners but instead predict which compression rate will give the best absorption from just two prototypes.
- has understood the principle influences of production parameters such as choice of fiber diameters on the acoustic properties of the headliner .
- has strong simulation support to enter new markets with new acoustic requirements.

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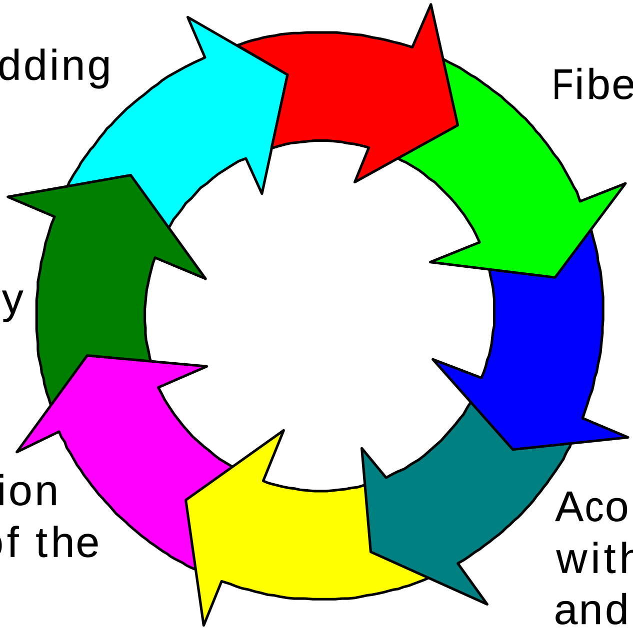
IPP benefits?

- Shortened product development cycle
- Fleece selection
- Integration of new properties
- Definition of mechanical properties
- Optimize design and function
- Verify acoustic requirements
- Optimize area weight
- Find ideal degree of compression
- Use advantage of multi-layer – single material
- Avoid acoustic measurements by simulation
- Align requirements, design and product



Closed product life cycle

Simulation of PET fleeces is a Tool towards integrated, intelligent product development.

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Fully 3d tools currently under development with partners, see talk Dr. Andrä, Block 4, Mobiltech.