Computer-Aided Optimization of the Acoustic Efficiency of Non-Wovens for an Intgrated Product Policy

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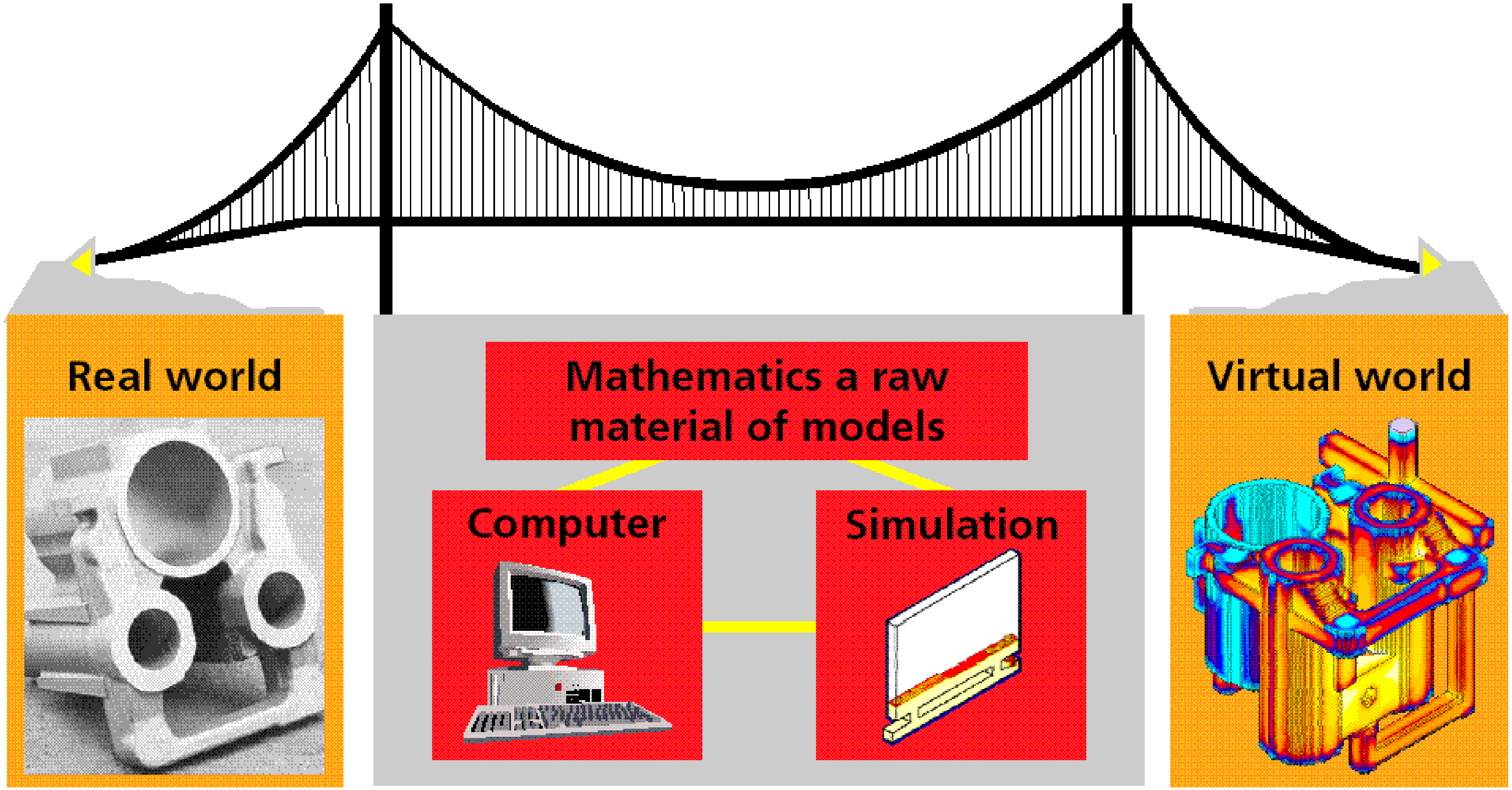
Outline

Introduction: Fraunhofer ITWM

Mathematics as a key technology



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Introduction: Fraunhofer ITWM

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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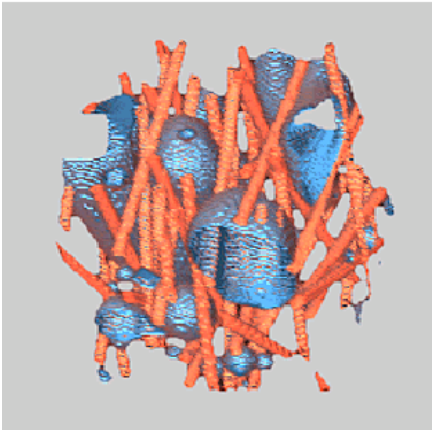
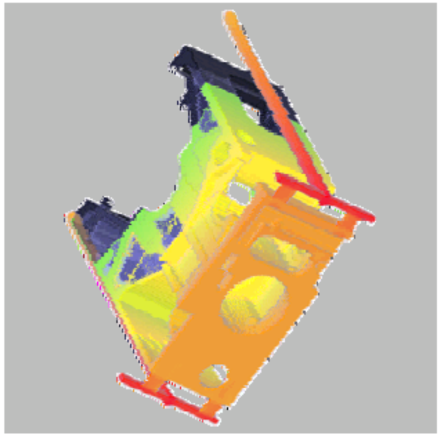
Introduction: Fraunhofer ITWM

Department "Flow and Complex Structures"

- Simulation of porous material
  - Moisture and heat transport
  - Filtration and design of filters
- Virtual material design
  - Microstructure simulation
  - Resistivity, acoustic absorption
- Filling processes
  - Simulation of casting processes
  - Fiber reinforced plastics (Injection moulding)
- Flood & risk management
  - Municipal sewer systems





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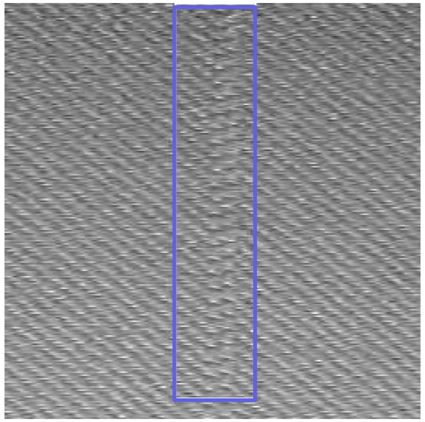
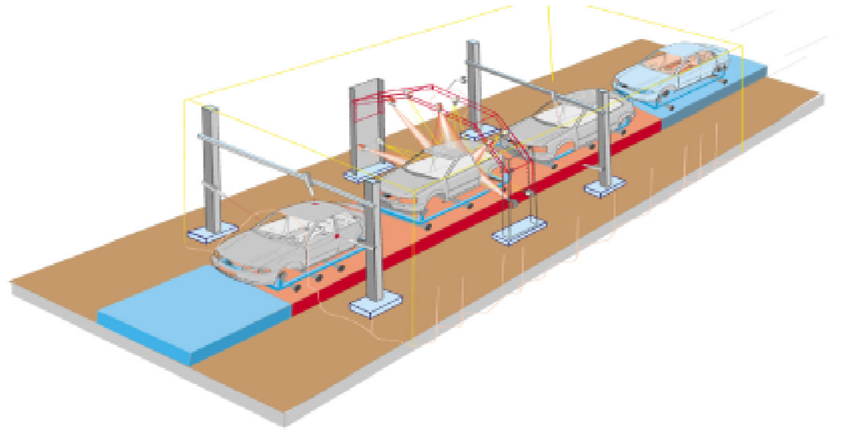
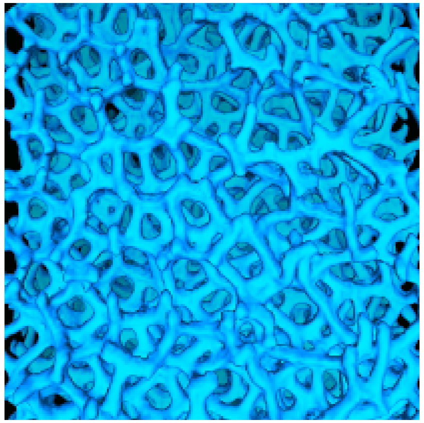
Introduction: Fraunhofer ITWM

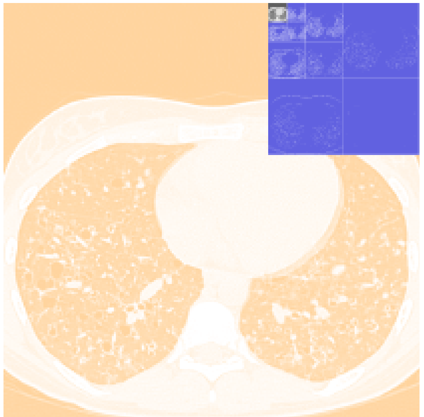
Department "Models and Algorithms in Image Processing"

- Surface inspection
  - Structured, also coloured surfaces (e.g. wood, paper, steel)
- 3D-Image analysis
  - Geometric characterization of 3D-structures
  - Modelling of microstructures
  - 3D-image processing
- Image / video compression
  - Wavelet based methods
- Autonomously working monitoring systems
  - Fast signal processing
  - Monitoring for railway systems









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Introduction: Problem

Acoustic trim for the interior of the car: Headliner made of fleece

Optimization of the microstructure of non-woven acoustical trim

Objectives:

- Optimal acoustic absorption spectrum
- High mechanical stiffness
- Light weight
- Easily recyclable material
- Low material and manufacturing costs
- Desired haptics/optics of the product

Application:

Interior of vehicles,
e.g. headliner

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Introduction: Requirements

Upcoming laws of the EU on end-of life vehicles require at least 85% of an automobile´s weight to be recycled.

However, the acoustic trim of vehicles is currently produced from composite materials which are difficult to separate.

The goal of the “Integrated Product Policy” (IPP) project at the Fraunhofer ITWM and its partners Audi, Sandler, and Faurecia is to develop improved acoustic trim, which is made of single materials, by using innovative computer simulations.

Parameters used in the simulations are calibrated with acoustic measurements on real trims.

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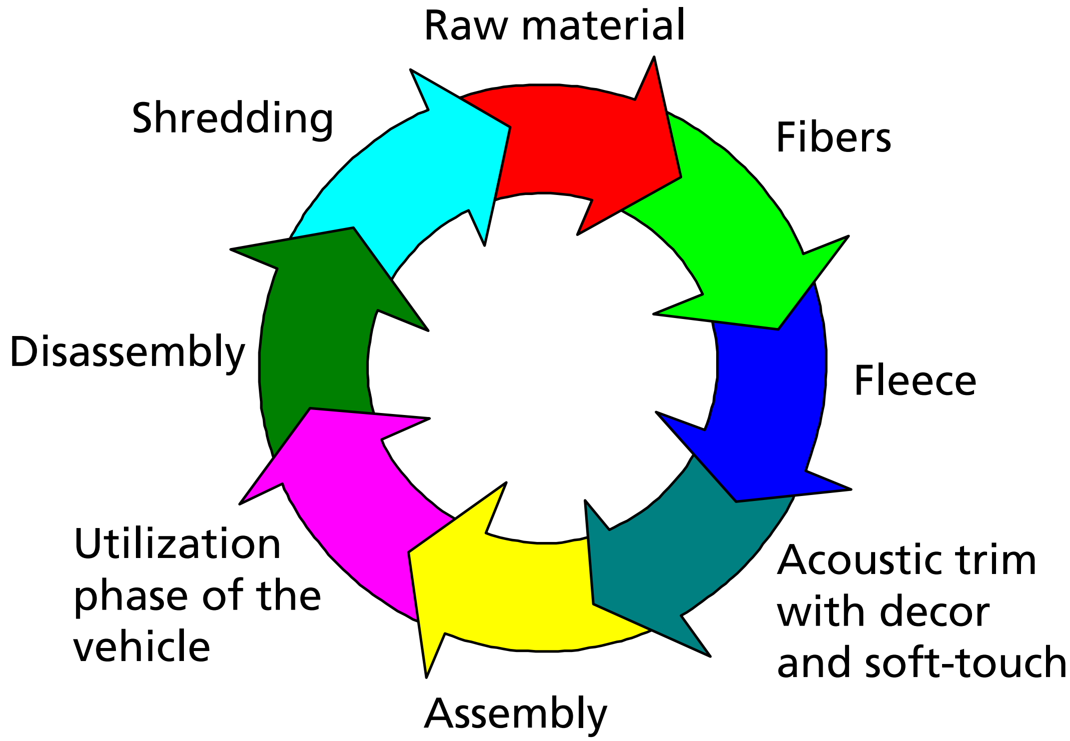
Introduction: IPP

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

Direct and Inverse Simulation

Direct Simulation

Given:
- Averaged geometric properties of the microstructure
- Geometry of the product (in an AutoSEA2 model)

Find:
- Absorption spectrum for the interior of the vehicle

Simulation steps:
- Stochastic geometry of microstructure
- Fluid dynamics in the microstructure
- Acoustic absorption 1D (material)
- Acoustic absorption 3D (product)

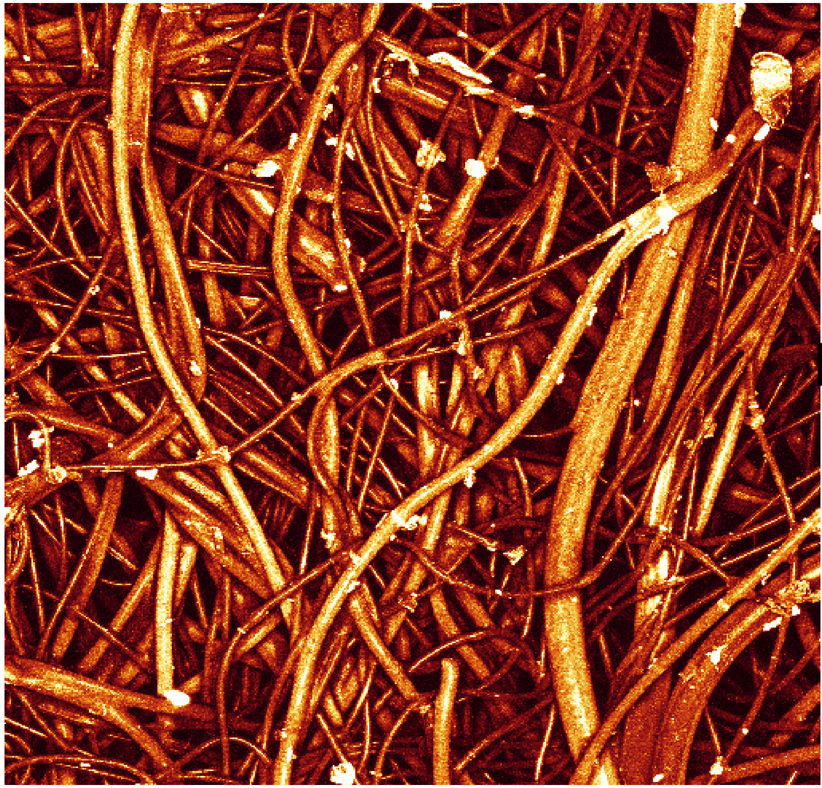
Inverse Simulation

Given:
- Desired absorption spectrum
- Desired geometry of the product (in an AutoSEA2 model)

Find:
- Optimal material and its microstructure

Solution steps:
- Precomputing a database for varying material properties by direct simulation
- Find the best fitting materials from the database (by using interpolation)

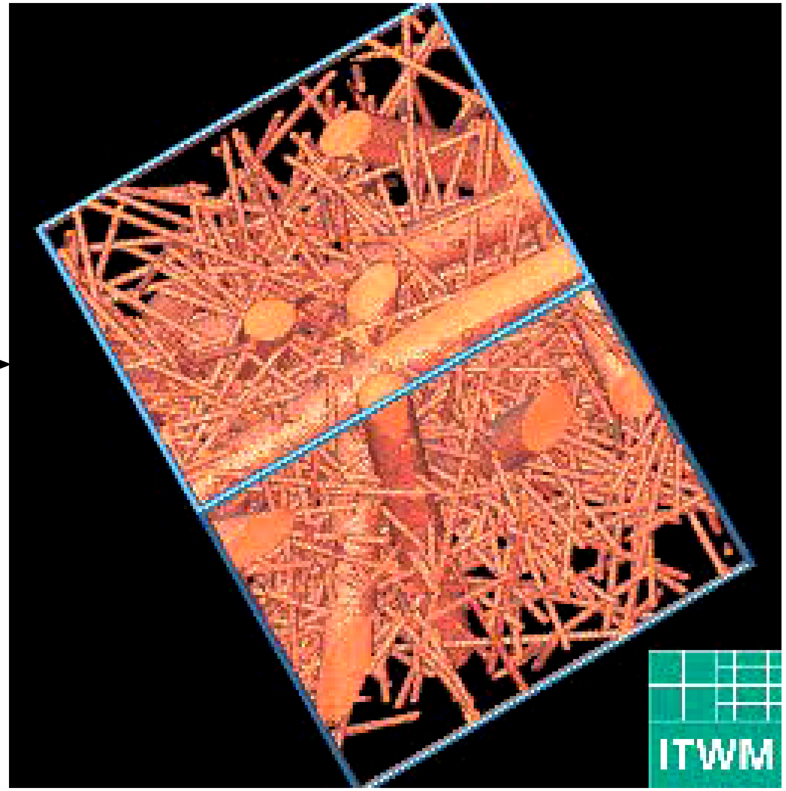
Direct Simulation: Geometrical properties of the microstructure



Micrograph

Properties:

Fibre shapes
Fibre diameters
Fibre distribution
Porosity
Anisotropy
etc.



Model of the microstructure
(from the computer simulation)

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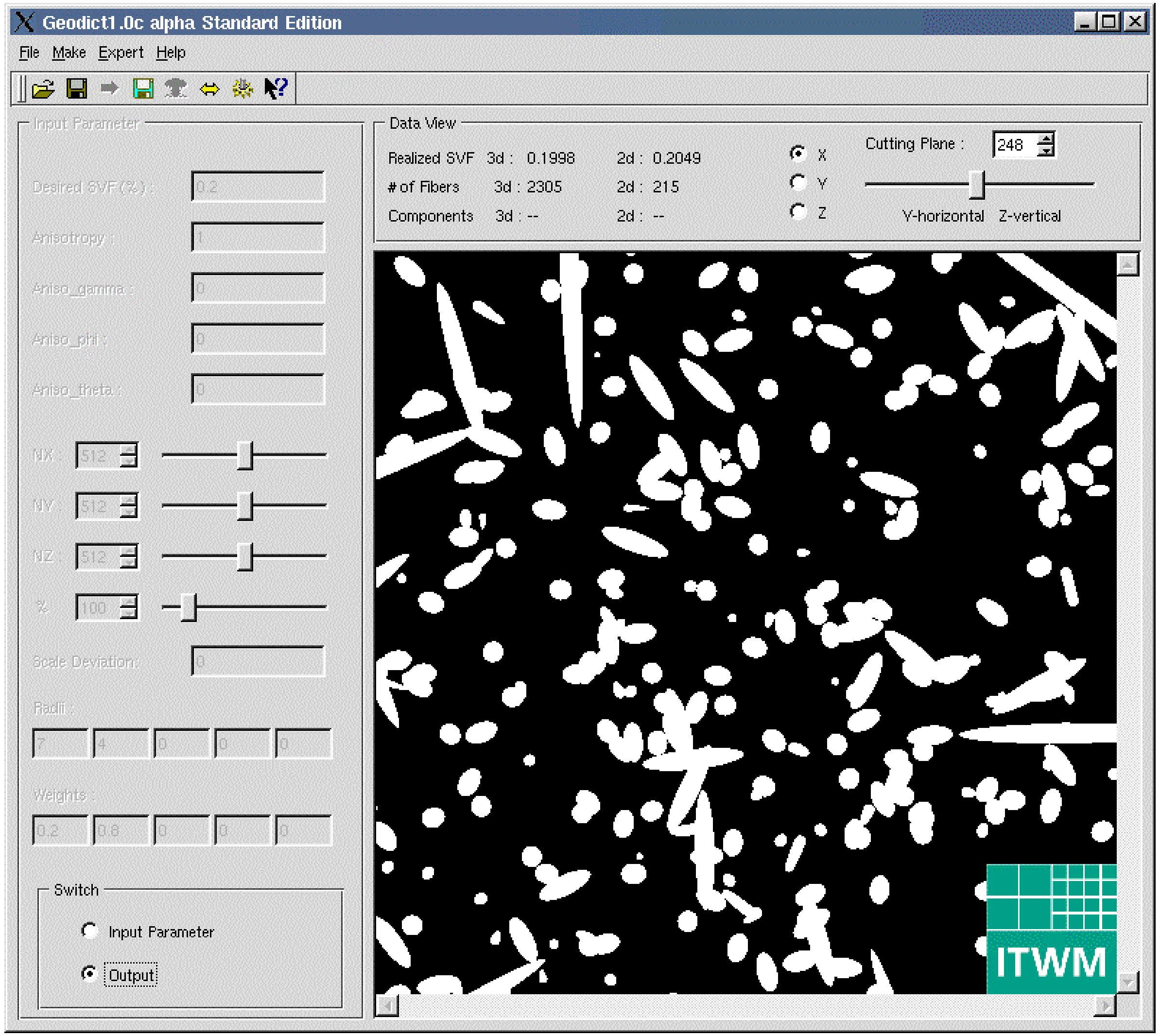
Direct Simulation: Geodict



Geodict

- generates stochastic microstructures (as input for computational fluid dynamics) interactively

- generates 3d surface data for microstructures in STL and VRML format

GUI with cross section of the generated microstructure

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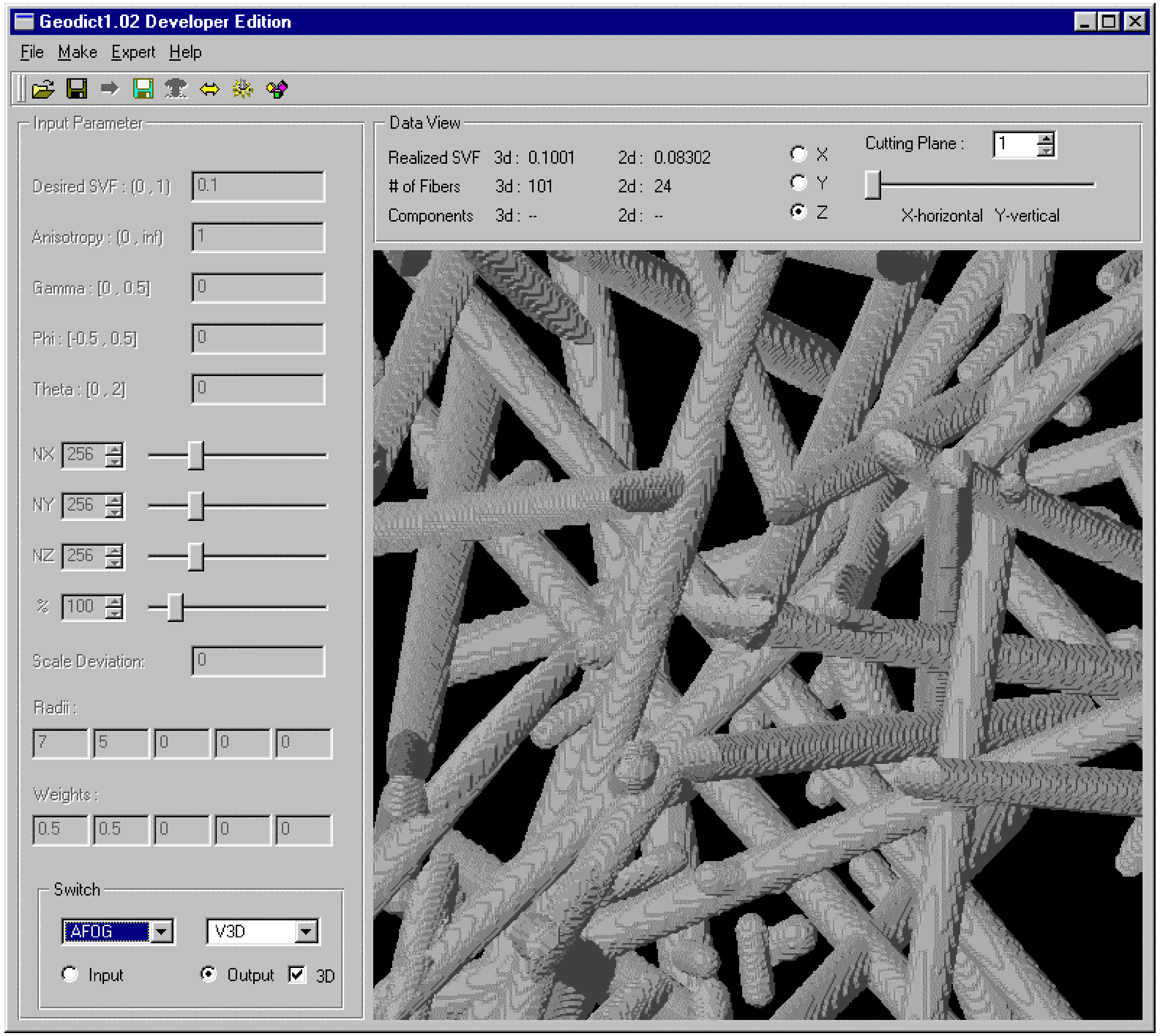
Direct Simulation: Geodict



Input parameters for the microstructure

- solid volume fraction
- anisotropy model and directions
- up to 5 different fiber radii with weighting factors
- fiber length and cross section
- overlapping or non-overlapping objects
- resolution in x-, y-, z-direction

GUI with 3D view on the generated microstructure

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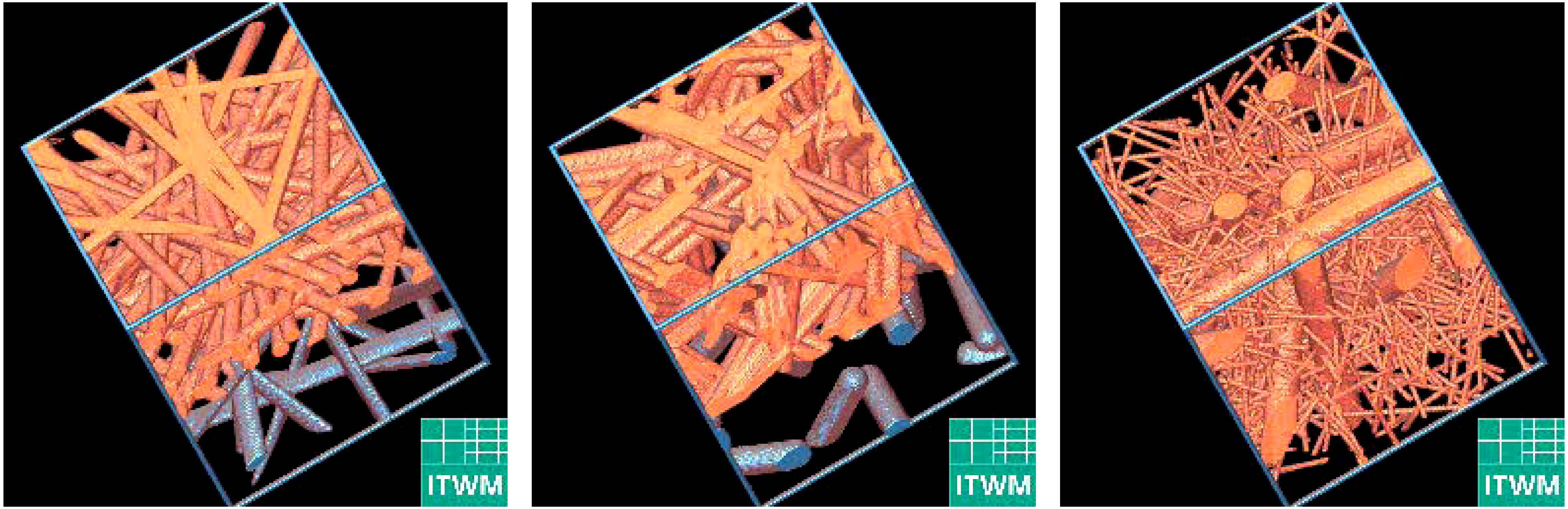
Direct Simulation: Geodict



Examples of microstructures generated by Geodict

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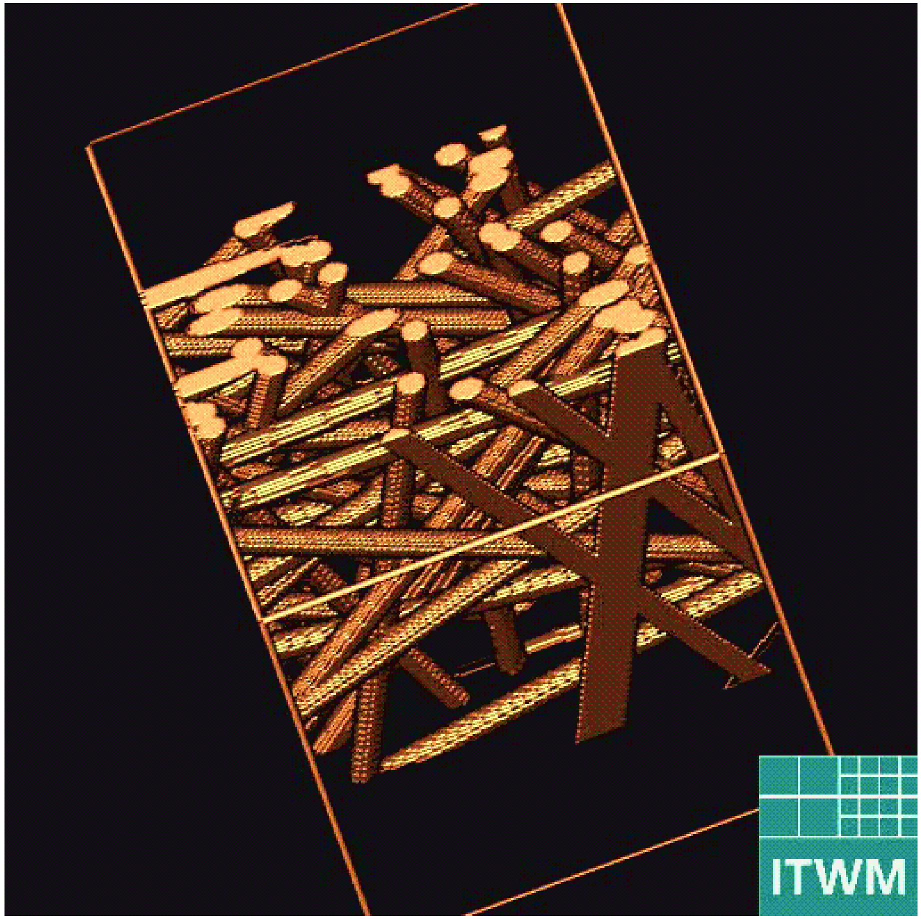
Direct Simulation: Fluid Flow



Free flow through thin fleece of cylindrical fibers

Input: Stochastic geometry model of
the microstructure from Geodict
(and further material parameters)

Solution of the (Navier-)Stokes equations

Algorithm: Lattice Boltzmann Method (LBM)

Software: PARPAC (Fraunhofer ITWM)

Result: Flow Resistivity

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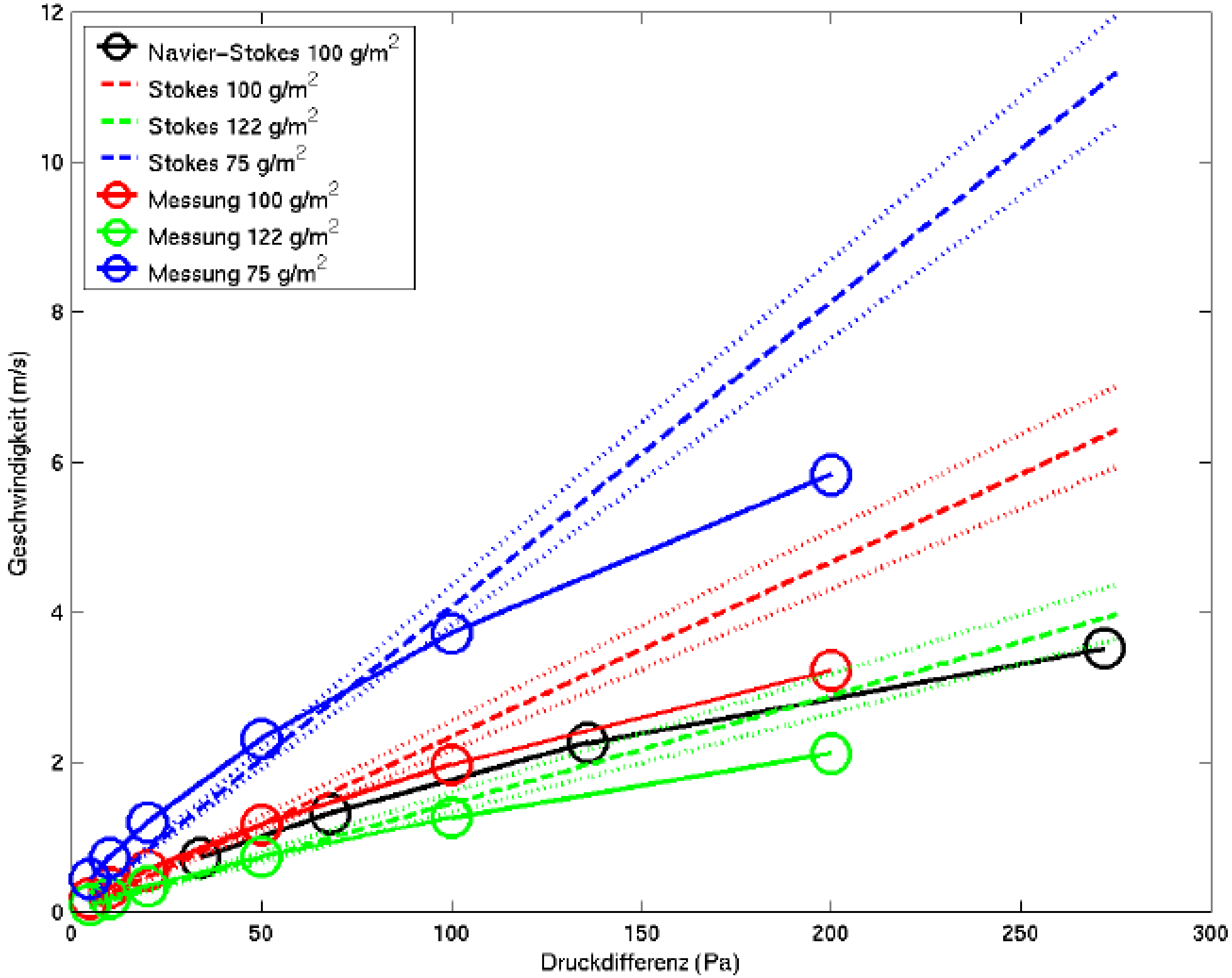
Direct Simulation: Fluid Flow



Comparison between Stokes/Navier-Stokes computations and measurements

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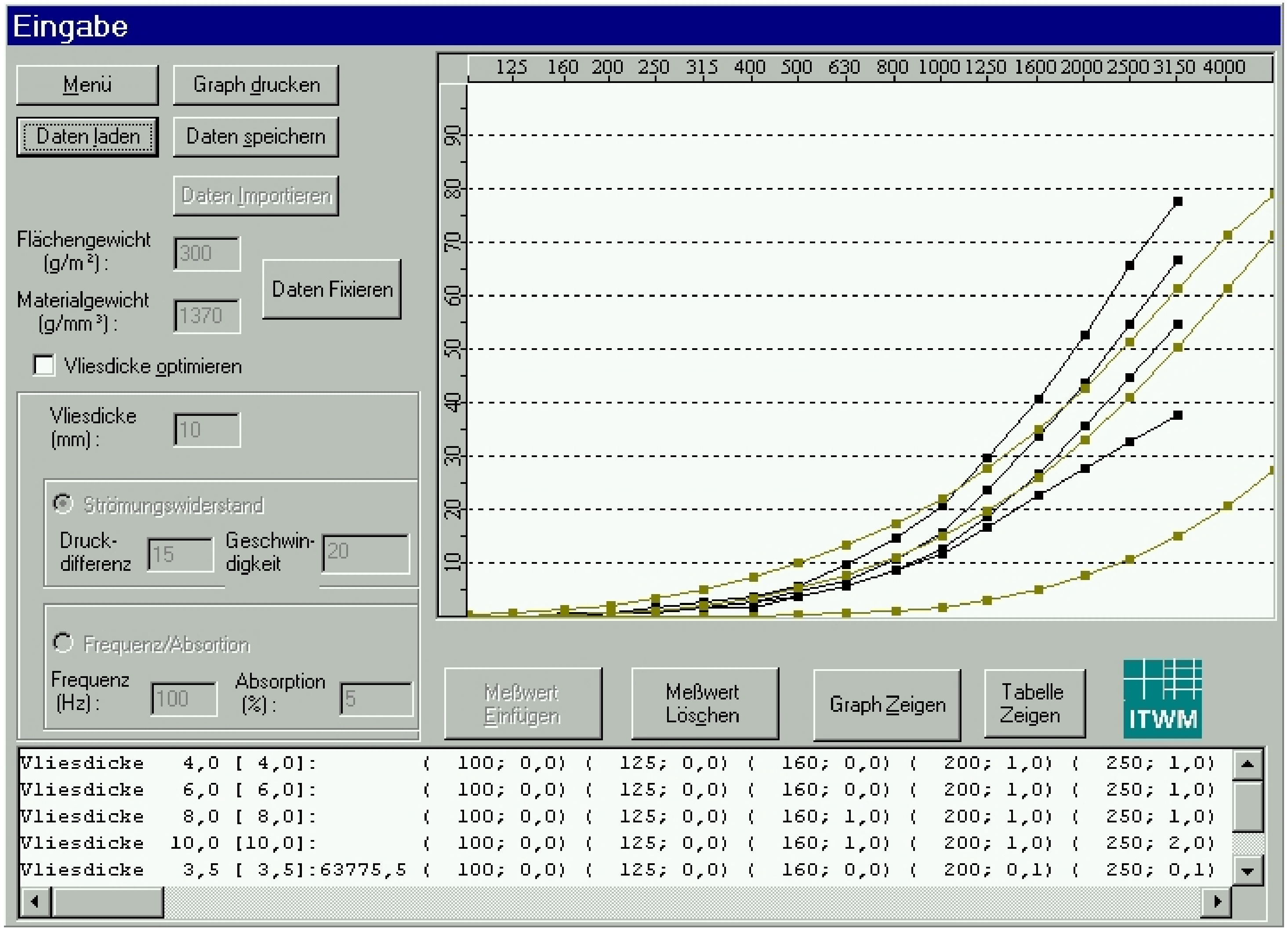
Direct Simulation: Akudict



Akudict is a tool for the prediction of that acoustical absorption, which is measured in the impedance tube, for non-wovens.

Input form for the flow resistivity and measurements in the impedance tube

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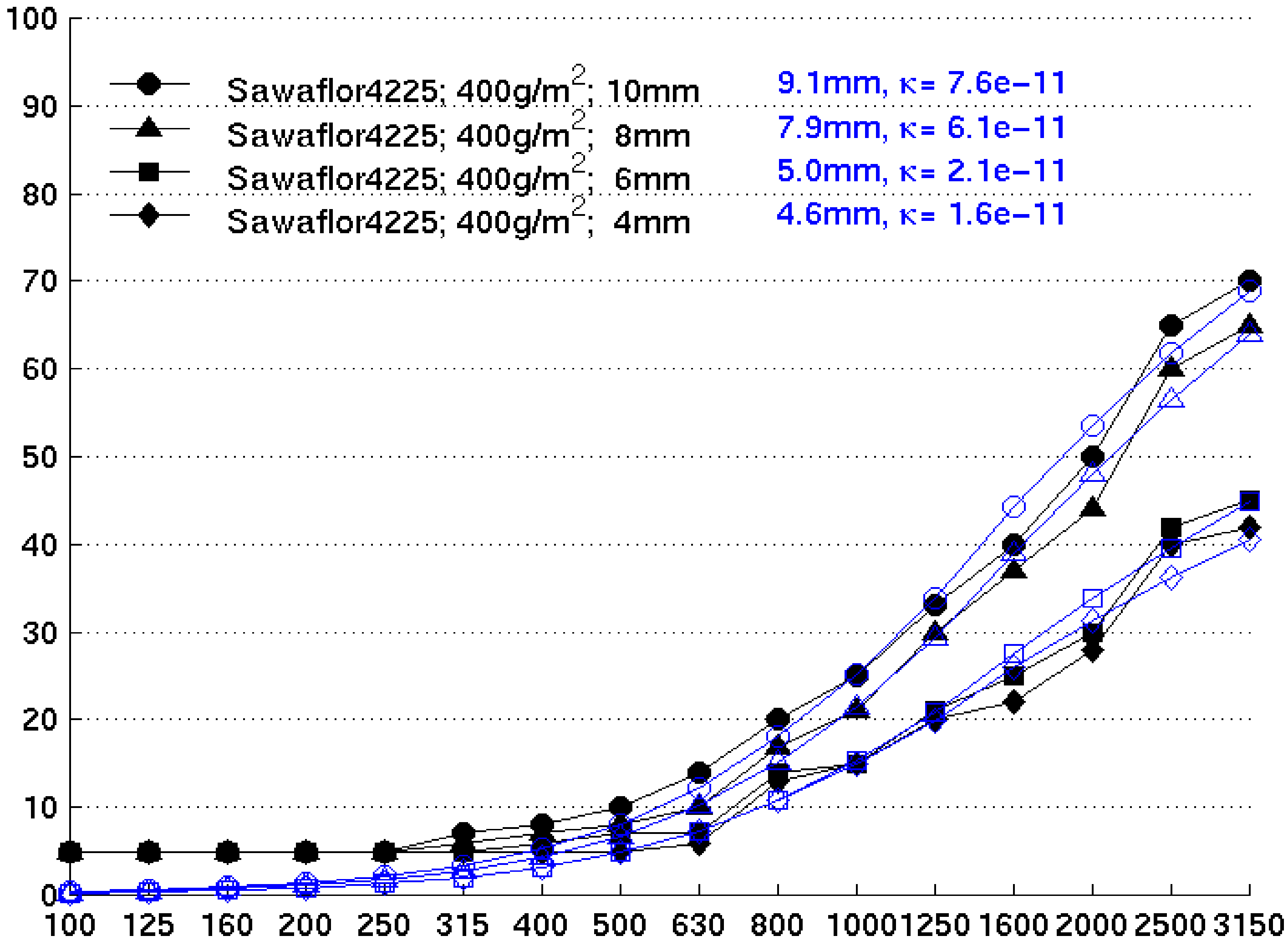
Direct Simulation: Akudict



Comparison of measurements (black) and simulations (blue)

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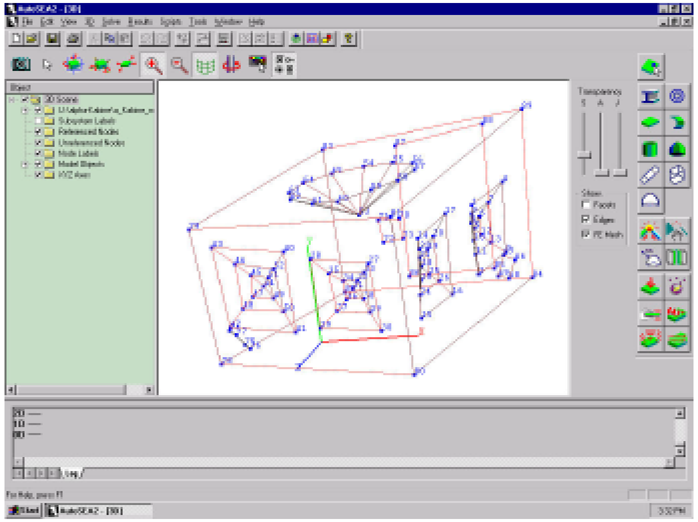
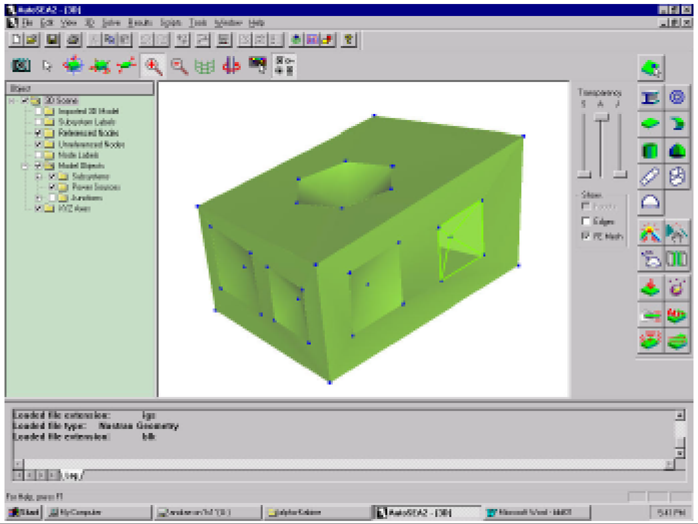
Direct Simulation: Alphadict



Measurements in the
Alpha Cabin are used
to calibrate the absorption
of the acoustical trim
in the diffusive field.



An simple SEA model
of the Alpha Cabin was
implemented.

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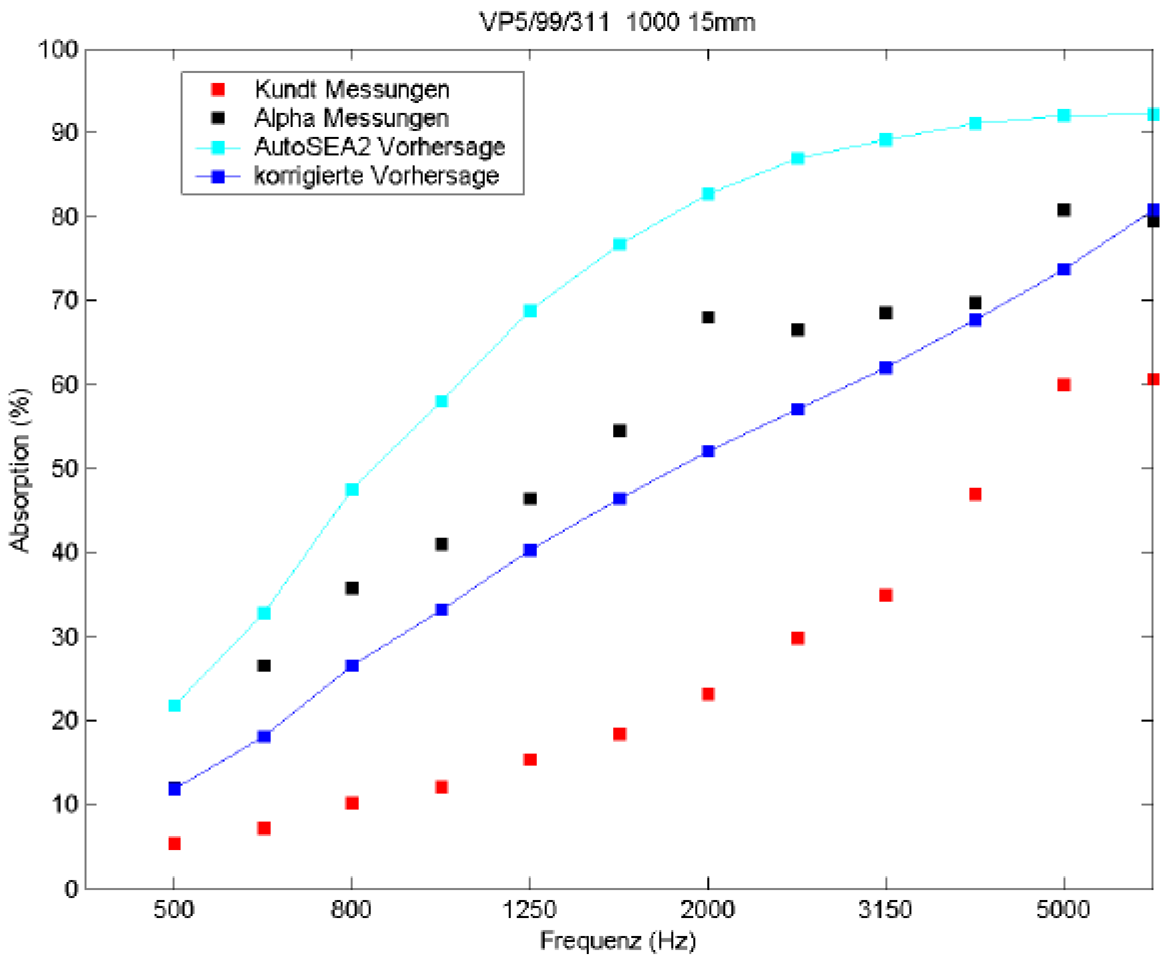
Direct Simulation: Alphadict



Red	Measurements: Impedance Tube
Black	Measurements: Alpha Cabin
Light Blue	Simulation: AutoSEA2
Blue	Simulation: Corrected Simulation with 2 parameters

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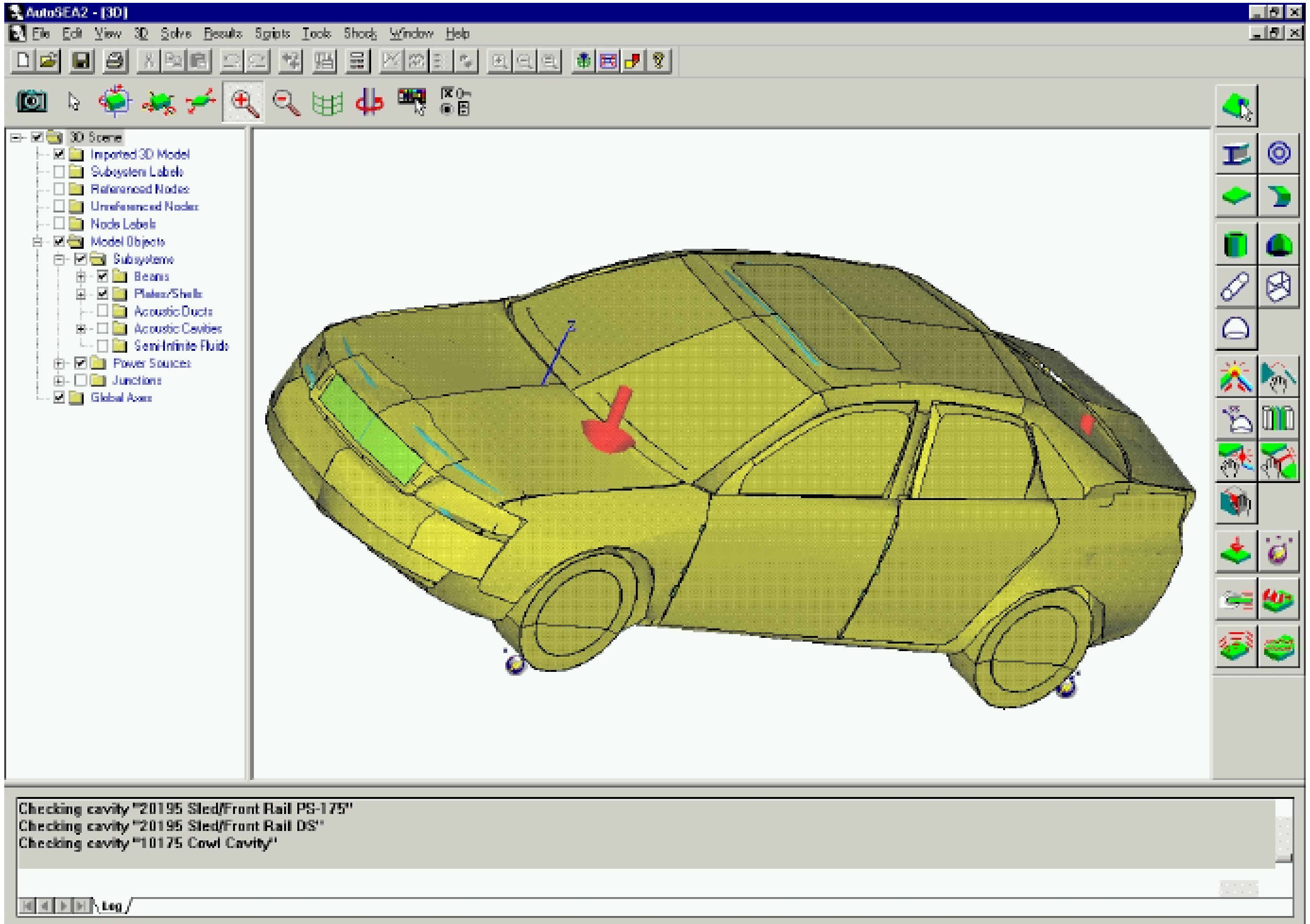
Direct Simulation: AutoSEA2



AutoSEA2 model from Audi/MSXI

The influence of the acoustical trim part on the acoustical absorption of the passenger cabin is modeled by SEA.

A fixed number of acoustic experiments is considered.

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Inverse Simulation

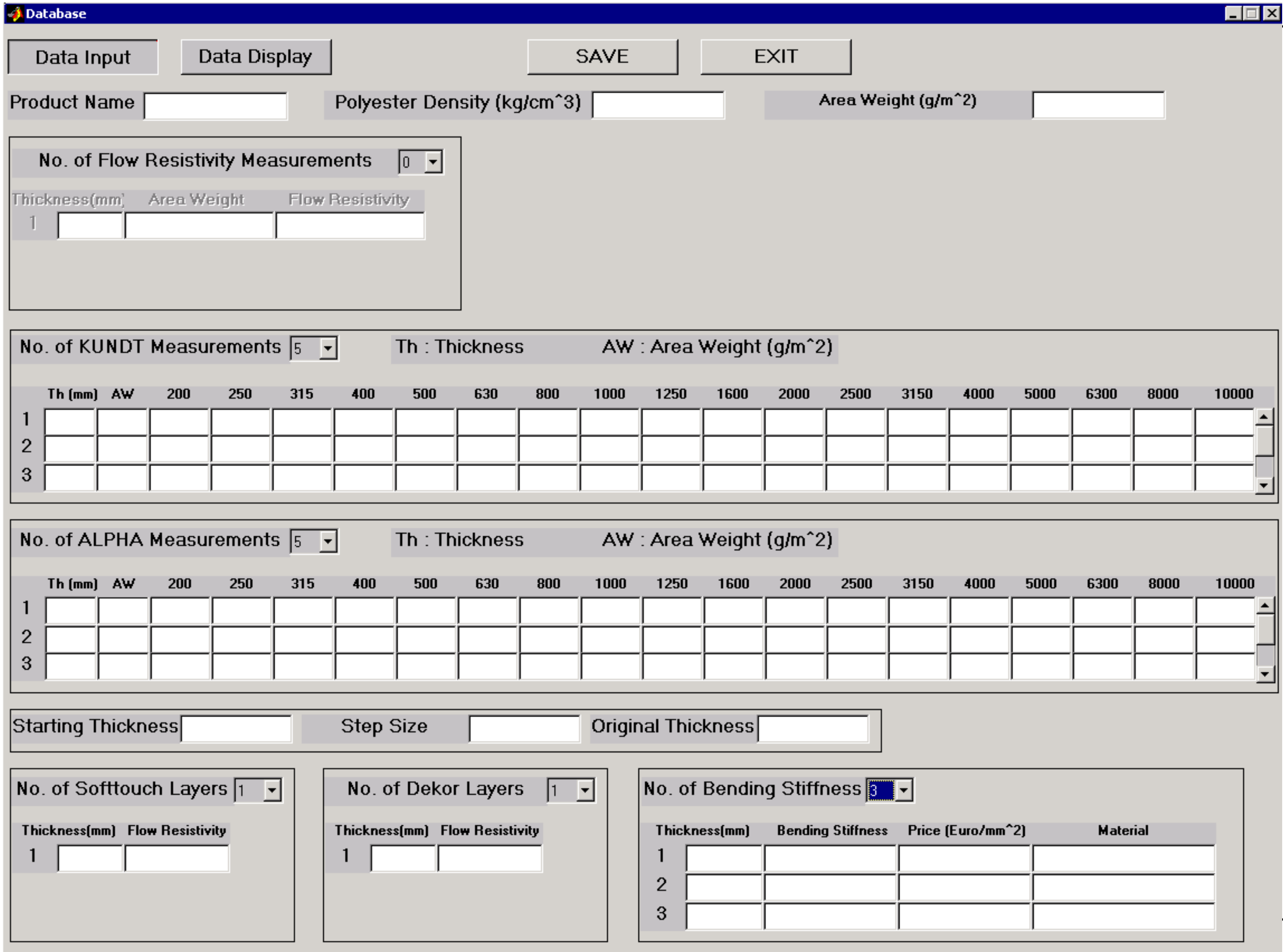
The computational effort for the direct simulation (especially for the fluid flow simulation) is very high.

The solution of the inverse problem requires several direct simulations.

Therefore, we compute a database, which contains for varying material parameters the corresponding absorption spectra in the vehicle, in previous.

By using this database, the solution of the inverse simulation is computed in few seconds.

Inverse Simulation: Material Database



The predicted values for (a) the flow resistivity,
(b) the absorption in the impedance tube and (c) the absorption in the Alpha-cabin can be completed (and also compared) with measured data.

GUI for the material database

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Inverse Simulation: Optimization Database

Input Form for Data Base of Acoustic Absorptions

File Name:	data_base.inp			
Data Base Name:	absorption001.db			
AutoSEA2 File:	alphaKabineOhneWand.va2			
Start Frequency:	100			
End Frequency:	100			
No. of Design Variables:	2			
Design Variables:	designFibers	designTreatmentL		
	Start	End	No. of Values	on log Scale
Design Variable 1	5000.0	200000.0	10	
Design Variable 2	1.0	20.0	10	
Design Variable 3			10	
Design Variable 4			10	

Write Input File for Data Base

The Absorption spectrum is precomputed for varying material parameters (design variables) and for fixed experiments.

WWW and Matlab interfaces are used for SEA-Simulations.

WWW interface for the generation of the optimization database

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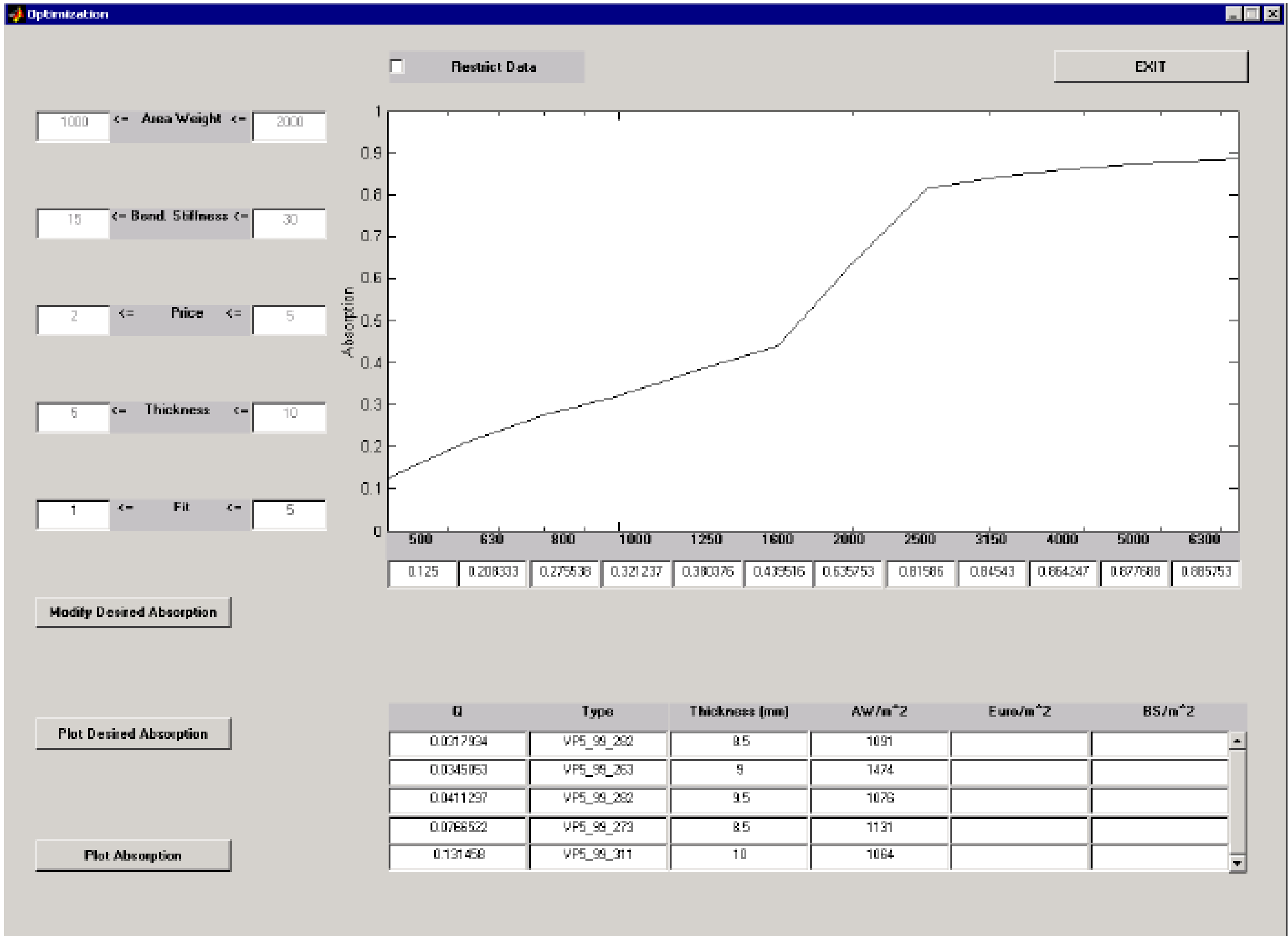
Inverse Simulation: Constraint Minimization Problem



Input form for the design of acoustic trim parts (e.g. headliner):

1. Objective function: Desired absorption spectrum
2. Constraints: Weight, Bending stiffness, etc.

GUI for the solution of the Constraint Minimization Problem (CMP)

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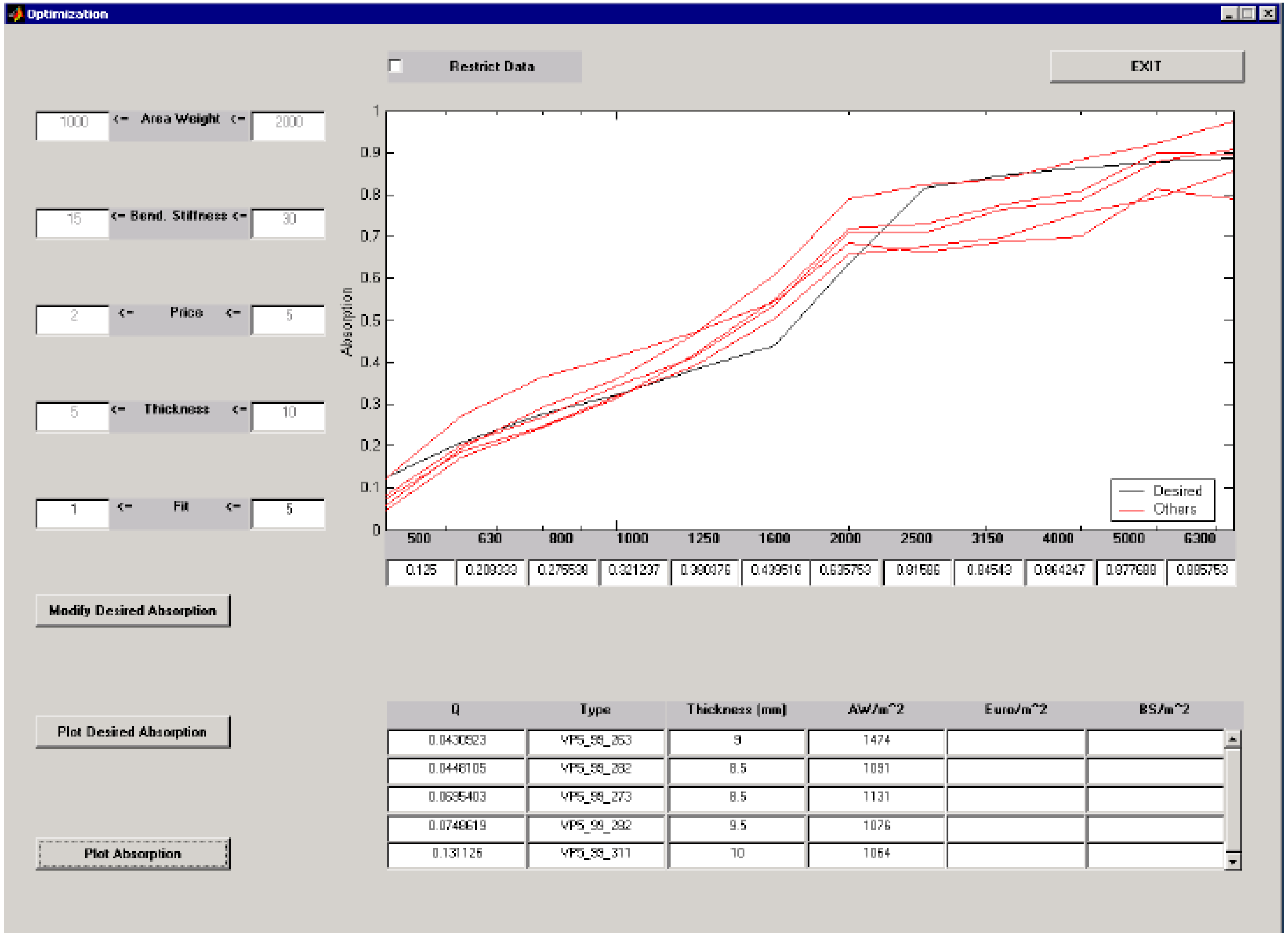
Inverse Simulation: Constraint Minimization Problem



The table at the bottom right side shows the best fitting materials with their absorption spectra plotted in red color.
The desired spectrum is Plotted in black.

Solution of the Constraint Minimization Problem (CMP)

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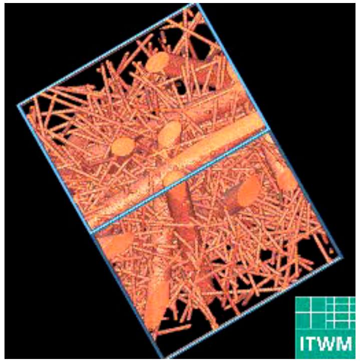
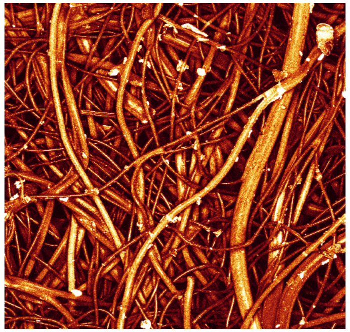
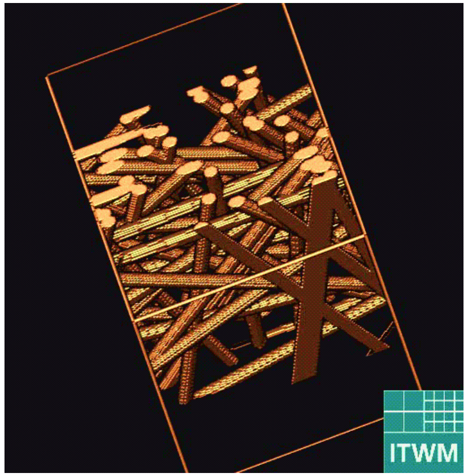
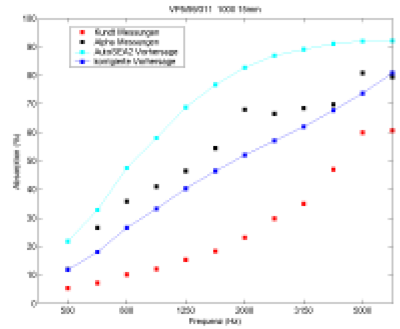
Summary

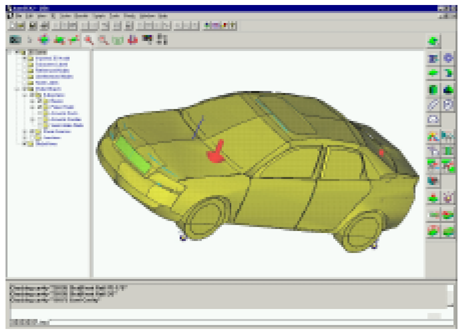
Simulation of the microstructure → Fluid flow simulation → Simulation of the material absorption











Simulation of the acoustical trim → Searching for optimal fleece → Extracting parameters from micrograph

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