Smart Filter Element Development

Creating ML & optimization based tools provided as webservices

Dr. Thomas Gose
Dr. Christoph Schulz
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MANN+HUMMEL

MANN+HUMMEL
Speaker Introduction

Dr. Christoph Schulz
Manager
Simulation Filter Elements
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- Diploma Aeronautics and Astronautics, University of Stuttgart
- PhD at Institute of Aerodynamics and Gas Dynamics, University of Stuttgart
  - Numerical Simulation of Atmospheric Boundary Layers and their Interaction with Wind Turbines
- Joined MANN+HUMMEL 2018
  - Simulation Engineer
  - Product Owner & Product Expert
  - Manager Simulation Filter Elements

MANN+HUMMEL
Speaker Introduction

- Graduated in Chemical Engineering at the University of Stuttgart
- PhD thesis at the Fraunhofer IGB / IGVT University of Stuttgart
- Joined MANN+HUMMEL in 2011:
  - Lead Product Engineer, Department of Oil Filtration
  - Simulation Engineer, Department of Simulation Filter Elements

Dr. Thomas Gose
Simulation Engineer
Simulation Filter Elements
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Filtration
We separate the **useful**
from the **harmful**

The company in figures

Over 80 years of innovation, expansion, and growth

1941
Founding Year

30+
Countries

23,000
Employees

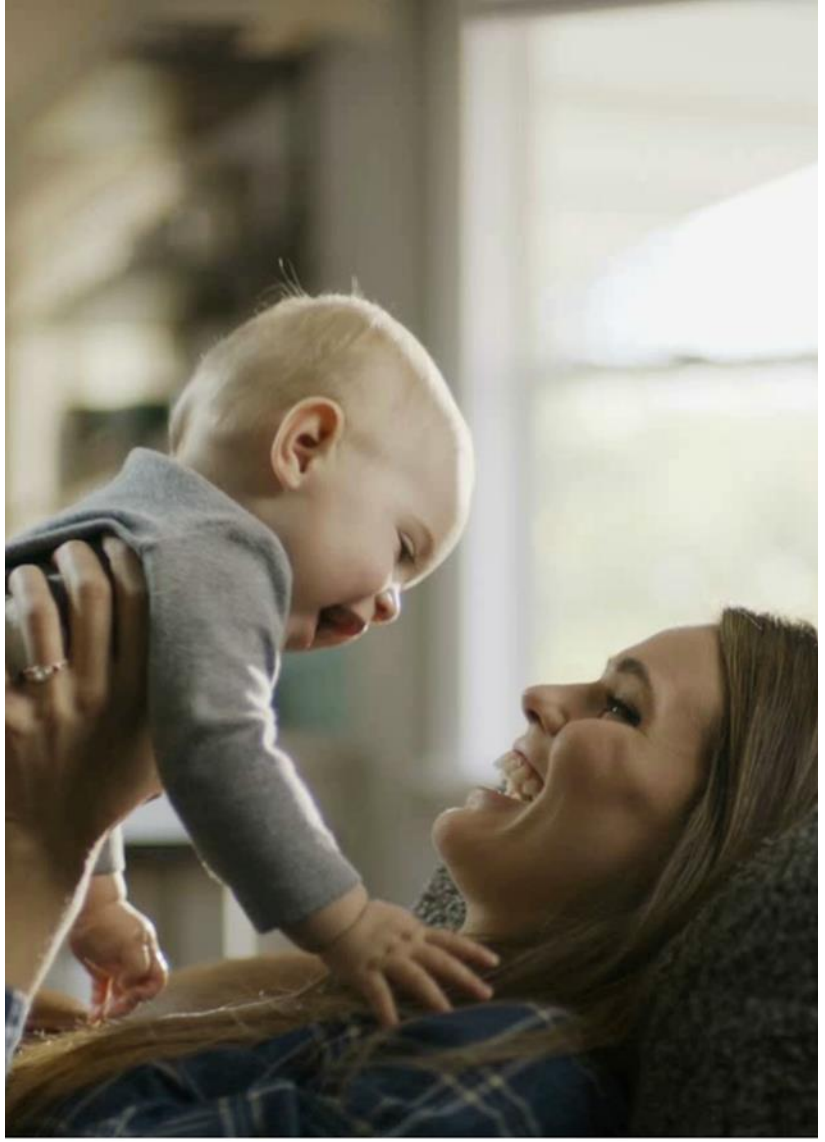
80+
Locations

4.2
Billion Euros of Sales Revenue

2,500
Patents and Applications

26
Filters per Second

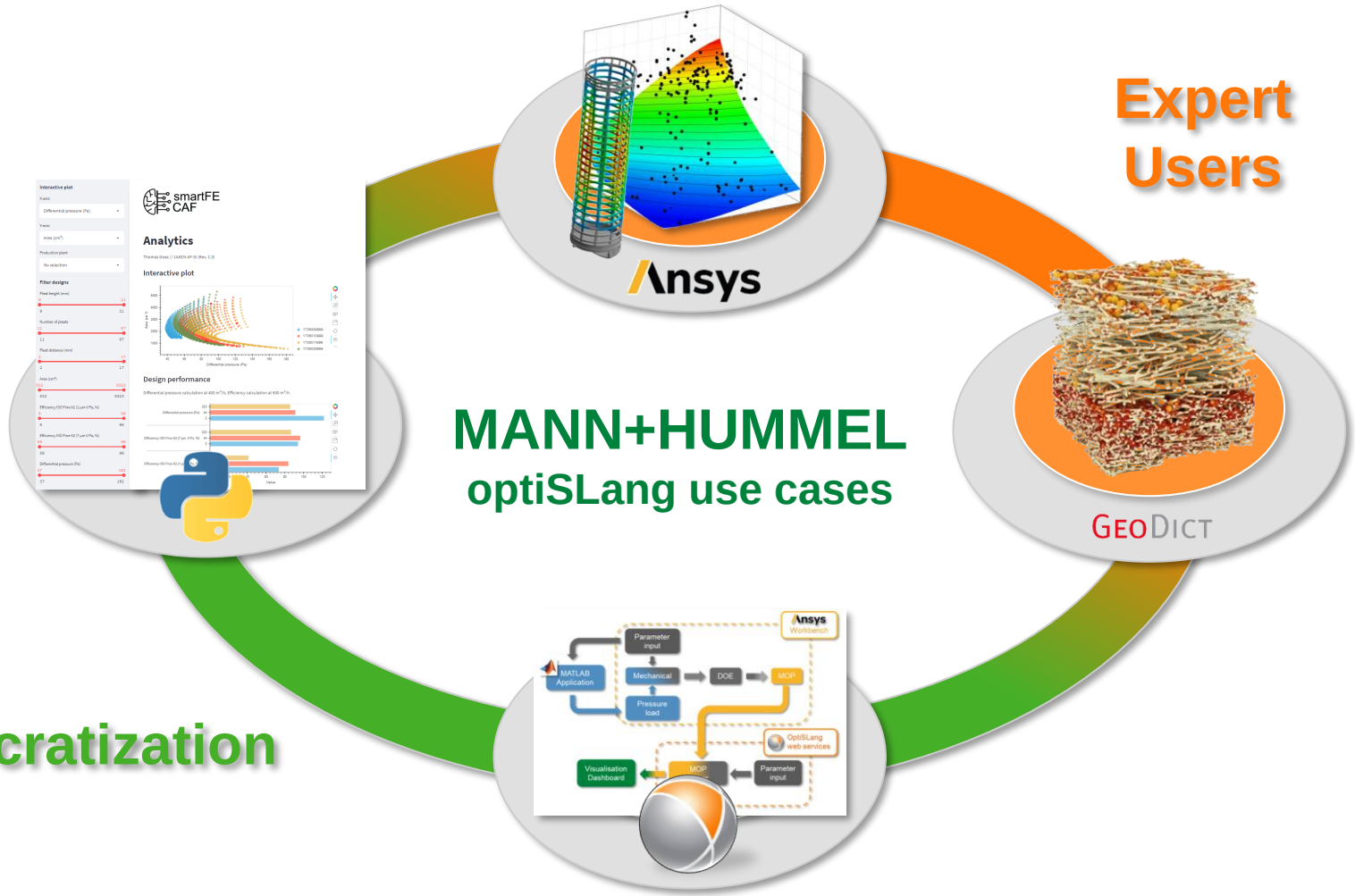
Cleaner Mobility



Cleaner Air

Cleaner Water

Smart Filter Element Development
Use Cases at MANN+HUMMEL



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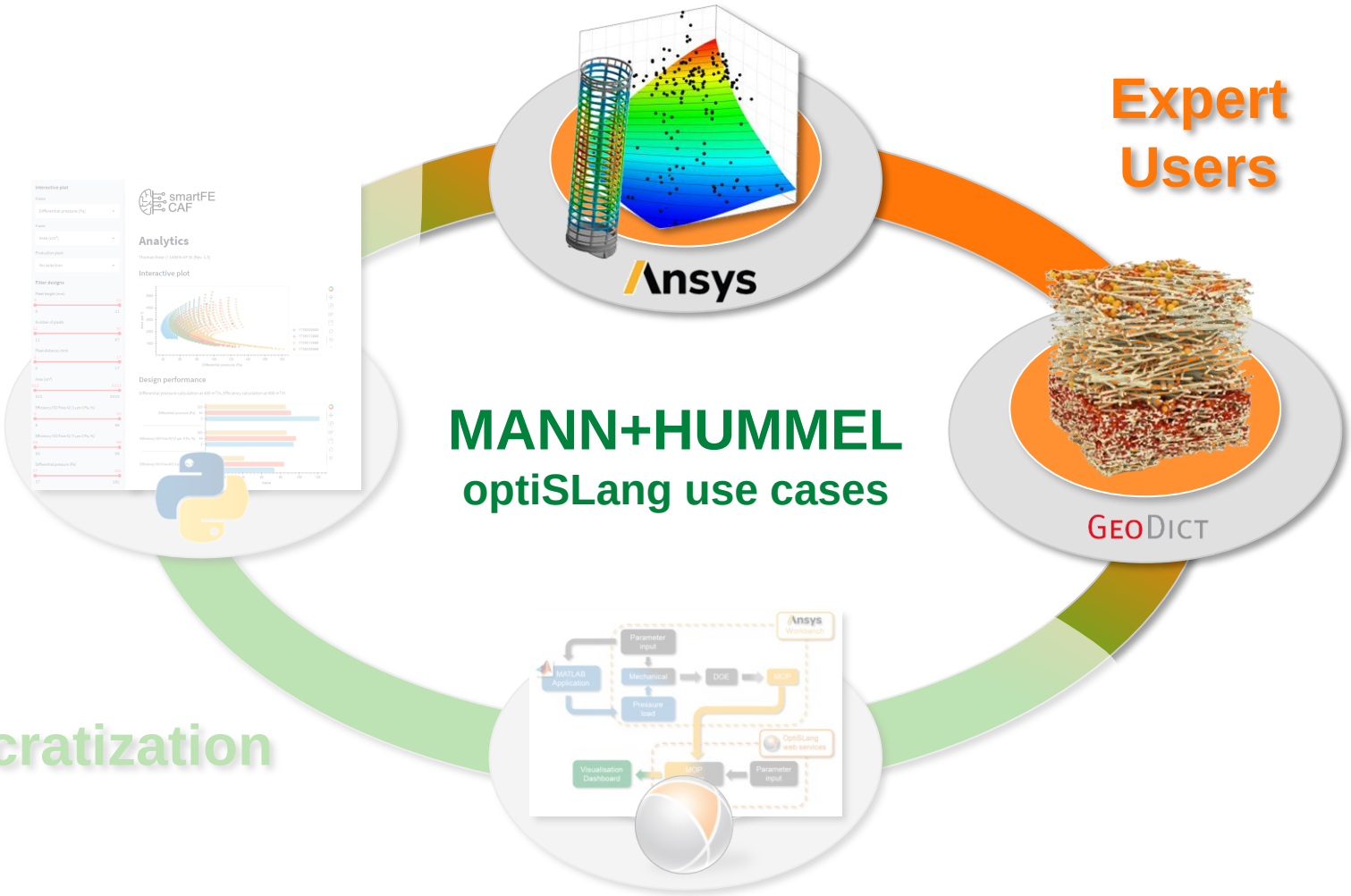
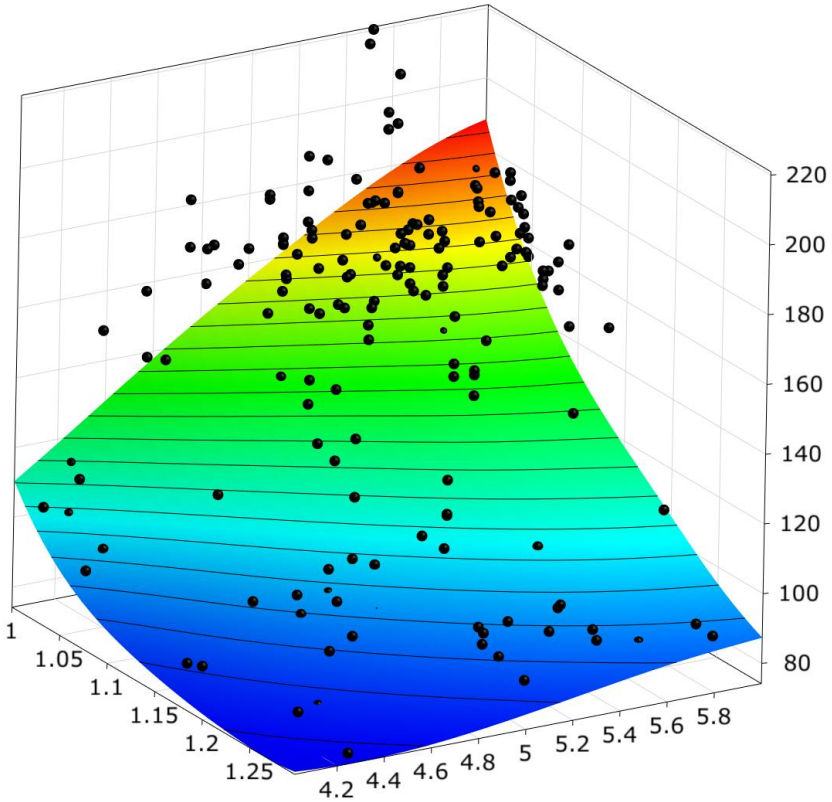


Expert Users
Element Scale

- **Product Optimization**
  - Performance
  - Material Costs
  - Pressure drop
  - Locations of Air Cleaners

- **FEA Example**
  - Mass / cost reduction targeted while keeping collapse strength
  - AMOP used
  - ~ 6% mass reduction achieved



Expert Users
Filter Media Scale – Virtual Development Process

Analysis

SEM images

µCT scan

flat sheet sample

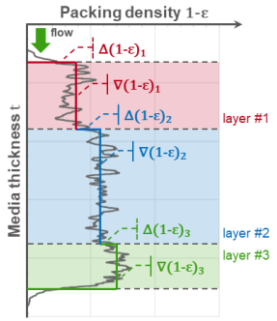
simulation testing

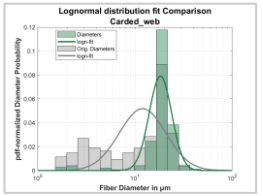
Characterization

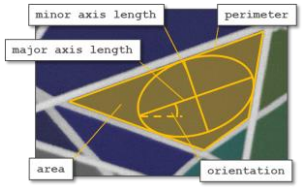
Fiber characteristics
- ✓ Fiber type
- ✓ Fiber diameter d_f
- ✓ Fiber shape $a\ b^{-1}$
- ✓ Fiber orientation α_f

Fiber structure
- ✓ Number of layers n
- ✓ Fiber mix φ_f
- ✓ Grammage G
- ✓ Thickness t
- ✓ Packing density $1-\varepsilon$

Media performance
- ✓ Pressure drop Δp_0
- ✓ Efficiency η
- ✓ Dust holding capacity dhc
- ✓ Particle collection $1-\varepsilon$







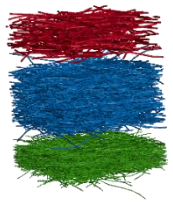
modeling validation

Optimization & Manufacturing

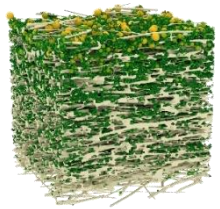
customer focus

innovative filtration product

enhanced filter material



parametric material model



virtual prototype

GEODICT optiSLang MathWorks python

Expert Users

Filter Media Scale - There is no free lunch

▪ Fiber characteristics	Number of variations
▪ Fiber type	→ 2
▪ Fiber diameter d	→ 4
▪ Fiber shape $a\ b^{-1}$	
▪ Fiber orientation	
▪ Fiber structure	
▪ Number of layers n	→ 2
▪ Fiber mix φ	→ 4
▪ Grammage G	→ 4
▪ Thickness t	→ 4
▪ Packing density $1-\varepsilon$	→ 4
Total design concepts:	4096

Computation time for Δp_0 / η_0 : ~4.0 hours per simulation

➢ **~16 k hours (680 days)**

Computation time for **dhc**: ~2.5 weeks / ~420 hours per simulation

➢ **~1720 k hours (196 years)**

- ➢ manageable only by high degree of automation
- ➢ reduce effort by using optiSLang

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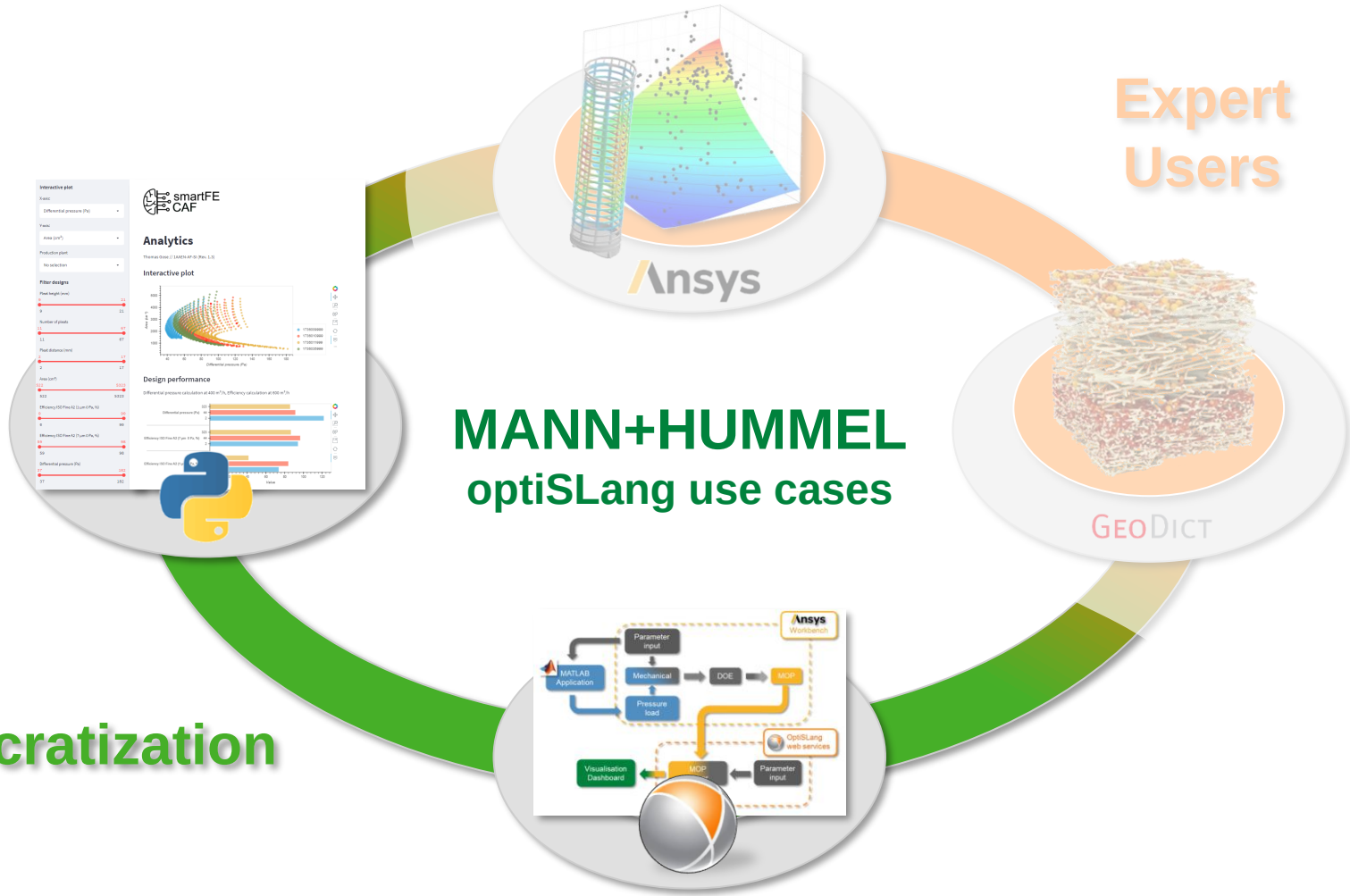
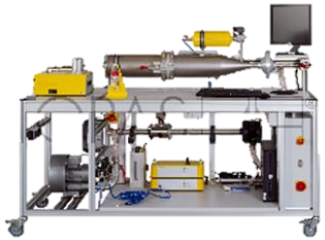
Use Cases at MANN+HUMMEL



Democratization
smartFE Vision



Measurement data

Simulation data

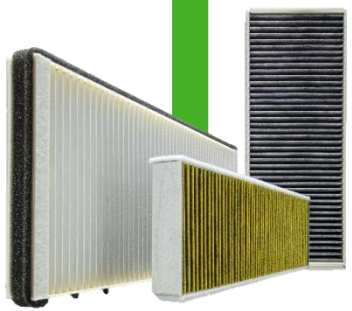
Material costs, Incoming goods inspection, ...

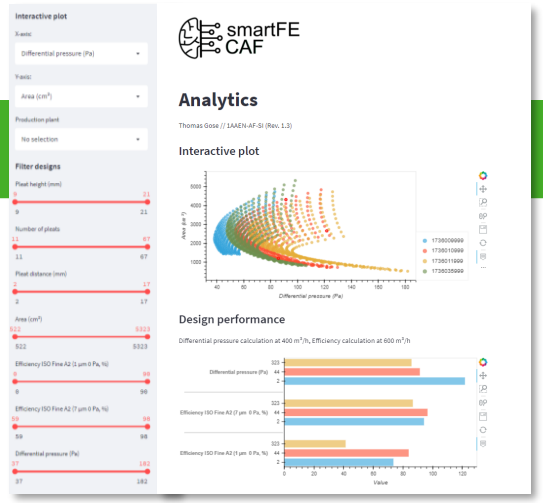
Further sources

“What is the optimal filter media and the optimal filter element design to achieve a given specification in my design space?”

AI

smartFE





Features

- Web-based application for global use
- Fast + intuitive element design workflow
- Interactive “what if” analysis + multi-objective optimization
- Reliable element performance prediction

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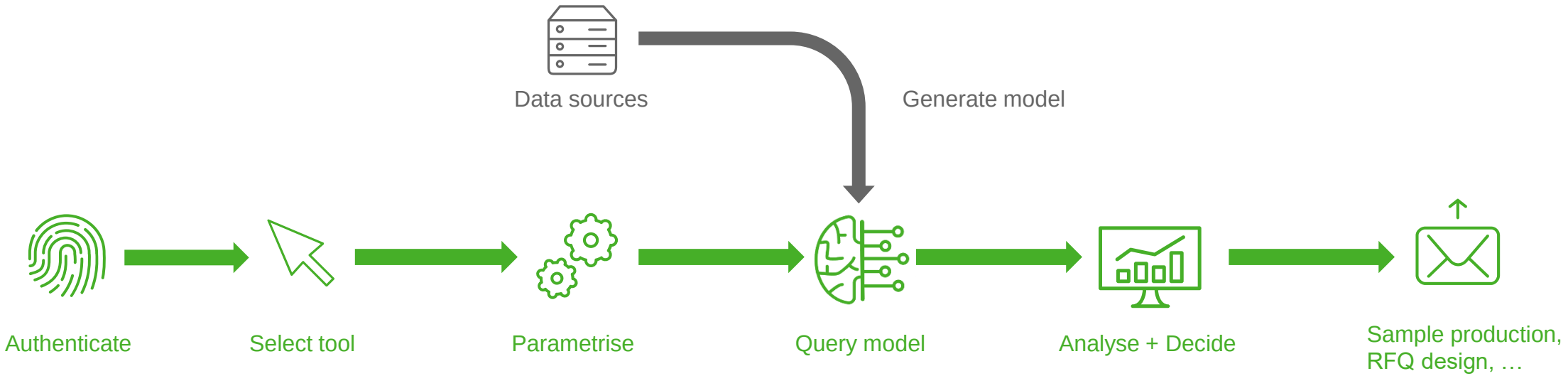
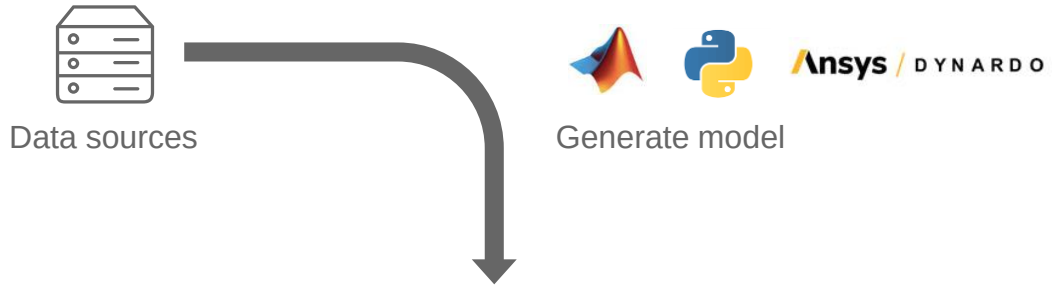
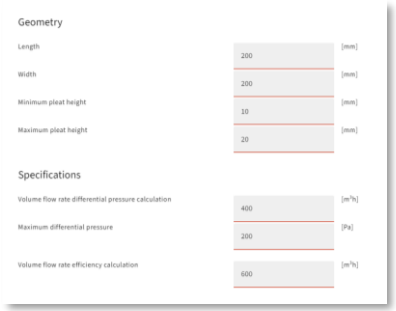
Democratization
Workflow Scheme

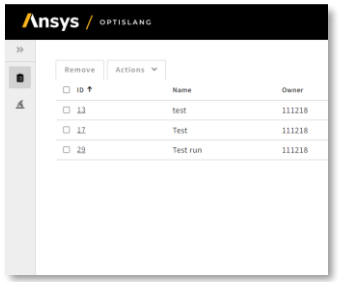


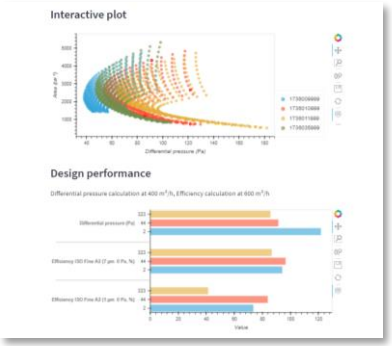
Democratization
Workflow Scheme

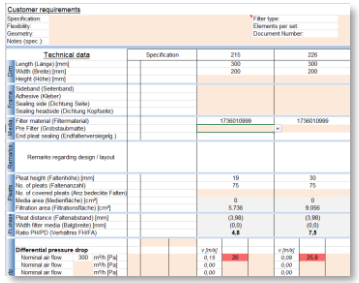


Authenticate → Select tool → Parametrise → Query model → Analyse + Decide → Sample production, RFQ design, …









Ansys / DYNARDO

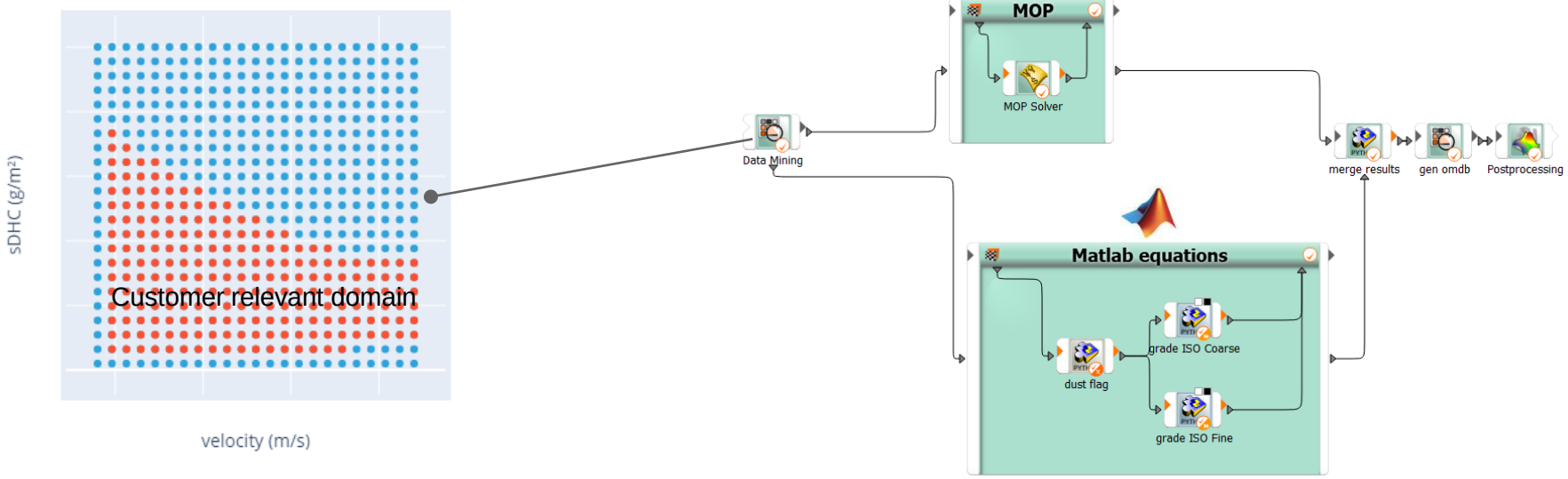
Democratization

Example 1: Model generation comparison

Case definition:

- Well defined physical prediction equations available
- Input data: 168 experimental measurements
- Setup: 3 parameters, 3 responses
- Side-by-side comparison of response prediction results from MOP and curve fitting model
- Static DOE - full factorial layout with 1058 design points

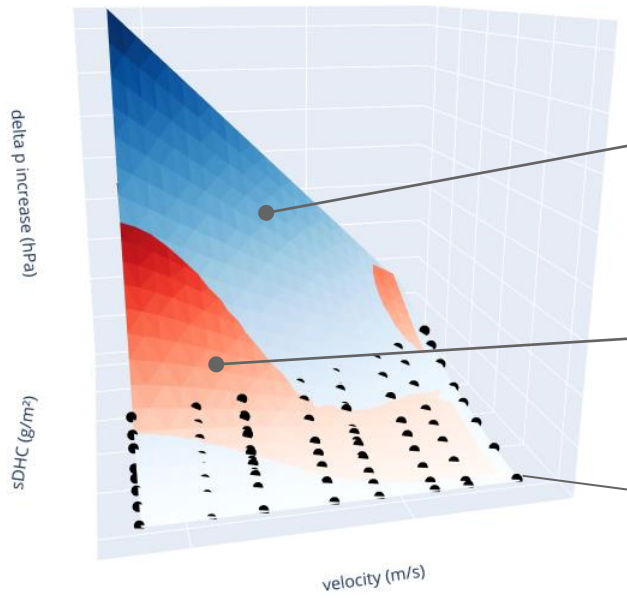
Response	CoP	CoD adj.	CoD adj.
Δp	0.995	0.996	0.985
Efficiency	0.987	0.993	-
Penetration	0.993	0.996	0.958



Democratization

Example 1: Model generation comparison – results

Differential pressure



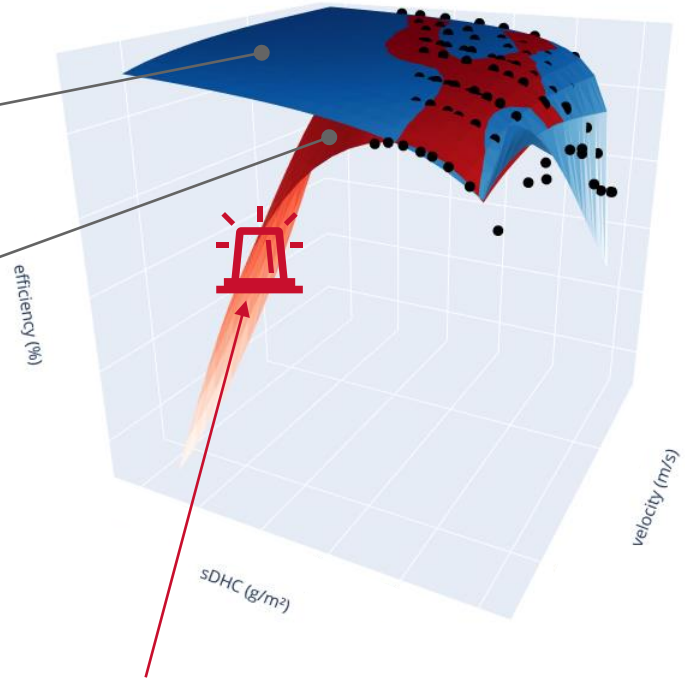
Curve fitting

Metamodel

Ansys / DYNARDO

Experiments

Filtration efficiency



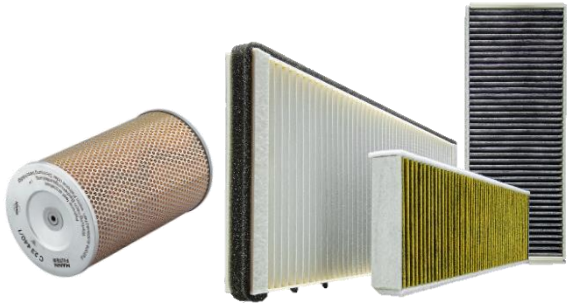
Overall difference in prediction between models is low

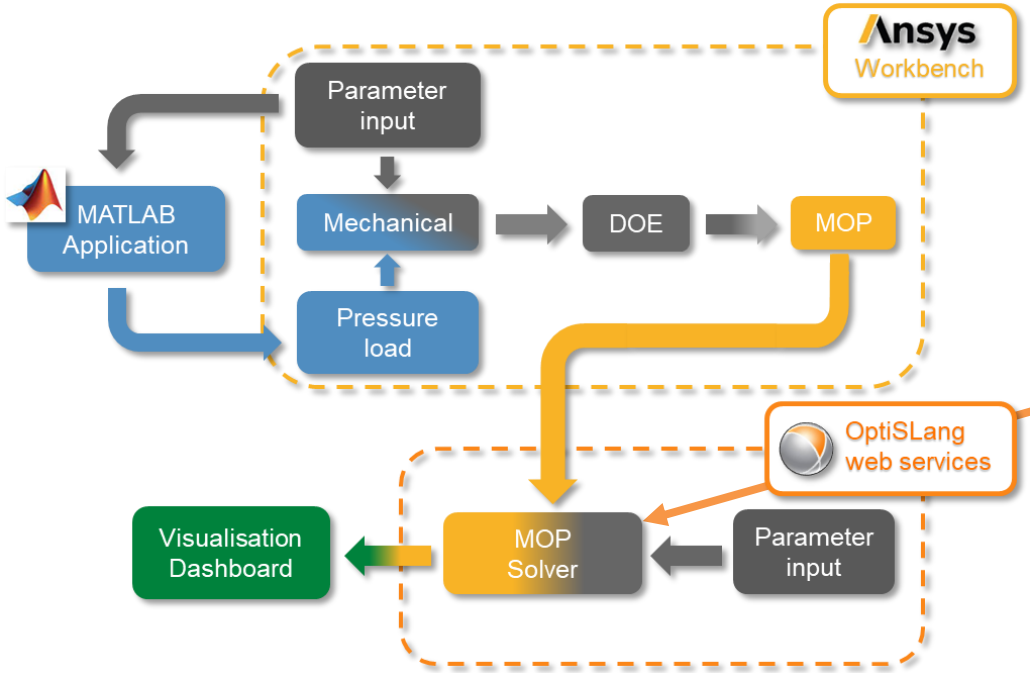
Non-physical predictions need to be covered via advanced MOP settings, e.g. prediction domain

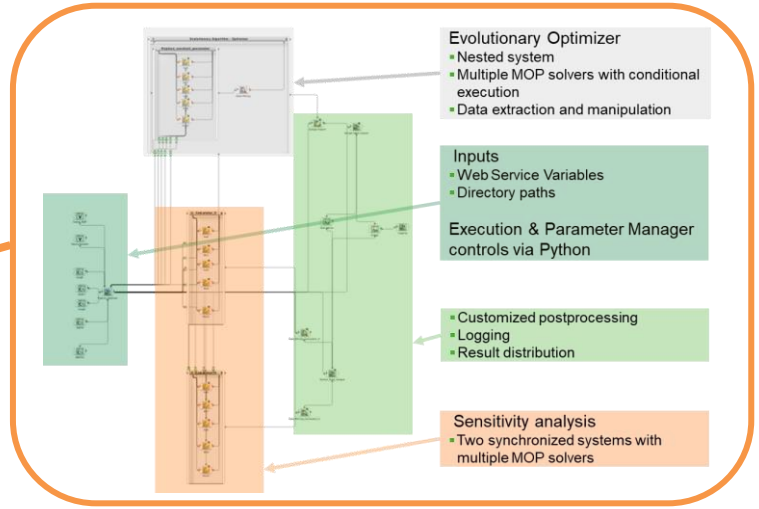
Democratization
Example 2: A MOP based workflow

Challenges:

- Constrains for sampling → clustered design space
- Approximation quality → reduced model range
- Multiple scenarios → modifying placeholder file, conditional executions







Democratization

Example 3: Customizable visualization capabilities

For our democratized applications interactive, customizable visualizations are an essential asset to

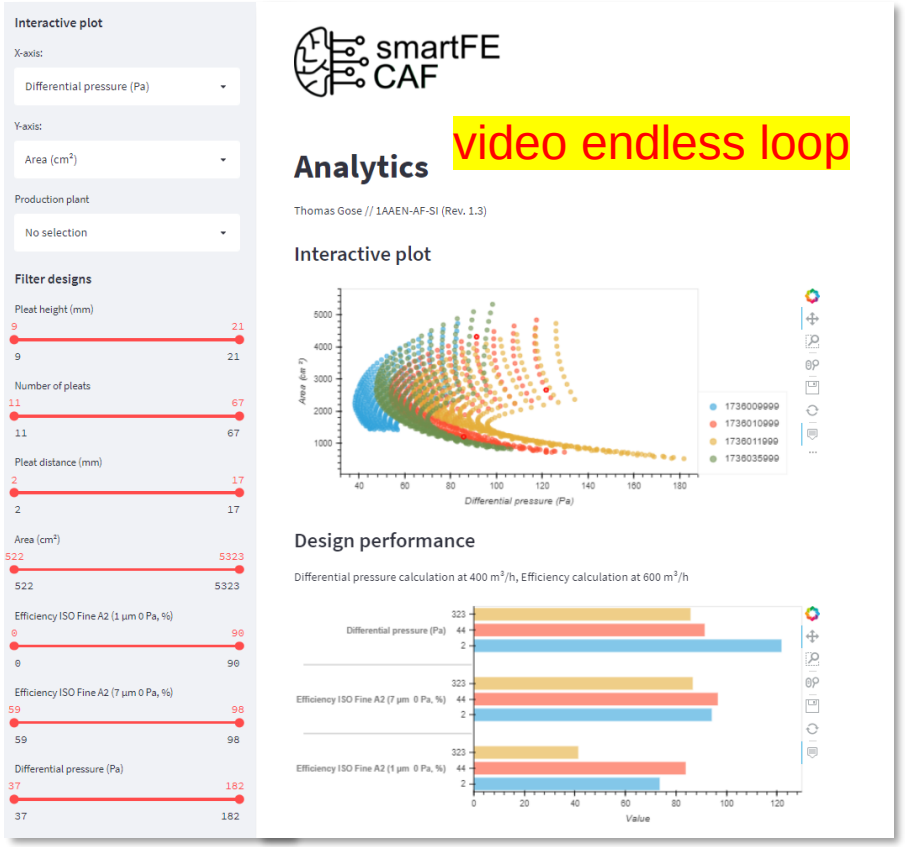
… visualize complex, multi-dimensional data,

… foster what if scenario evaluations,

… enable multi-objective optimizations,

… enhance user experience,

… take better design decisions.



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