UNLOCKING INSIGHTS - ENHANCING OUTPUT THROUGH USER-CENTRIC DESIGN OF INTELLIGENT ENGINEERING TOOLS

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Leadership in Filtration

MANN+HUMMEL

THE COMPANY IN FIGURES

From German Mittelstand to Global Player

Founding Year

1941

In Germany

Employees

23,385

worldwide

Locations

80+

on 6 continents

Turnover

4.7

billion €

EBIT

16

million €

EBIT margin

0.3

percent

Total assets

4.1

billion €

Figures from the year 2023

OUR MISSION

Filtration in Principle

Contaminated fluid

Clean fluid

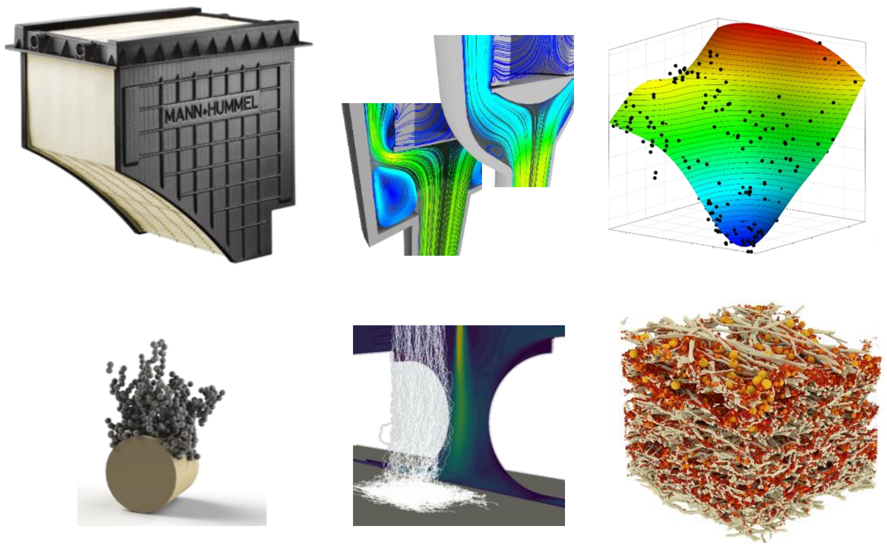

cleaner
MOBILITY

Public

FOCUS TOPICS

Simulation & Digitalization – 2 Pillars

Digital Twins & Optimization



Cost reductions
Less physical **prototypes**
Less physical **testing**
Reduction of development **costs**

Creating Data

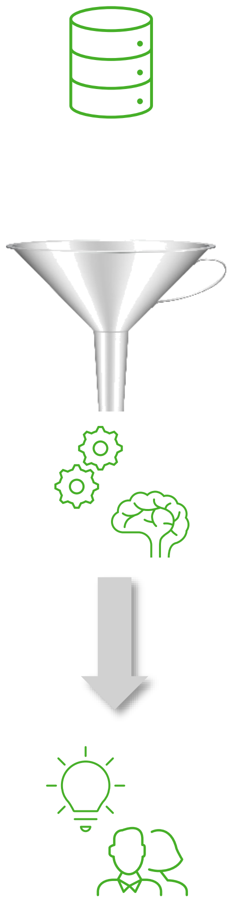
Engineering Tools

smartFE EAF
autoDHC.
AutoFiber
smartFE CAF
AUTO GRID
AutoLCA
Cyclone Design Tool

Standardization
Enabling to use large amounts of **data**
Maximizing outcome of test data
Cost indications in early design stages

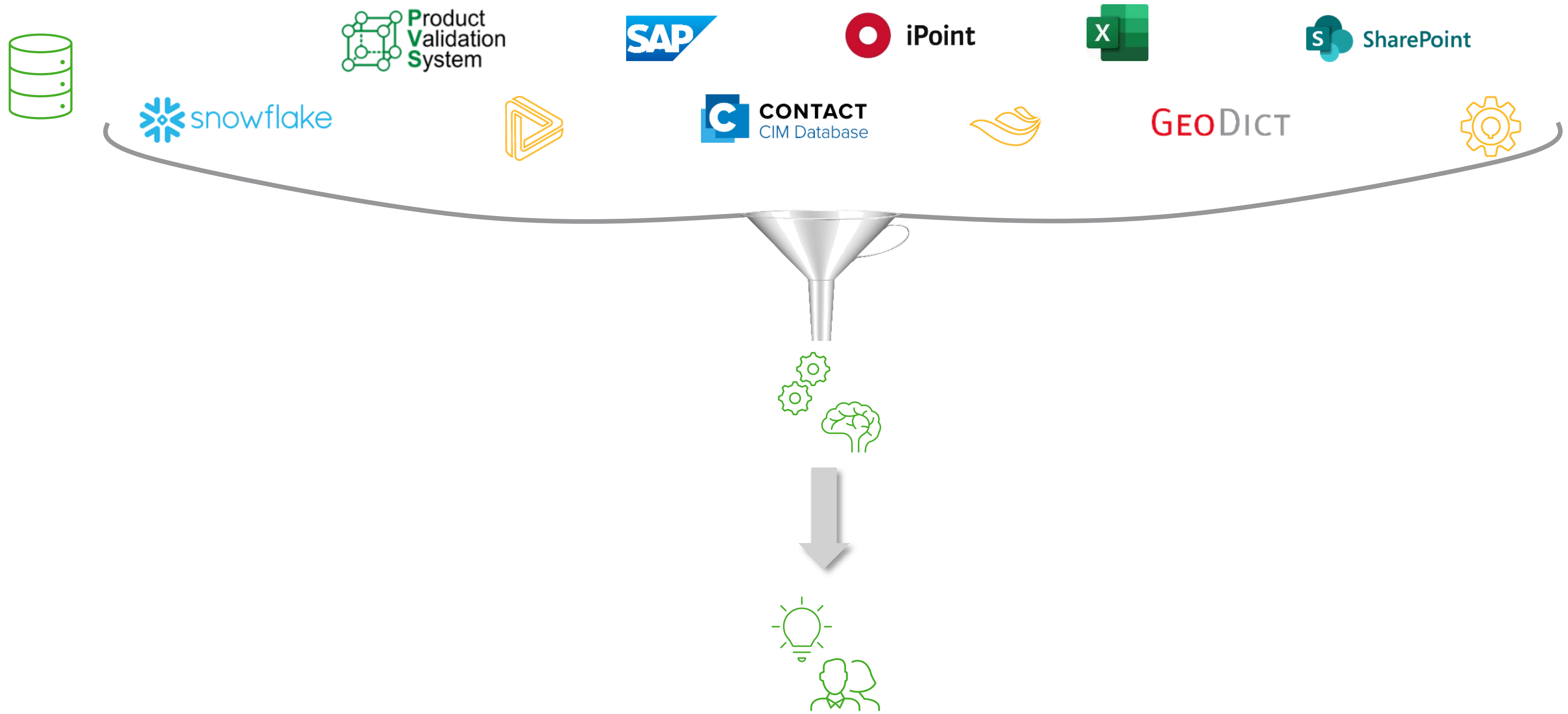
Using Data

Data Value Stream



CREATING AND USING DATA

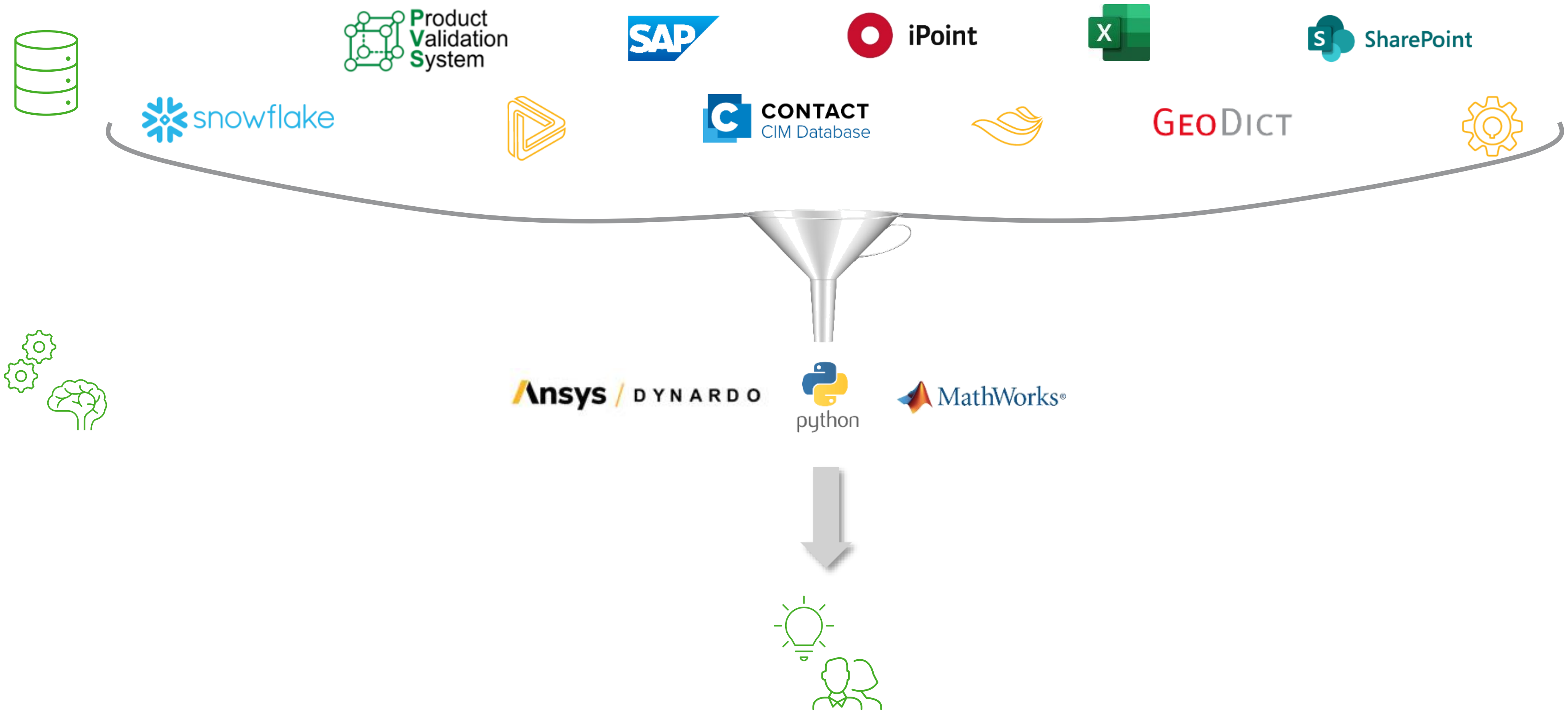
Data Value Stream



non-exhaustive

CREATING AND USING DATA

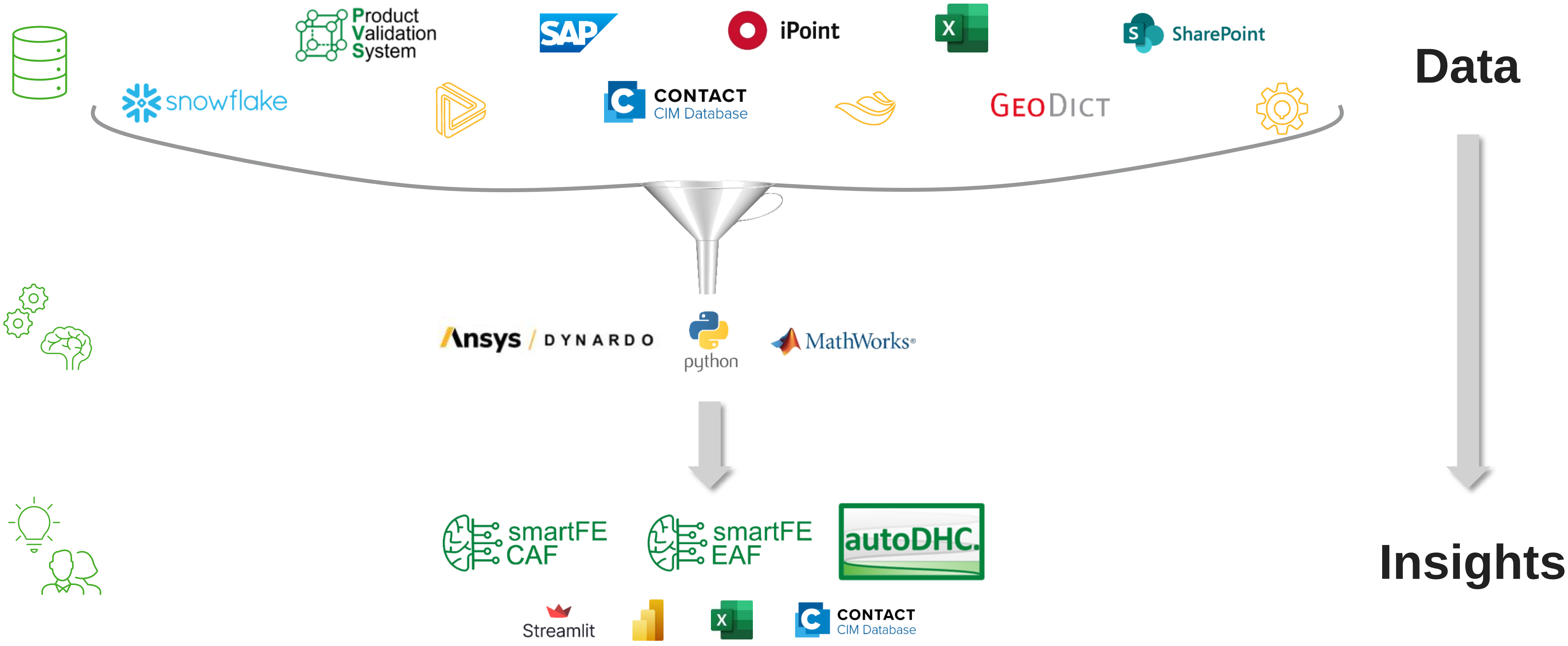
Data Value Stream



non-exhaustive

CREATING AND USING DATA

Data Value Stream



non-exhaustive

Creating Data

Filter Media Simulation

Creating Data by Filter Media Simulation

Analysis

SEM images

µCT scan

flat sheet sample

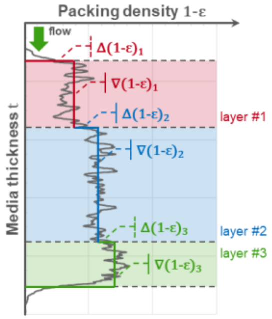
simulation testing

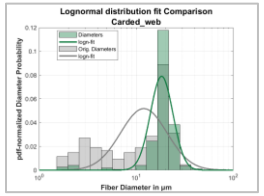
Characterization

Fiber characteristics
- ✓ Fiber type
- ✓ Fiber diameter
- ✓ Fiber shape

Fiber structure
- ✓ Number of layers
- ✓ Fiber mix
- ✓ Grammage
- ✓ Thickness
- ✓ Packing density

Media performance
- ✓ Pressure drop
- ✓ Efficiency
- ✓ Particle collection





model validation

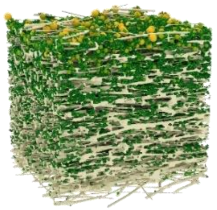
Optimization & Manufacturing

customer focus

innovative filtration product

enhanced filter material

parametric material model



virtual prototype

GeoDict · Ansys / DYNARDO · MathWorks · python

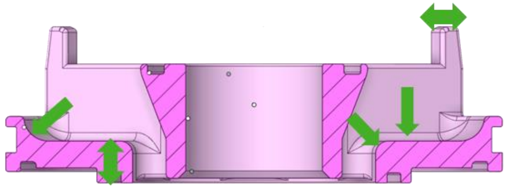
Creating Data

Filter Element Simulation

Creating Data by Filter Element Simulation

Product

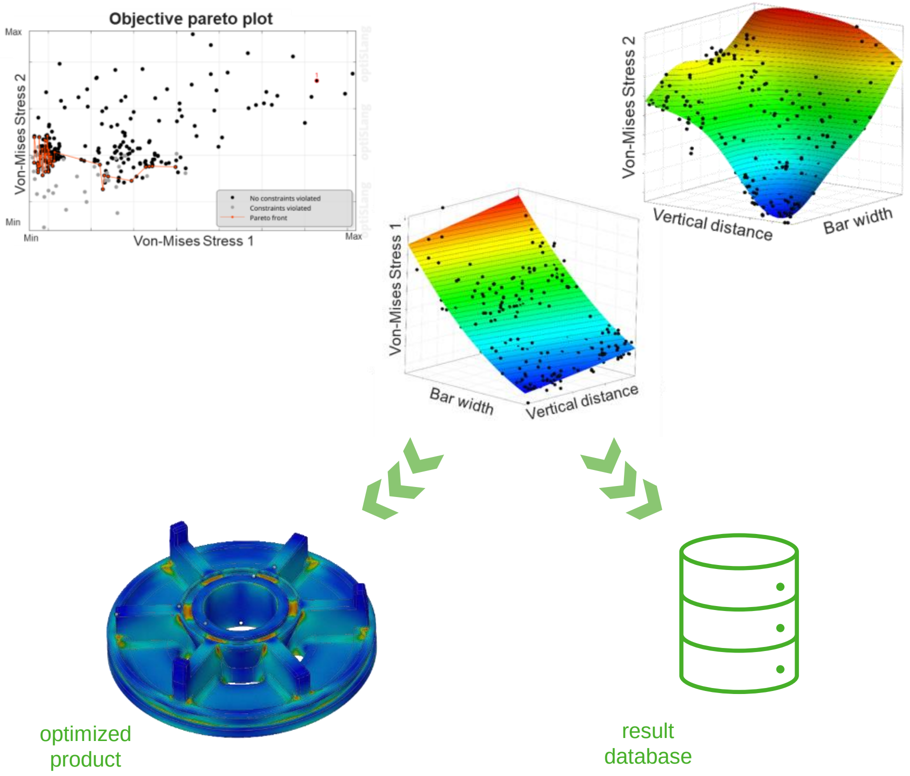
Parametrization



Parameter | Start designs | Criteria | Settings | Other | Result designs

	Name	Parameter type	Reference value	Constant	Value type
1	Hole_Radius	Optimization	3	☐	REAL
2	BAR_WIDTH	Optimization	6	☐	REAL
3	Rib_Radius	Optimization	2	☐	REAL
4	Vertical_Distance	Optimization	5.9	☐	REAL
5	Vertical_Radius	Optimization	1	☐	REAL

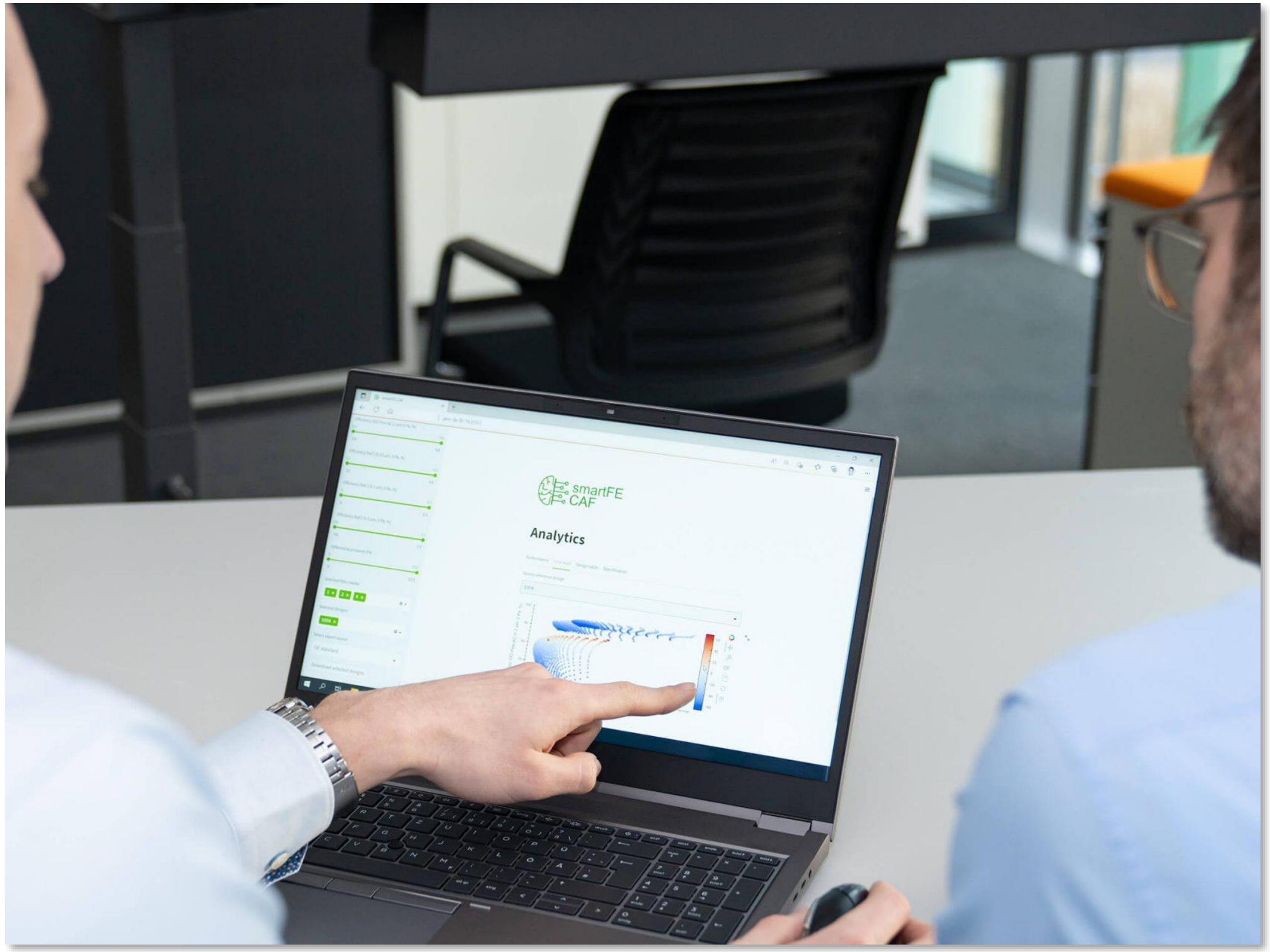
Optimization & Database Creation



Public

Using Data

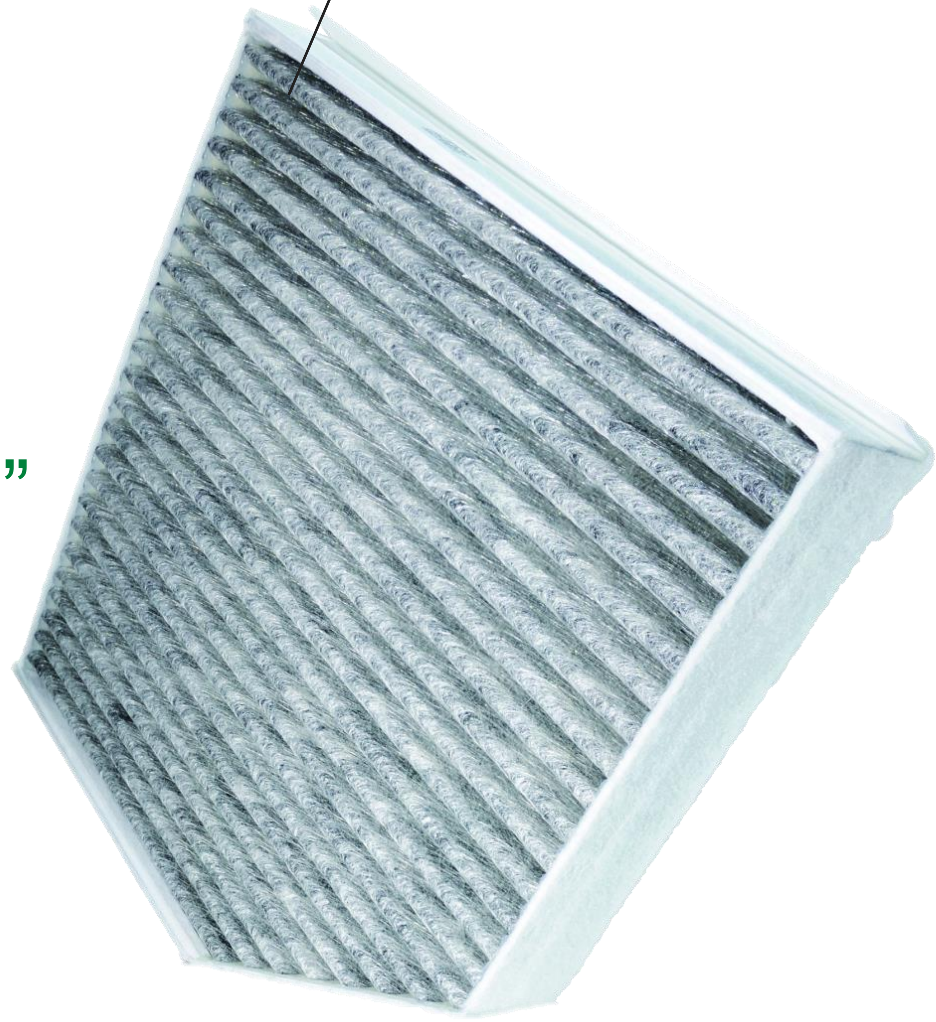
smartFilterElement Development



Core Question

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

Automotive Cabin Air Filter element

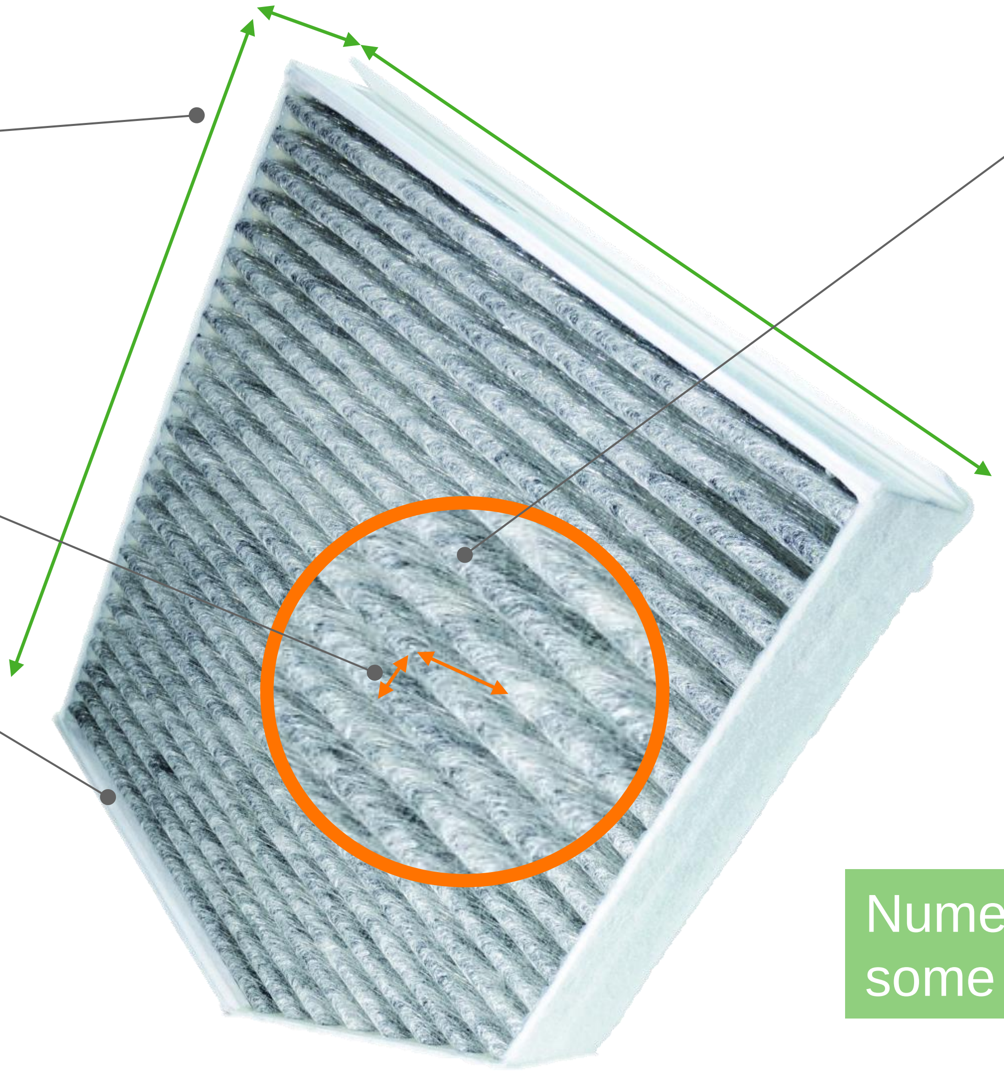


Parameters governing Filter Element Development

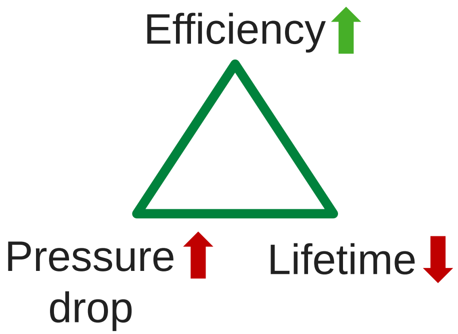
Bellow Geometry
- Length
- Width
- Height
- Pleat distance
- Pleat height

Element design
- Sideband
- Glueing
- …

Process parameter
- Fluid
- Volume flow
- …



Filter media
- Fiber characteristics
- Performance measures

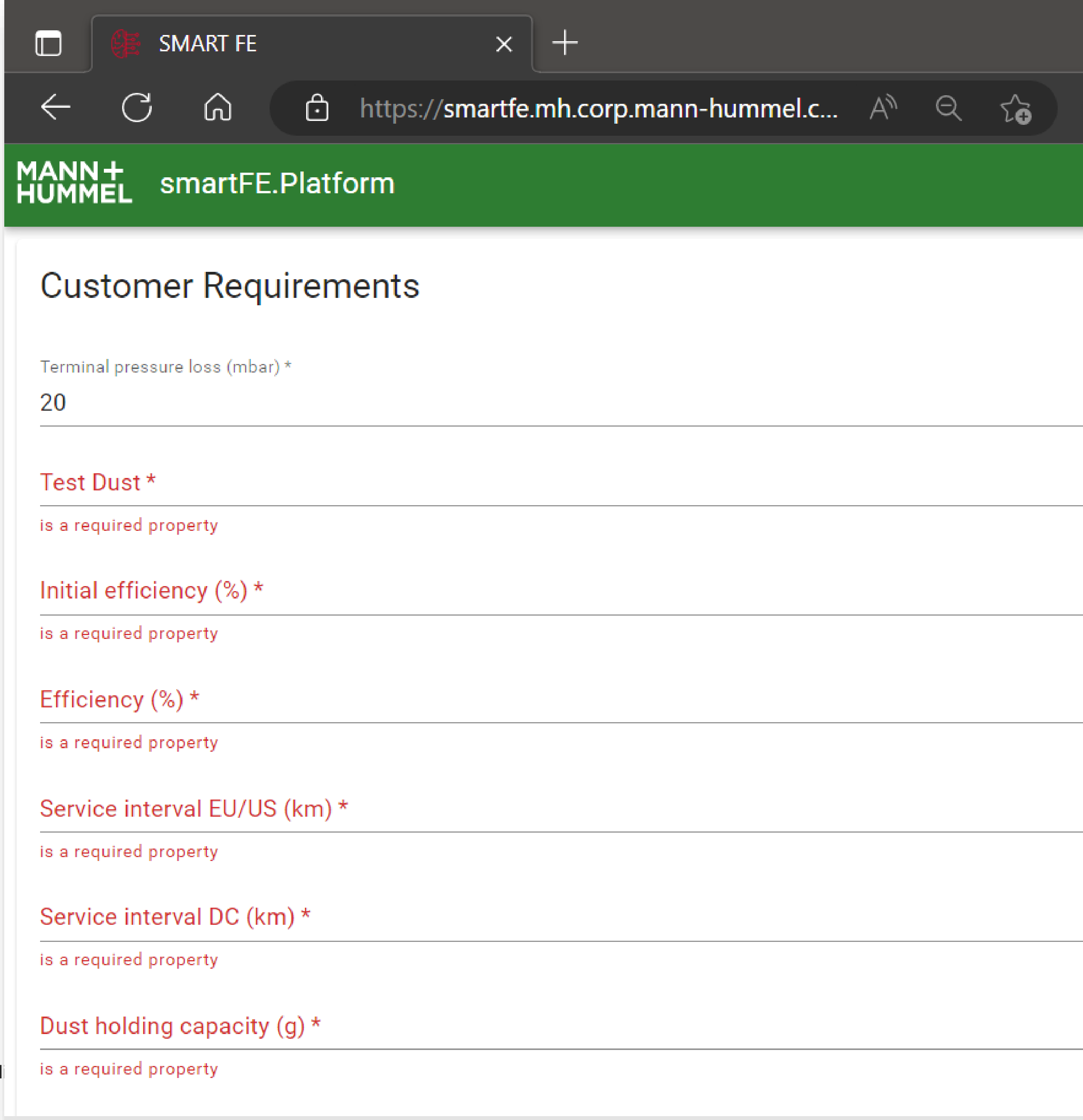


- Added functionalities: activated carbon, gas adsorption, etc.

Numerous parameters need balancing, some goals are even conflicting.

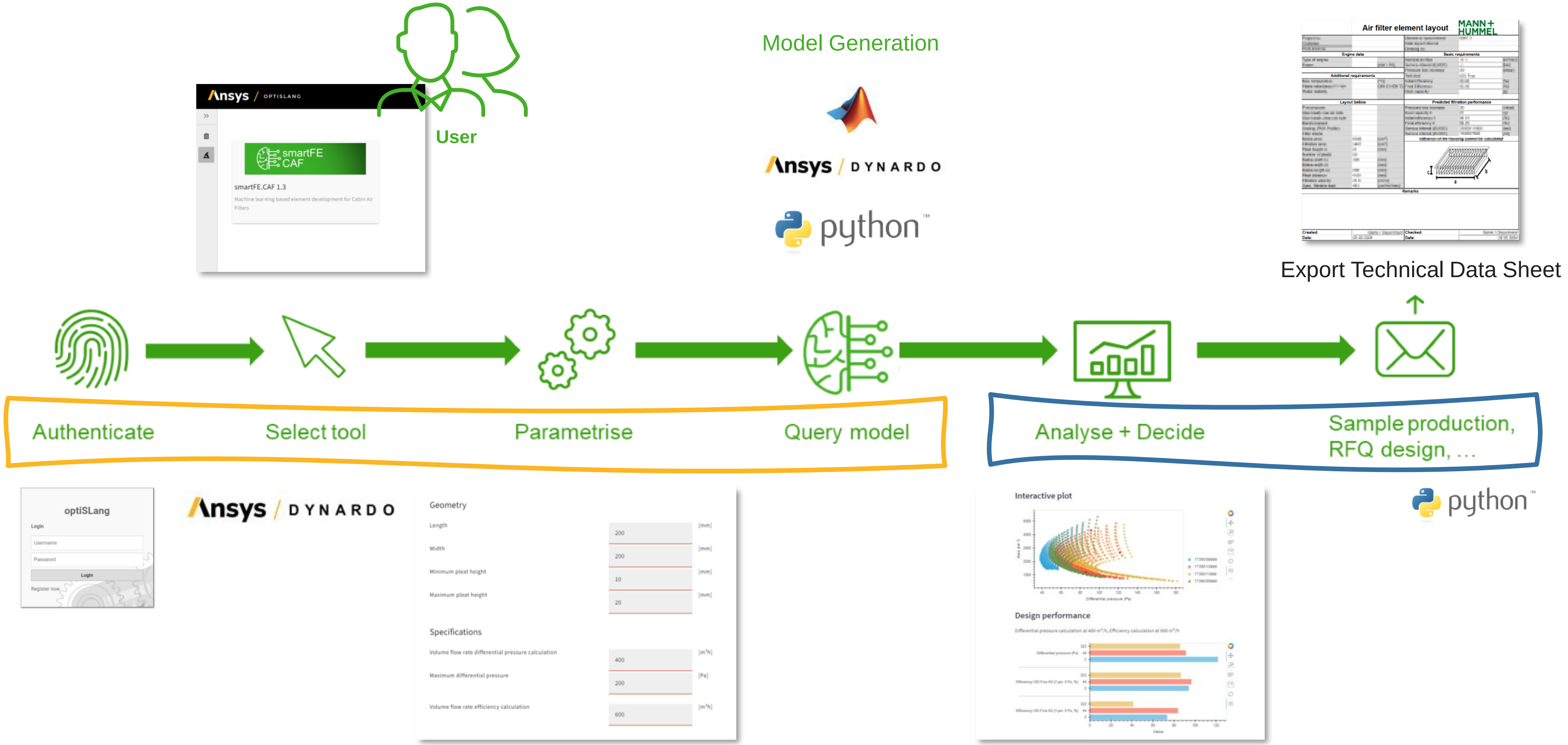
Democratizing Applications

smartFilterElement Development



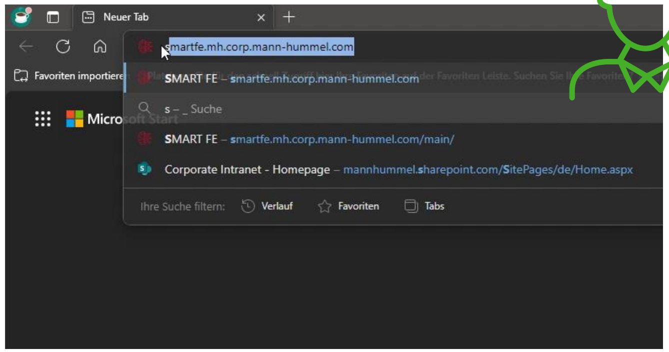
WORKFLOW AT A GLANCE – 1ST GENERATION

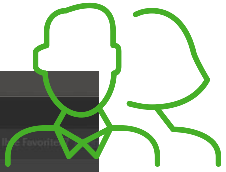
smartFE – smart Filter Element Development



WORKFLOW AT A GLANCE – 2ND GENERATION

smartFE – smart Filter Element Development



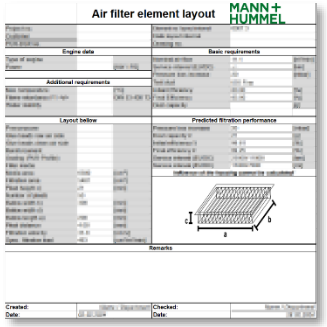


User

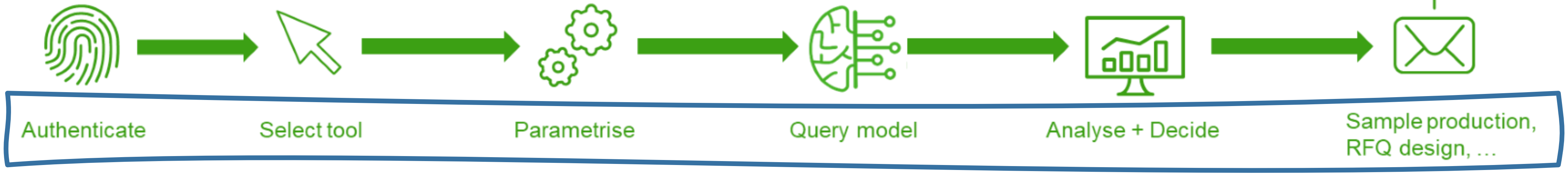
Model Generation

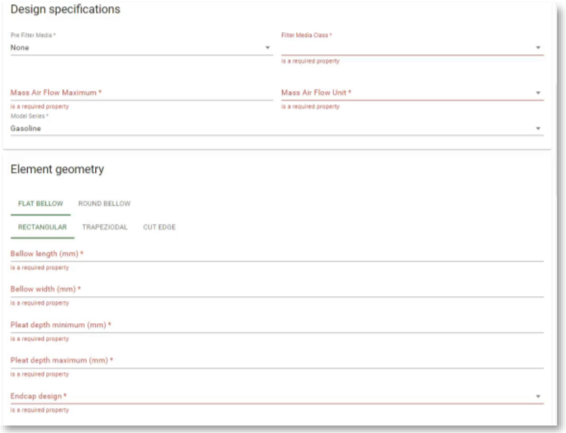
Ansys / DYNARDO

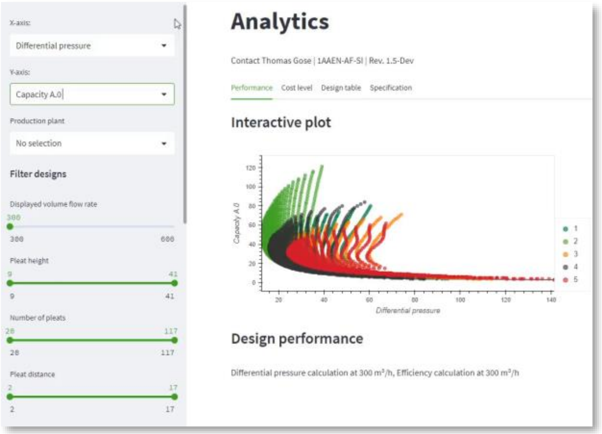
python



Export Technical Data Sheet



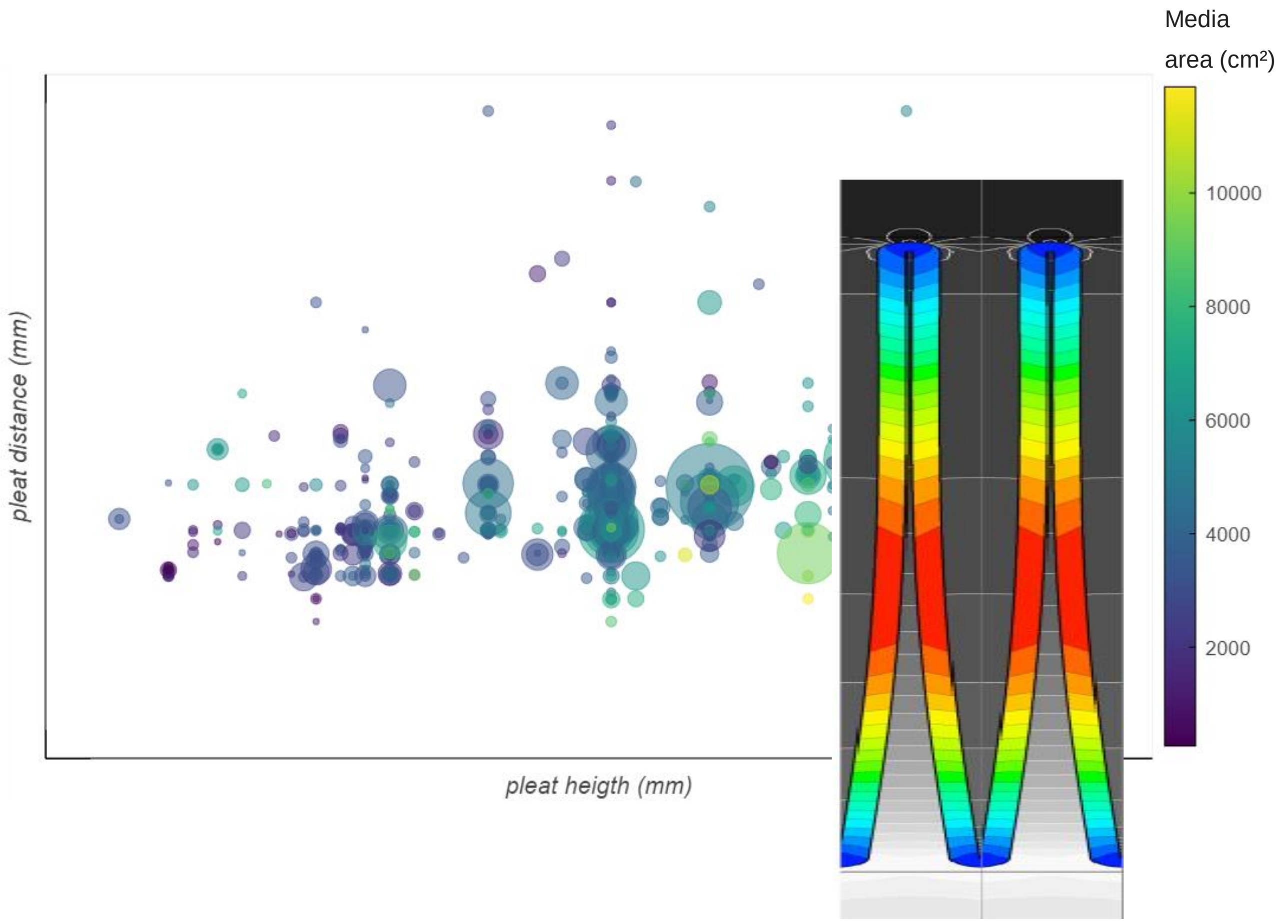




python

Modelling Approach

smartFilterElement Development



What are the benefits of using machine learning?

To predict the **filter element performance** e.g., efficiency, lifetime, pressure drop we apply

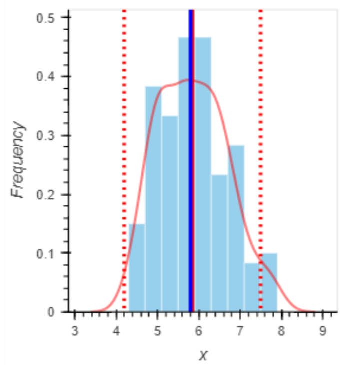
Data-driven methods

Knowledge-driven methods

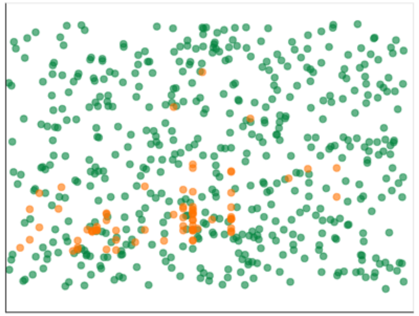
What are the benefits of using machine learning?

To predict the **filter element performance** e.g., efficiency, lifetime, pressure drop we apply

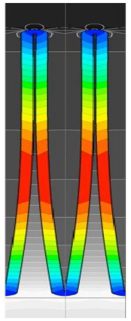
Data-driven methods		Knowledge-driven methods



Descriptive statistics



Machine learning

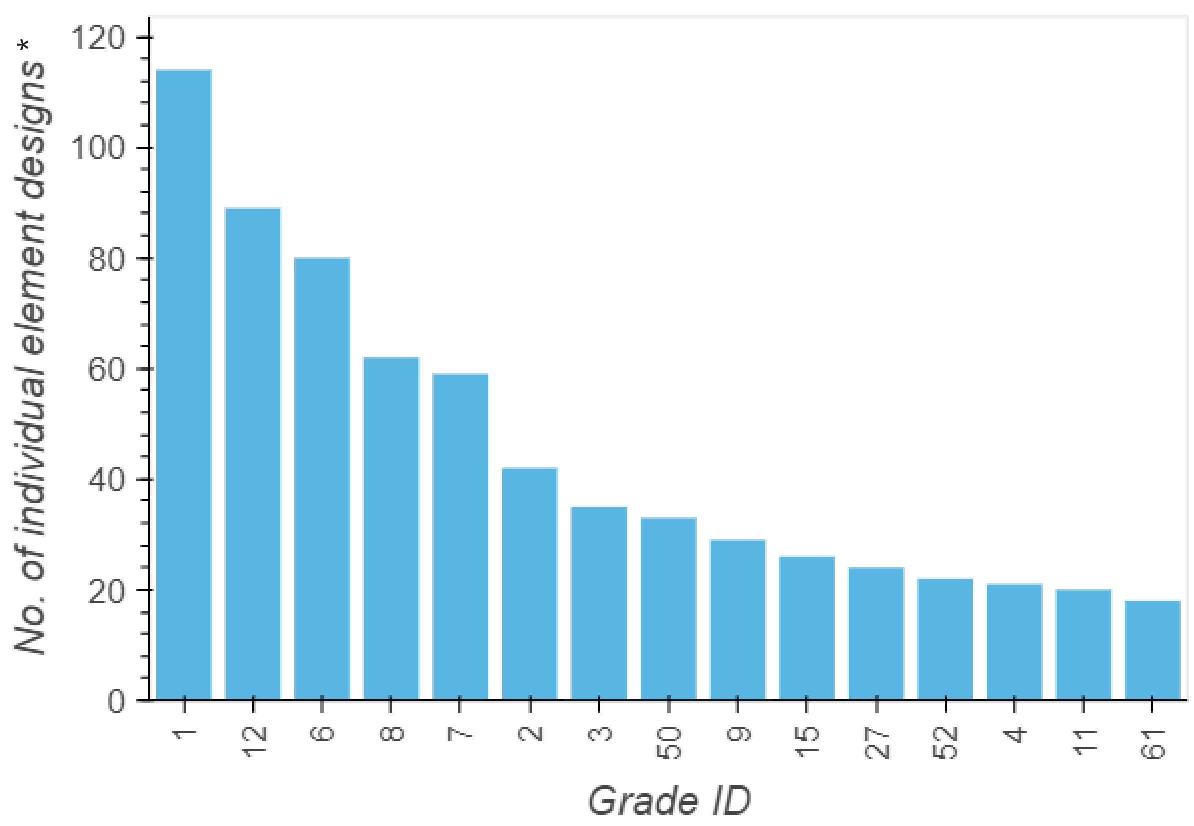


Simulation

Machine learning promises more accuracy than statistics and much faster estimates than simulation.

CHALLENGES IN FILTER ELEMENT DATA

Amount of Individual Designs



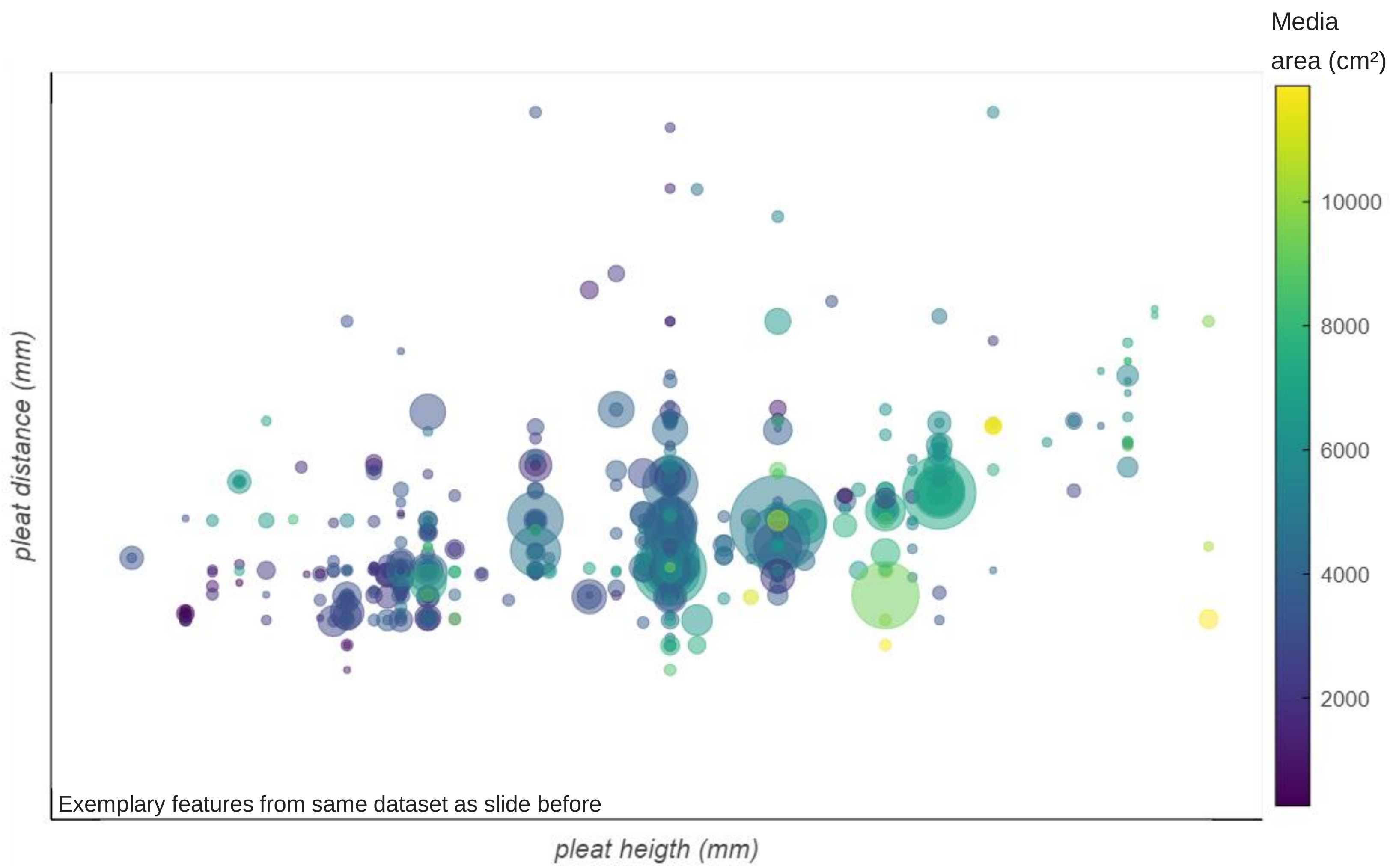
Observations

- Performance measurements are captured from individual element designs
- Significant variations between media grades

Overall amount of data variates significantly within grades and is relatively low for machine learning

* Unique combination of pleat height – pleat distance – media area

Distribution of Data in Parameter Space



Exemplary features from same dataset as slide before

Observations

- Distribution inhomogeneous with several cluster formations
- Variation of pleat height higher compared to pleat distance
- Feature space is not ideally sampled from ML perspective

Modelling each grade individually amplifies feature inhomogeneity

Assessing Model Quality

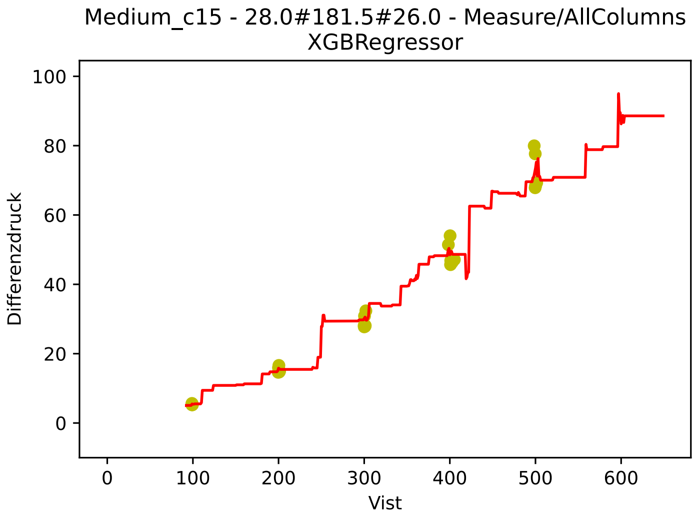
Public

Besides metrics, interpretability and physical prediction behavior are important model quality factors

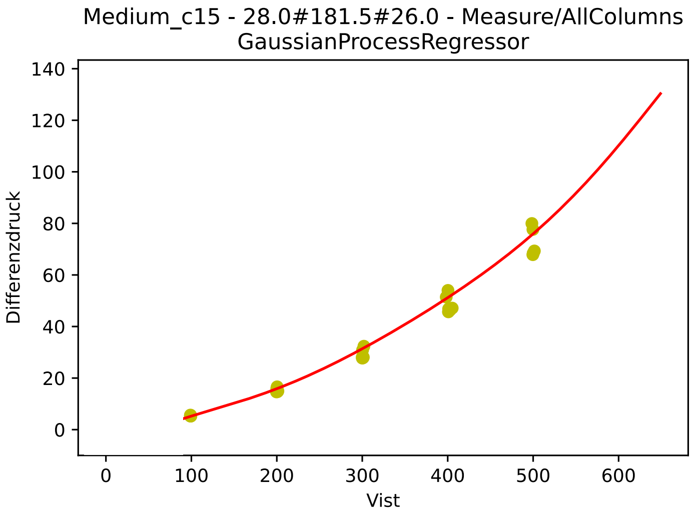
Metrics

- Mean squared error (MSE)
- Coefficient of determination (CoD, R^2)

Interpretability e.g., predicted differential pressure curves for single element design



Low physical prediction behavior



High physical prediction behavior

Can methods be combined?

…to predict the **filter element performance** e.g., efficiency, lifetime, pressure drop

Measurement data

Simulation data

MODELLING APPROACH

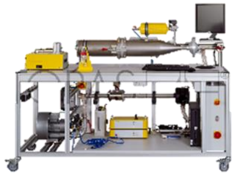
Can methods be combined?

…to predict the **filter element performance** e.g., efficiency, lifetime, pressure drop

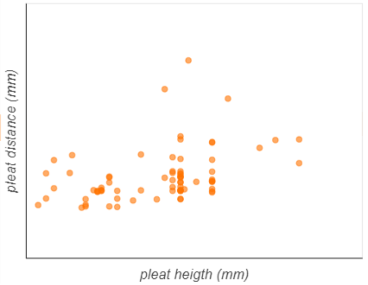
Measurement data	Hybrid data	Simulation data

MODELLING APPROACH

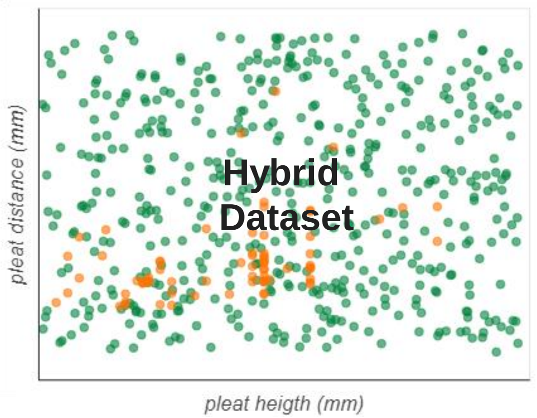
Hybrid Modelling Approach

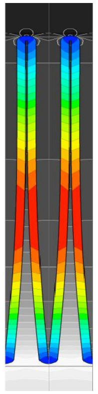


Measurement Data



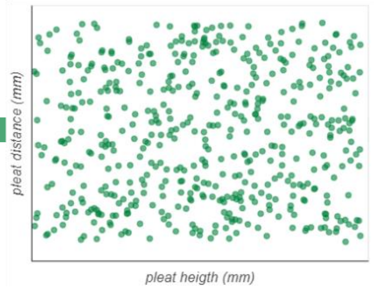
Measurement Samples
e.g. pressure drop results





Simulation Model

Model Calibration



Sampling (LHS), Solve Model

Machine learning

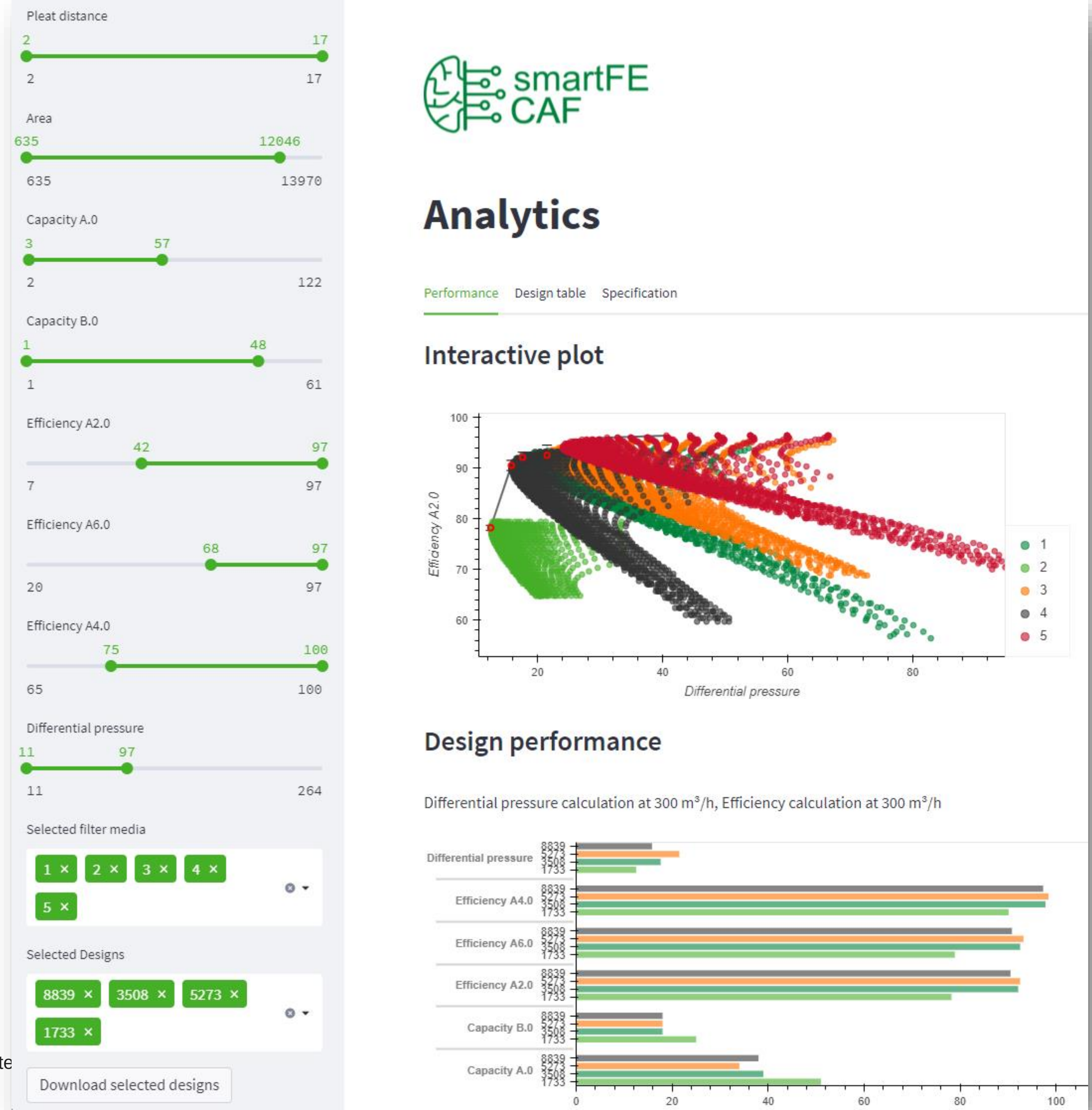
Characteristics
- Supervised
- Regression
- Batch

Important factors
- Feature engineering
- Hyperparameter optimization
- Interpretability of the model

Depending on the complexity of the output parameter more advanced models need to be considered.

Interactive analytics

smartFilterElement Development



Relevance of Interactive Analytics

Benefits of ML approach

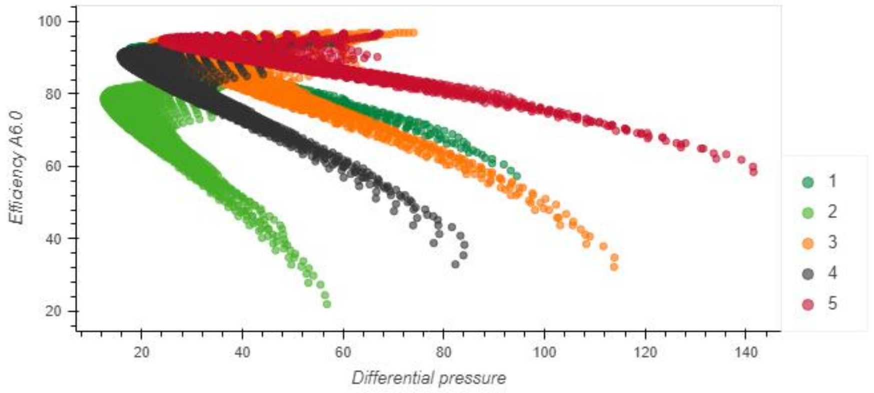
- High-resolution sampling of the parameter space
- High number of potential element designs

Characteristics of the element development process

- Necessity of evaluating curated information depending on the development goals
- Conflicting goals need balancing
- Non-linear design workflow

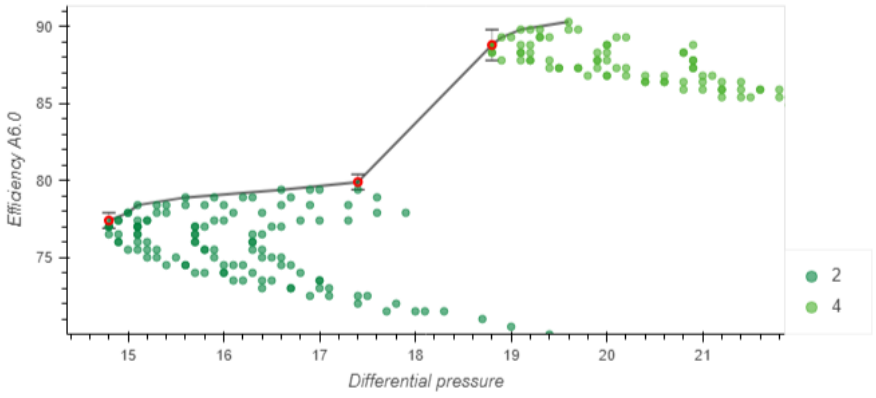
Requirements for the analytics

- Interactive, reversible, intuitive
- Foster "what-if" scenarios
- Leverage complex and multi-dimensional data
- Enable multi-objective optimizations



~8500 potential designs

3 selected designs

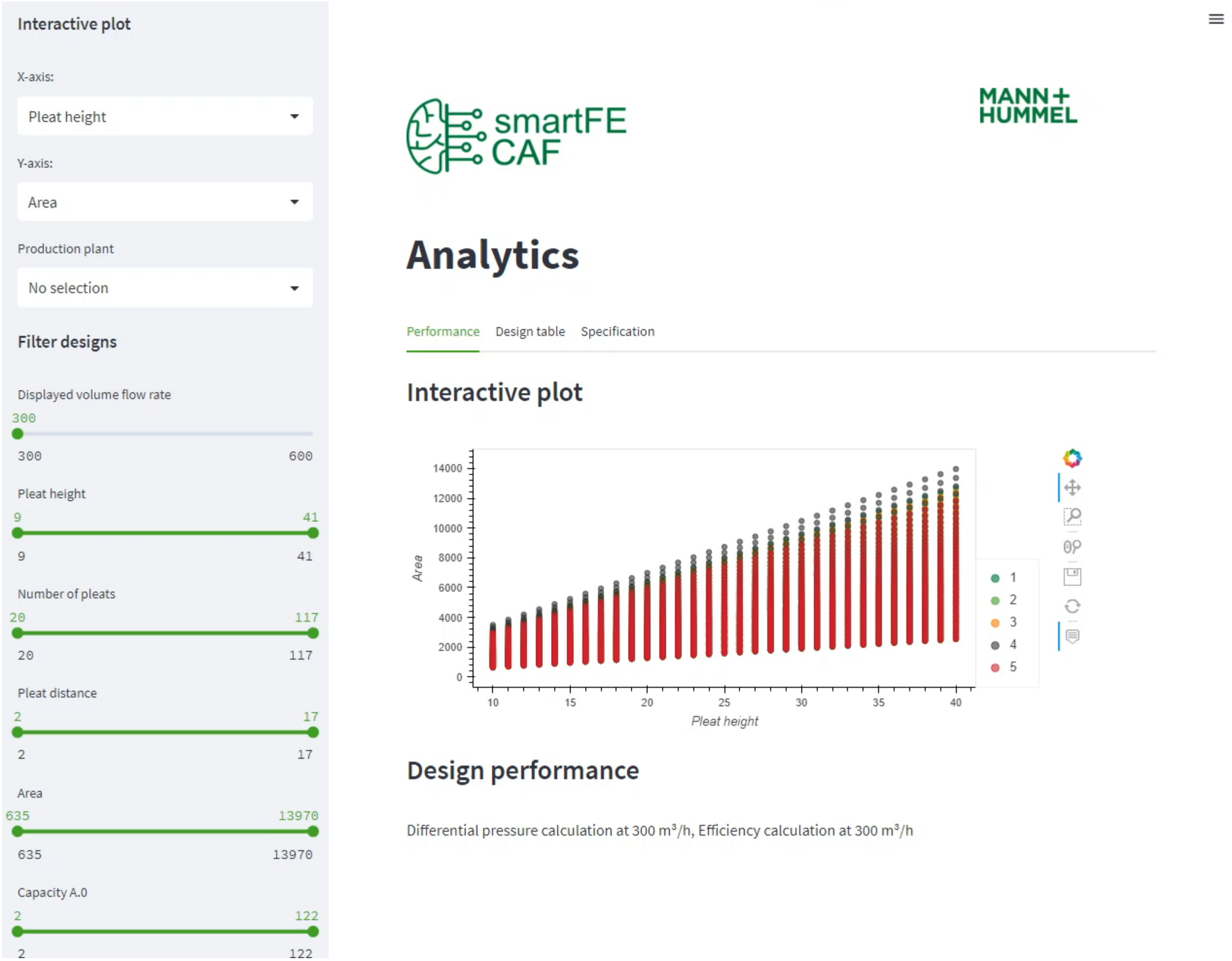


VISUALIZATION OF RESULTS

Conducting Scalable Analytics

Features

- Web based application
- Interactive plot axis selector
- Range slider set depending on input specifications
- Multiselect elements for media grades and selected designs
- Heuristic default filter settings
- Inline multi-objective optimization
- Topic specific overlays for tolerances etc.



SMARTFE VISION

Driving towards data-driven element layouts

Data Acquisition + Processing

Data Verification + Governance

Performance + Cost Indication

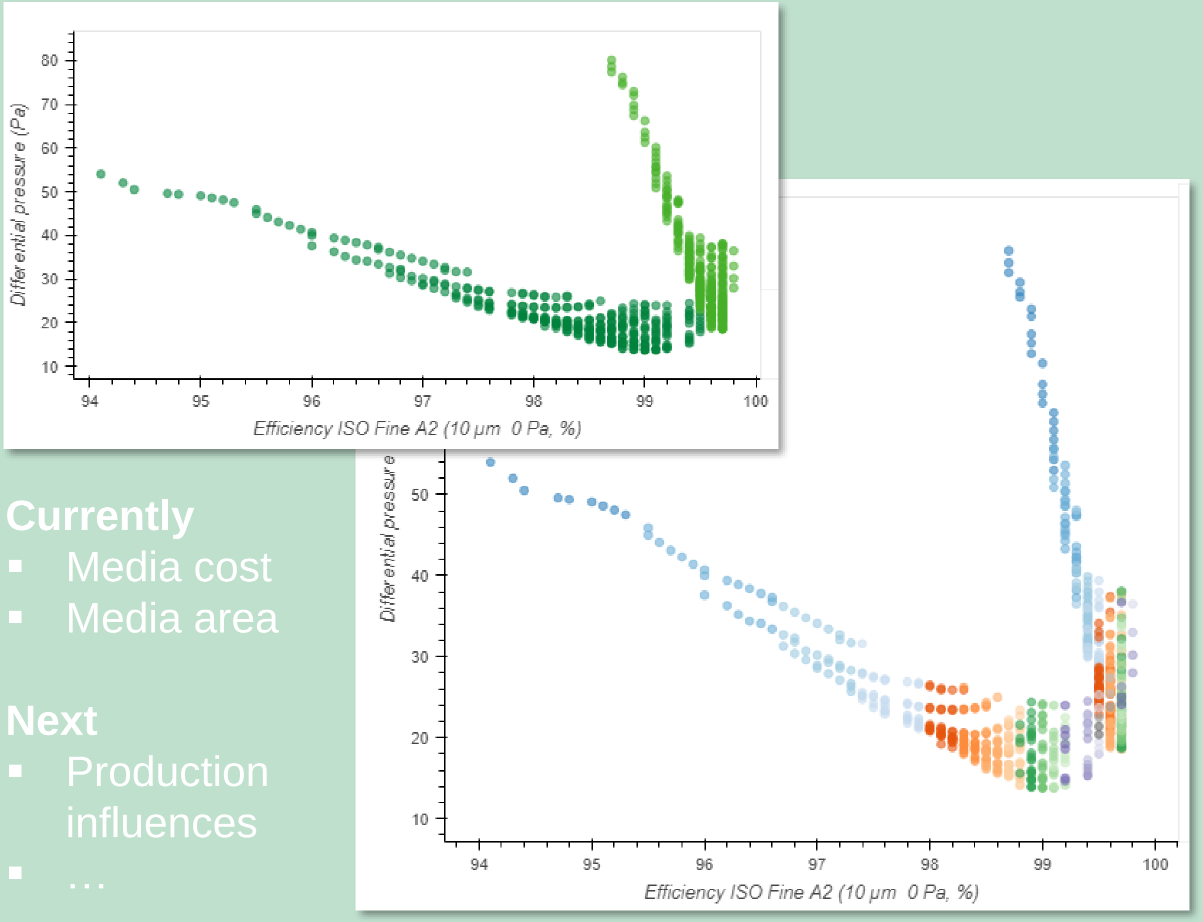
Driving towards data-driven element layouts

Data Acquisition + Processing

Data Verification + Governance

Portfolio Owner

Performance + Cost Indication



Currently

- Media cost
- Media area

Next

- Production influences
- …

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smartFE

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