

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

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Manager Simulation Filter Elements



Leadership in Filtration

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**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

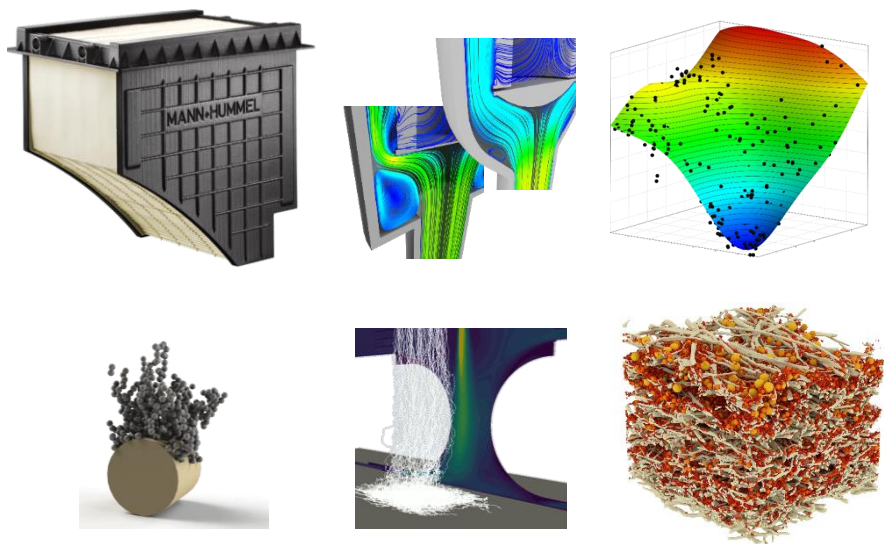


An aerial photograph of a winding asphalt road cutting through a dense, lush green forest of tall evergreen trees. Two cars, one white and one dark, are driving along the curve of the road. The text 'cleaner MOBILITY' is overlaid on the right side of the image.

cleaner
MOBILITY

Simulation & Digitalization – 2 Pillars

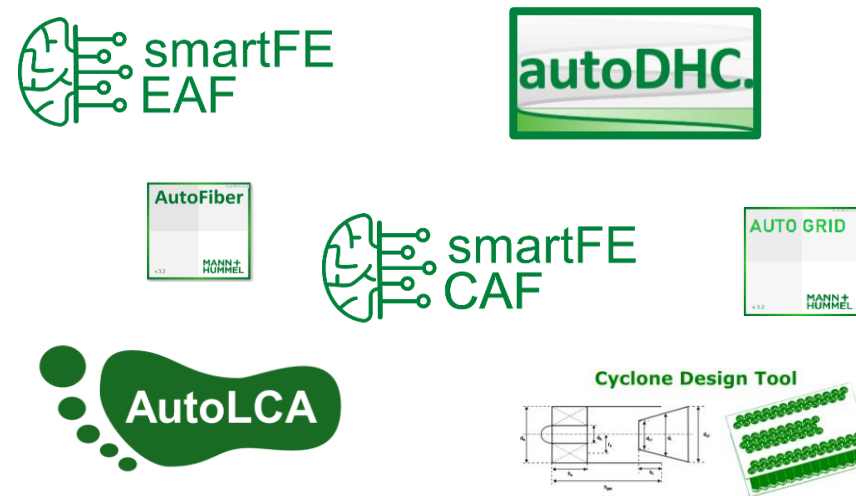
Digital Twins & Optimization



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

Creating Data

Engineering Tools

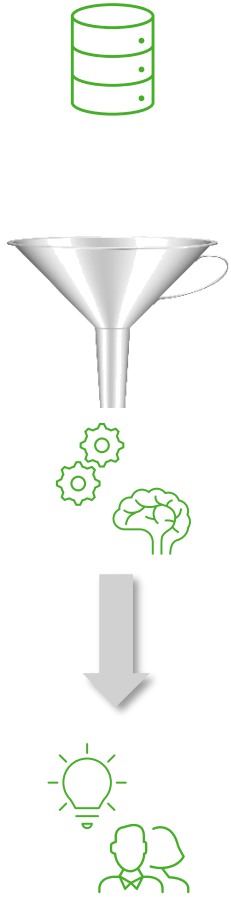


Standardization
Enabling to use large amounts of data
Maximizing outcome of test data
Cost indications in early design stages

Using Data

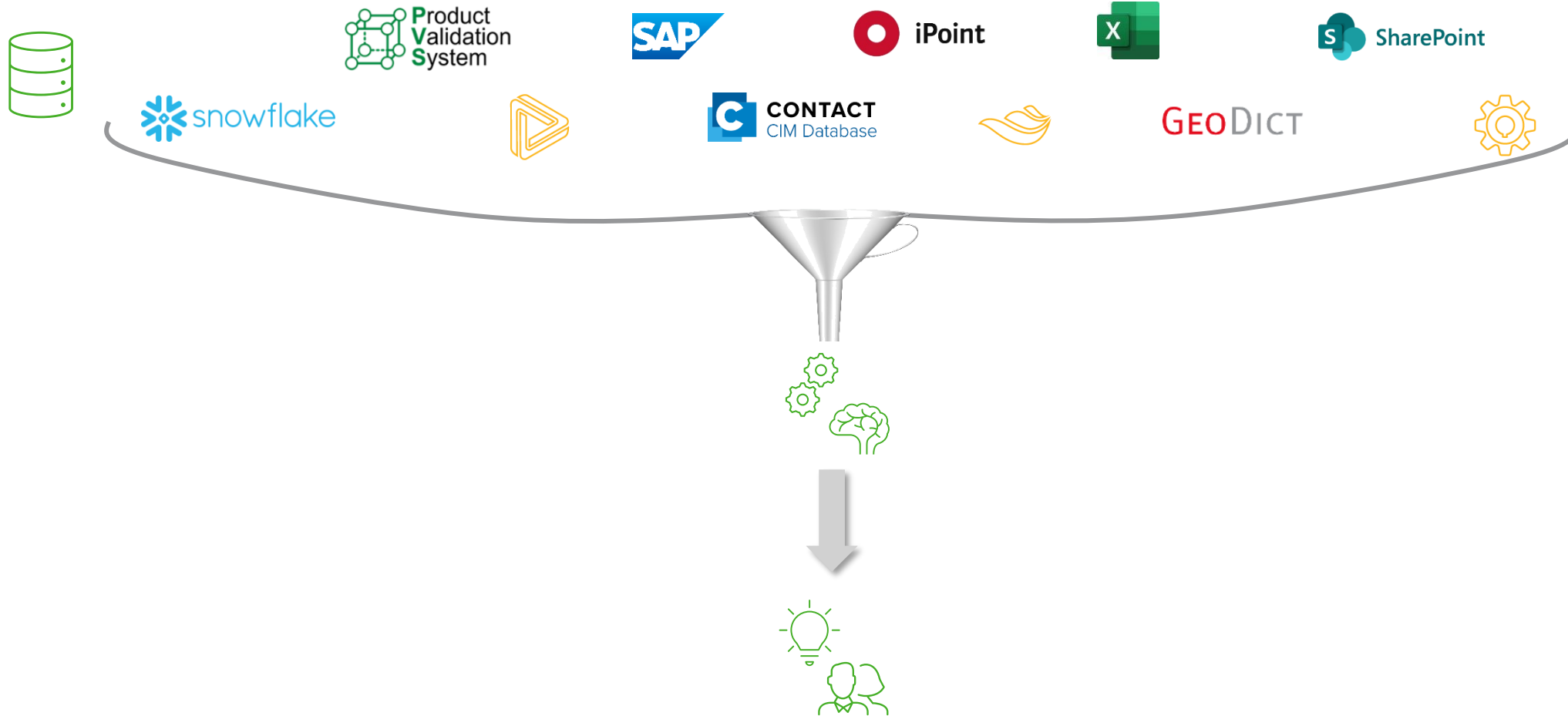
CREATING AND USING DATA

Data Value Stream



CREATING AND USING DATA

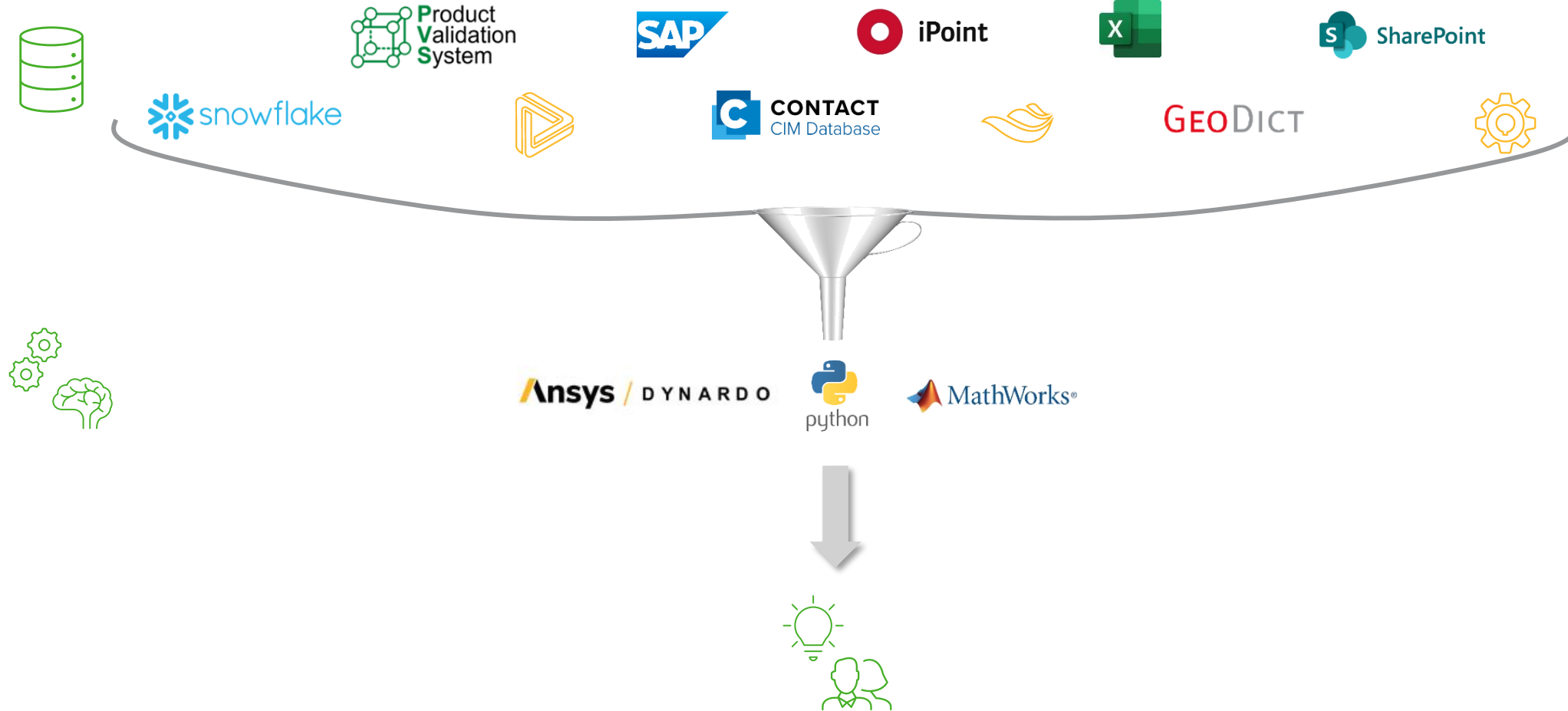
Data Value Stream



non-exhaustive

CREATING AND USING DATA

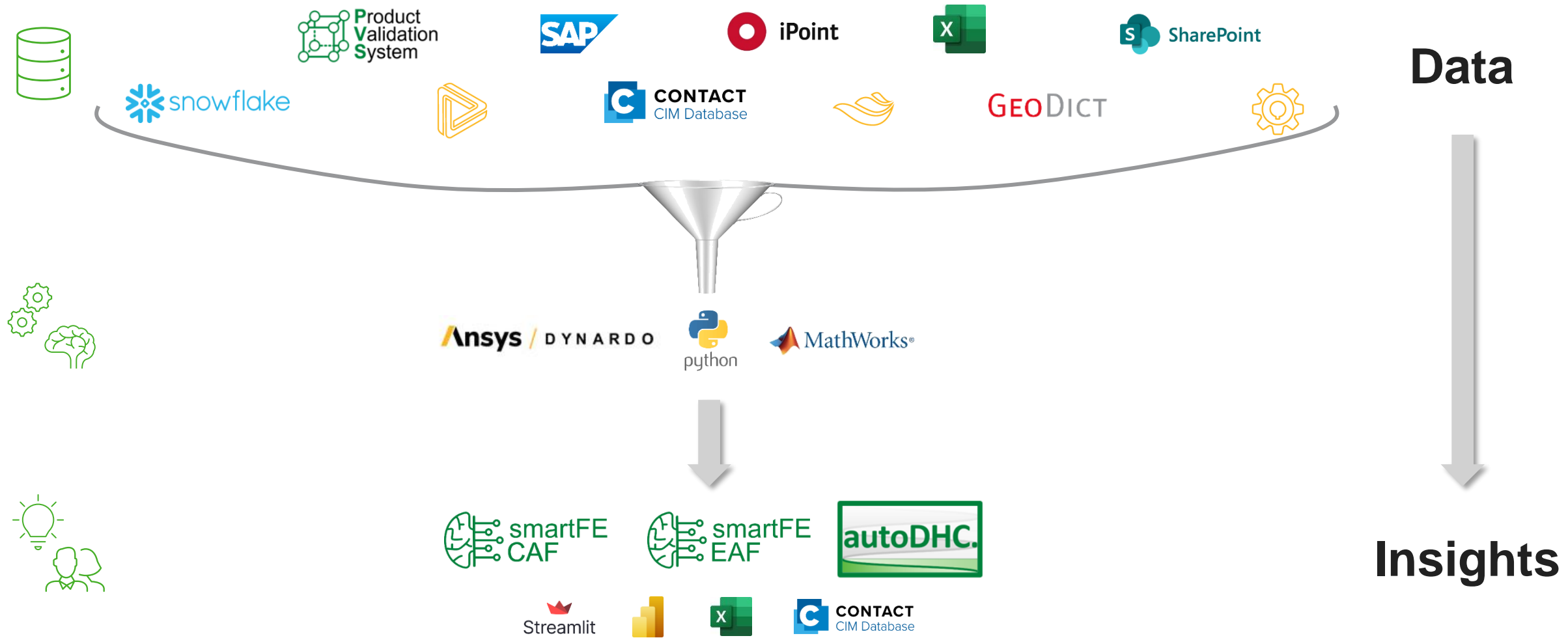
Data Value Stream



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

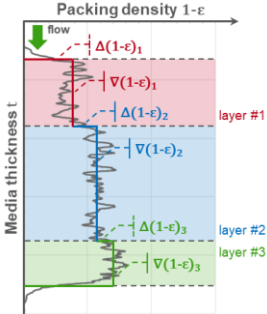
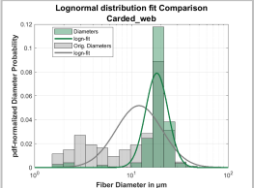

- ✓ Fiber type
- ✓ Fiber diameter
- ✓ Fiber shape

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

GEO DICT

Ansys / DYNARDO

MathWorks

python

Creating Data

Filter Element Simulation

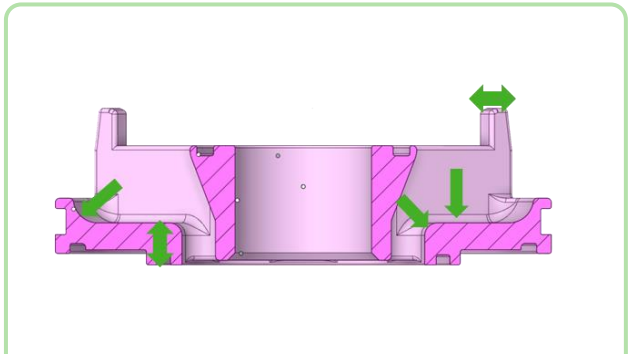


Creating Data by Filter Element Simulation

Product


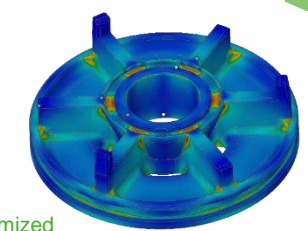
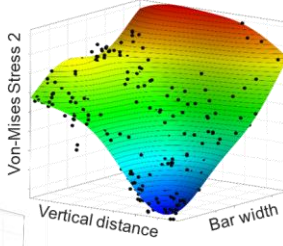
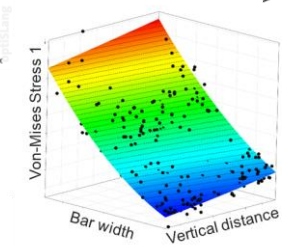
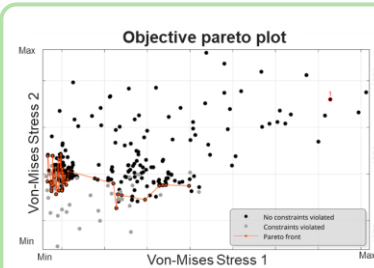


Parametrization



Parameter	Start designs	Criteria	Settings	Other	Result designs
Name	Parameter type	Reference value	Constant	Value type	
1 Hole_Radius	Optimization	3	<input type="checkbox"/>	REAL	
2 BAR_WIDTH	Optimization	6	<input type="checkbox"/>	REAL	
3 Rib_Radius	Optimization	2	<input type="checkbox"/>	REAL	
4 Vertical_Distance	Optimization	5.9	<input type="checkbox"/>	REAL	
5 Vertical_Radius	Optimization	1	<input type="checkbox"/>	REAL	

Optimization & Database Creation



optimized product

result database

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?”



Parameters governing Filter Element Development

Bellow Geometry

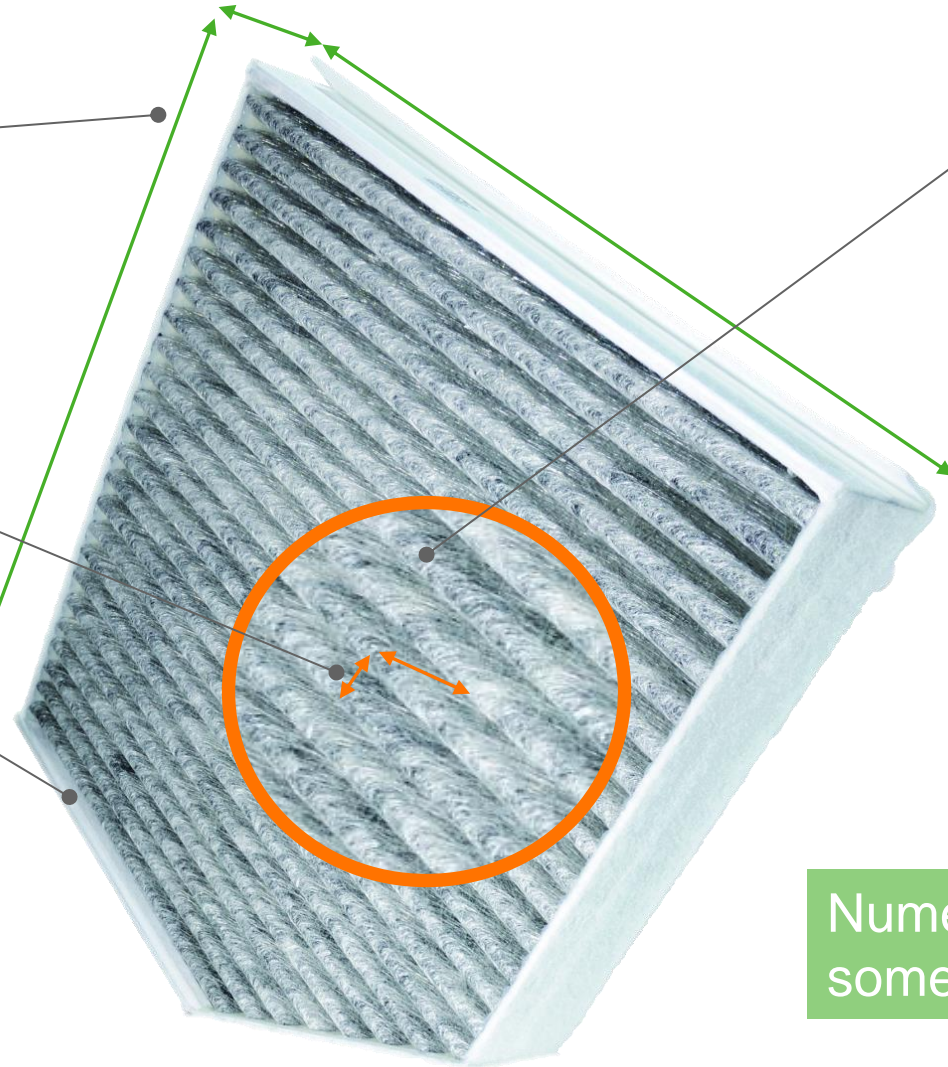
- Length
- Width
- Height
- Pleat distance
- Pleat height

Element design

- Sideband
- Glueing
- ...

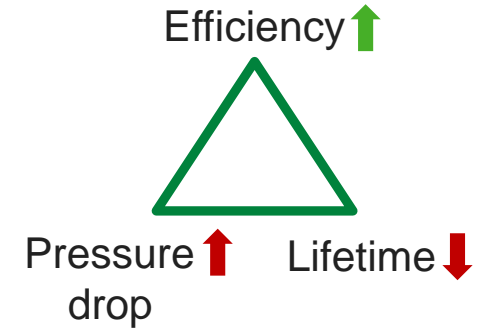
Process parameter

- 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

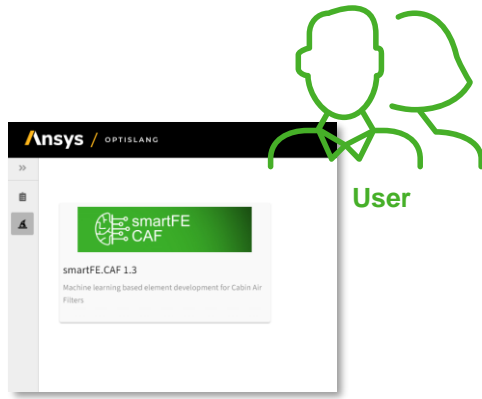
smartFilterElement Development

The screenshot shows a web browser window with the URL `https://smartfe.mh.corp.mann-hummel.c...`. The page header features the MANN+HUMMEL logo and the text "smartFE.Platform". The main content area is titled "Customer Requirements" and lists several properties, each with a red asterisk indicating it is a required property:

- Terminal pressure loss (mbar) *
20
- Test Dust *
is a required property
- Initial efficiency (%) *
is a required property
- Efficiency (%) *
is a required property
- Service interval EU/US (km) *
is a required property
- Service interval DC (km) *
is a required property
- Dust holding capacity (g) *
is a required property

WORKFLOW AT A GLANCE – 1ST GENERATION

smartFE – smart Filter Element Development



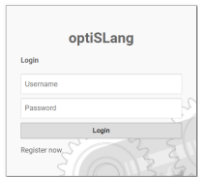
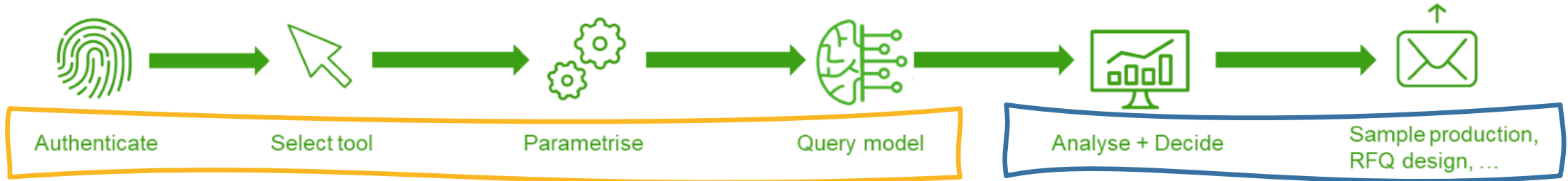
Model Generation



The image shows a technical data sheet for an 'Air filter element layout' by MANN+HUMMEL. It contains various tables and sections:

- Engine data:** Includes engine type, power, and speed.
- Basic requirements:** Lists filter efficiency, pressure drop, and other specifications.
- Additional requirements:** Details specific filter characteristics.
- Layout below:** Shows a diagram of the filter element layout.
- Predicted filtration performance:** Provides a table of performance metrics.
- Remarks:** A section for additional notes.

Export Technical Data Sheet

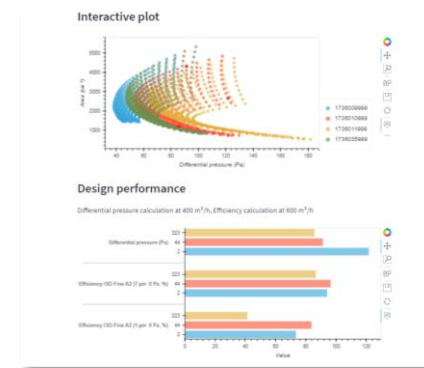


Geometry

Length	200	[mm]
Width	200	[mm]
Minimum pleat height	10	[mm]
Maximum pleat height	20	[mm]

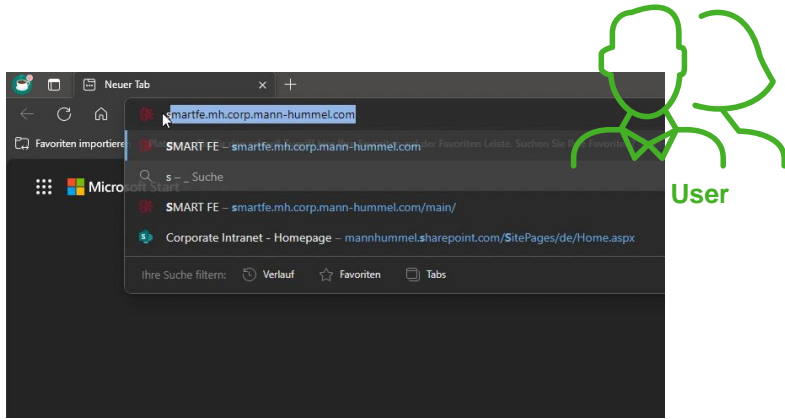
Specifications

Volume flow rate differential pressure calculation	400	[m³/h]
Maximum differential pressure	200	[Pa]
Volume flow rate efficiency calculation	600	[m³/h]



WORKFLOW AT A GLANCE – 2ND GENERATION

smartFE – smart Filter Element Development

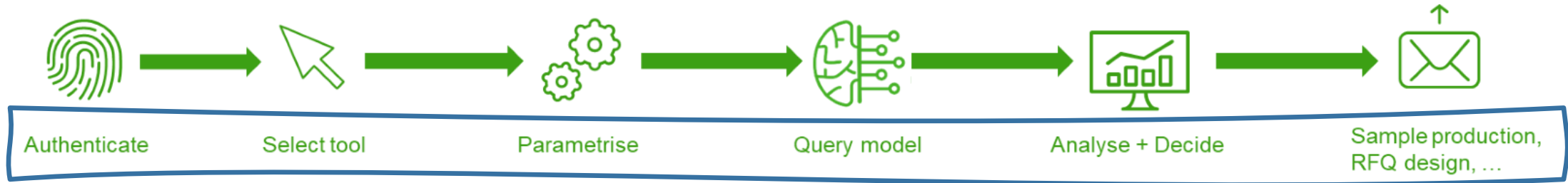


Model Generation



Air filter element layout		MANN+HUMMEL
Engine data	Basic requirements	
Additional requirements	Layout below	
Layout below	Predicted filtration performance	Remarks
Created: Date	Checked: Date	

Export Technical Data Sheet



Design specifications

Pre Filter Media *
None

Filter Media Class *
is a required property

Mass Air Flow Maximum *
is a required property
Liquid Gasoline

Mass Air Flow Unit *
is a required property

Element geometry

FLAT BELLOW ROUND BELLOW
RECTANGULAR TRAPEZOIDAL CUT EDGE

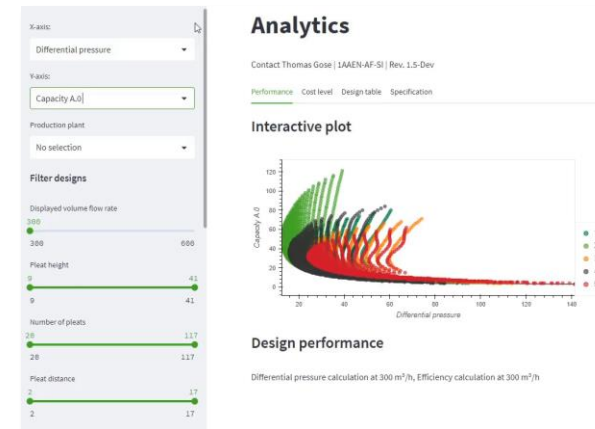
Bellow length (mm) *
is a required property

Bellow width (mm) *
is a required property

Fleat depth minimum (mm) *
is a required property

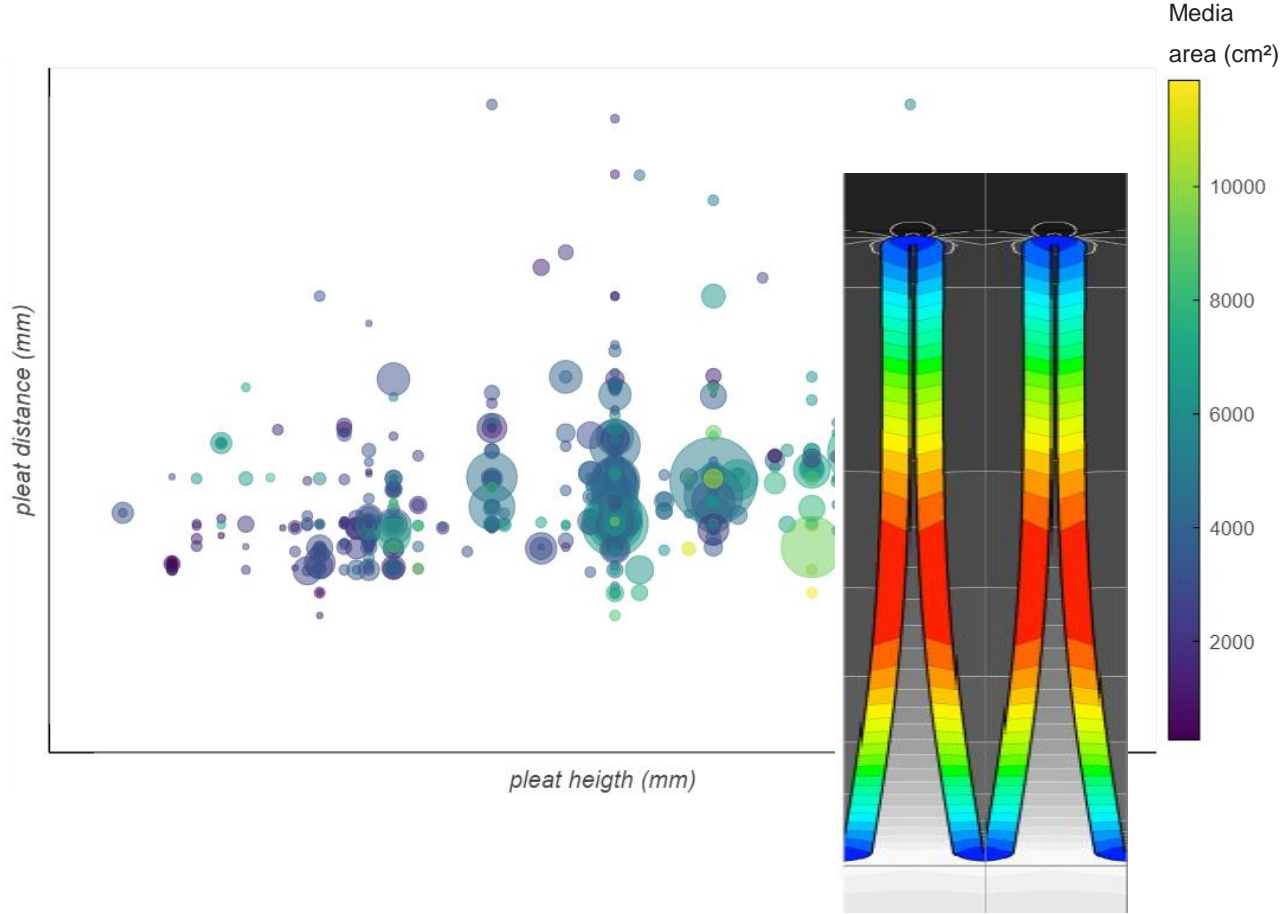
Fleat depth maximum (mm) *
is a required property

Endcap design *
is a required property



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

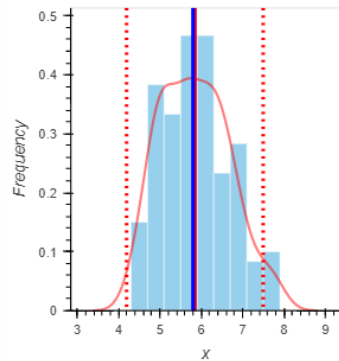
Knowledge-driven methods

What are the benefits of using machine learning?

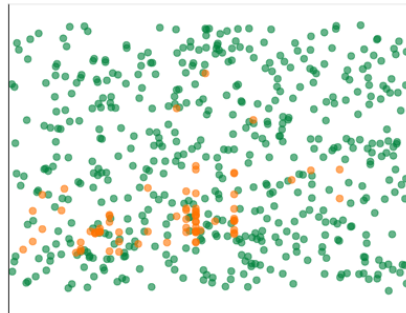
To predict the **filter element performance** e.g., efficiency, lifetime, pressure drop we apply

Data-driven methods

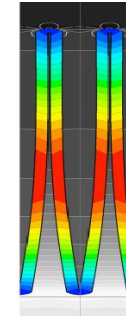
Knowledge-driven methods



Descriptive statistics



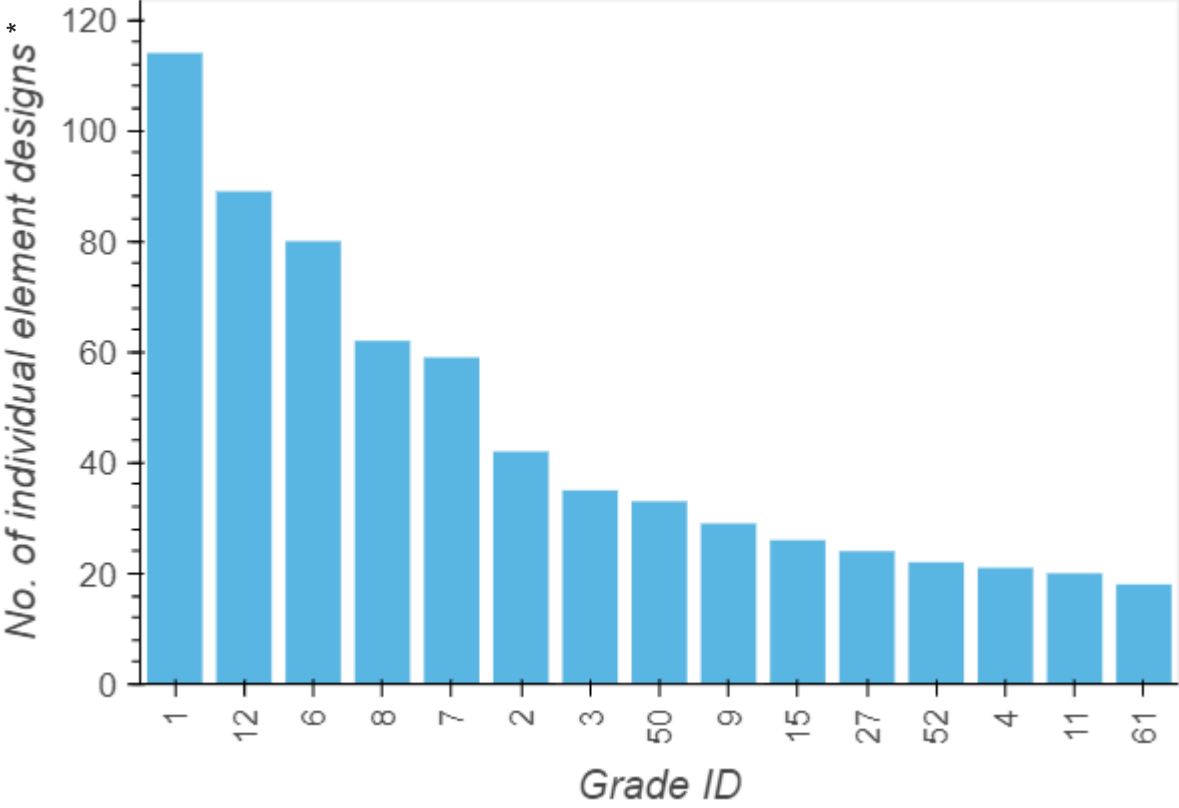
Machine learning



Simulation

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

Amount of Individual Designs



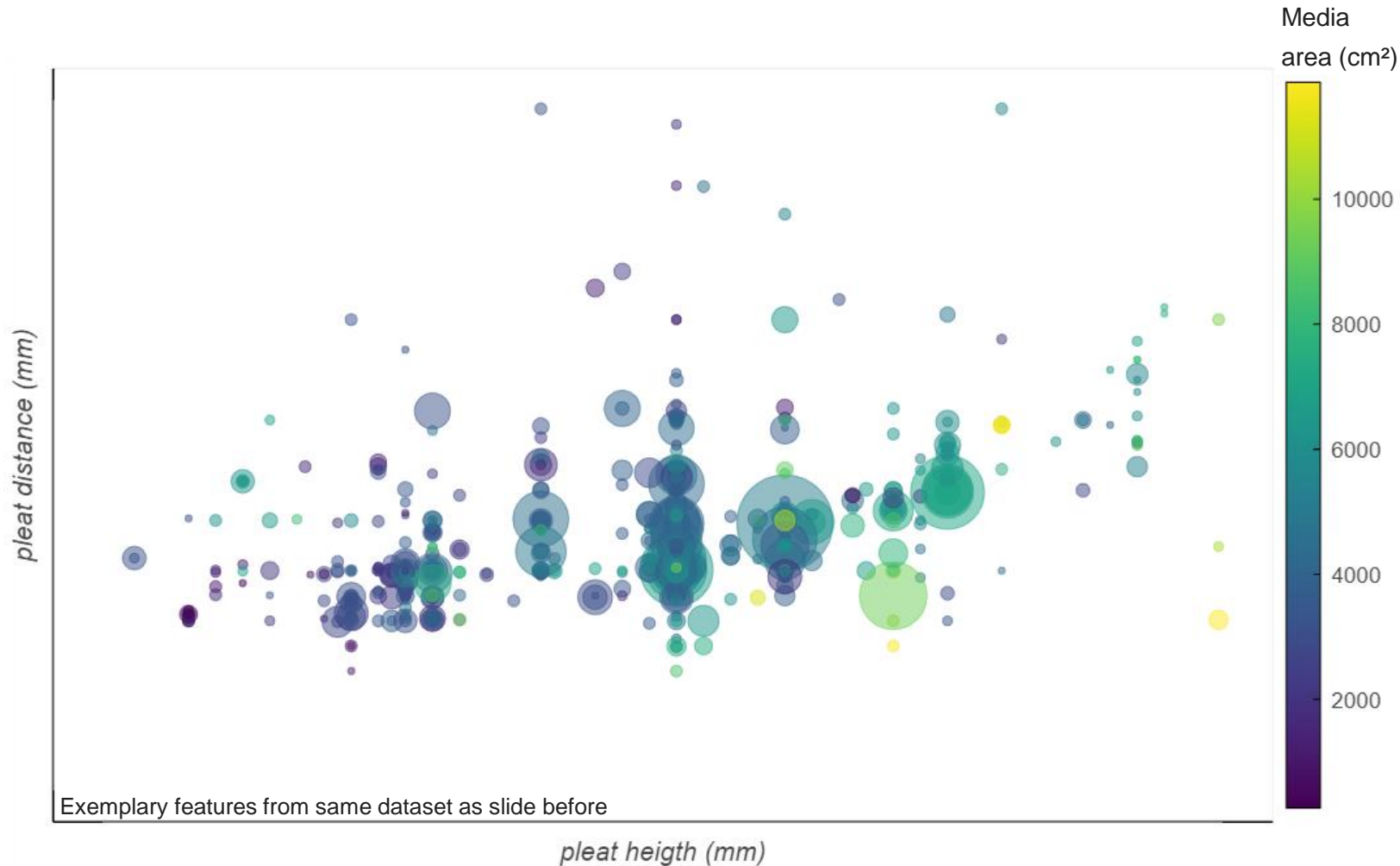
Observations

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

Overall amount of data varies 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



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

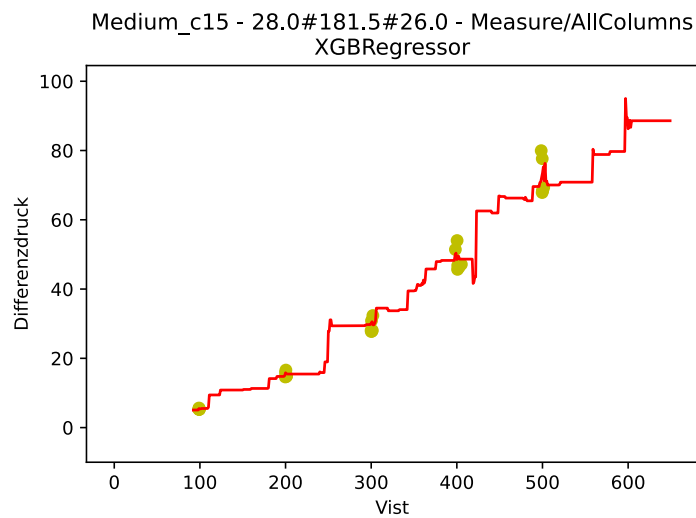
Assessing Model Quality

Metrics

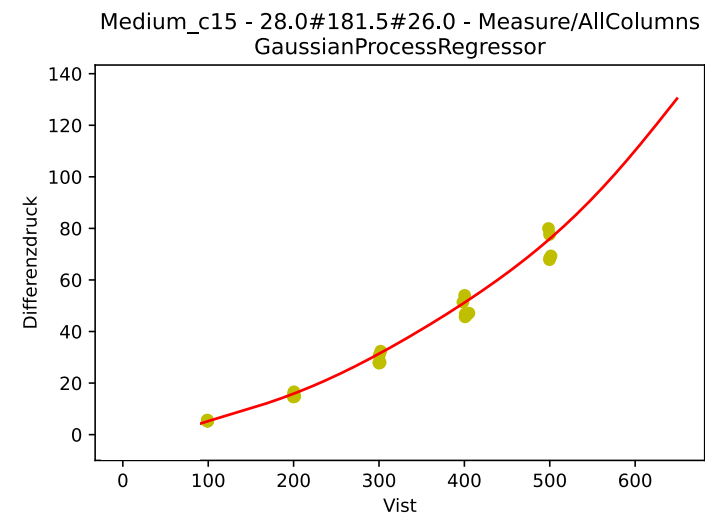
- Mean squared error (MSE)
- Coefficient of determination (CoD, R^2)

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

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

Can methods be combined?

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

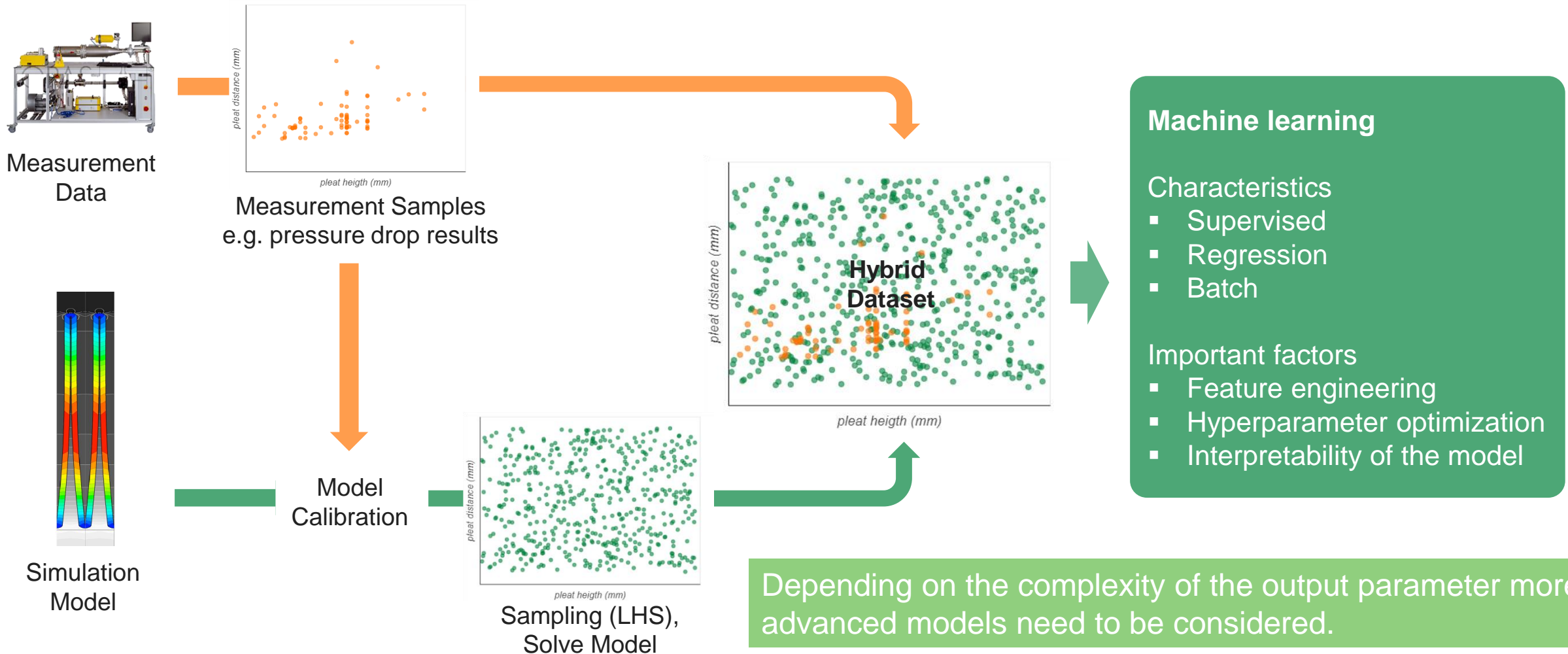
Measurement data

Hybrid
data

Simulation data

MODELLING APPROACH

Hybrid Modelling Approach



Interactive analytics

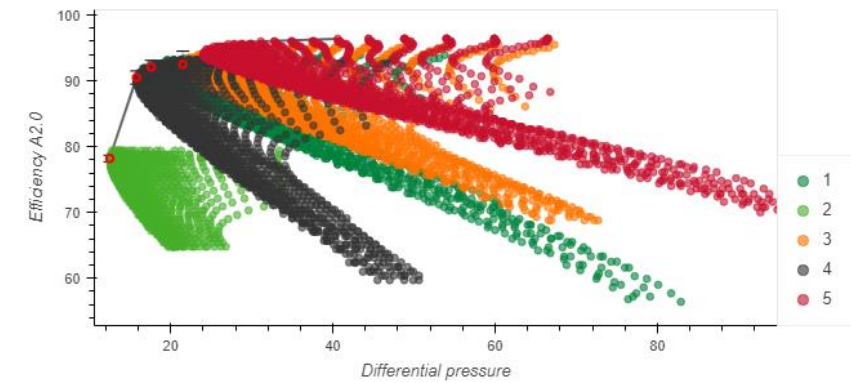
smartFilterElement Development



Analytics

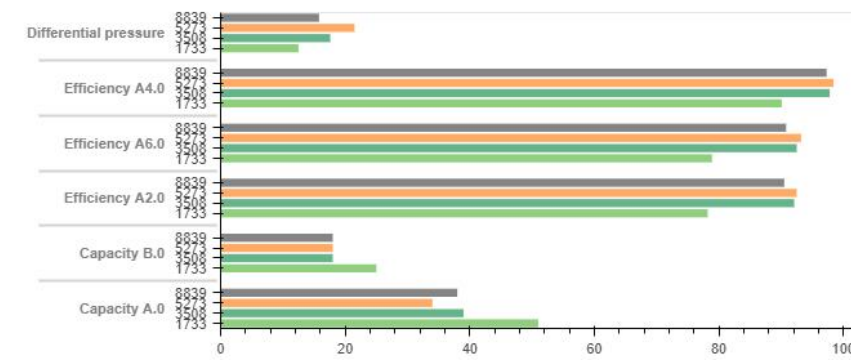
Performance Design table Specification

Interactive plot



Design performance

Differential pressure calculation at 300 m³/h, Efficiency calculation at 300 m³/h



Relevance of Interactive Analytics

Benefits of ML approach

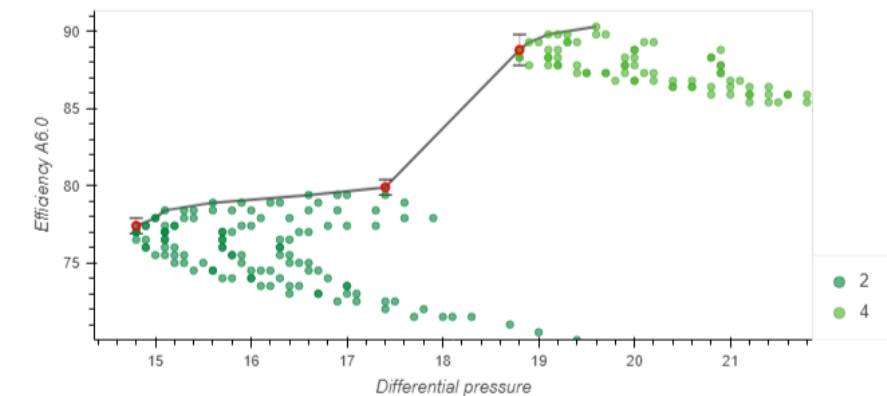
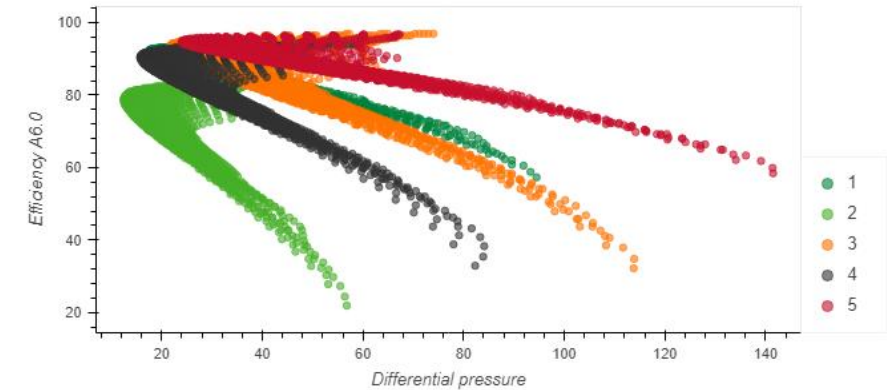
- High-resolution sampling of the parameter space
- High number of potential element designs

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



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.

Interactive plot

X-axis:

Y-axis:

Production plant:

Filter designs

Displayed volume flow rate: (range: 300 - 600)

Pleat height: (range: 9 - 41)

Number of pleats: (range: 20 - 117)

Pleat distance: (range: 2 - 17)

Area: (range: 635 - 13970)

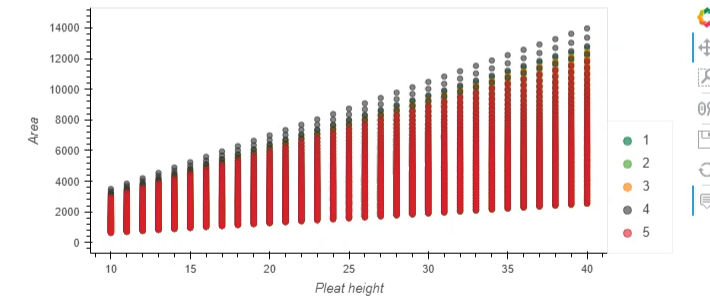
Capacity A.0: (range: 2 - 122)



Analytics

Performance Design table Specification

Interactive plot



Design performance

Differential pressure calculation at 300 m³/h, Efficiency calculation at 300 m³/h

Driving towards data-driven element layouts

Data Acquisition + Processing



Data Verification + Governance

Performance + Cost Indication

Driving towards data-driven element layouts



Data Verification + Governance

Detailed indicative price by plant

plant_name: FTCN, MCCN, MHAR, MHBA, MHBR, MHDE MK, MHES, MHIN Bawal, MHMX, MJCN

Absolute price comparison by plant

Average of last price, Average of current price

Relative price change by plant

Price difference: 0.0%, -4.7%, -11.5%, -25.4%

Portfolio Owner

Performance + Cost Indication

Currently

- Media cost
- Media area

Next

- Production influences
- ...



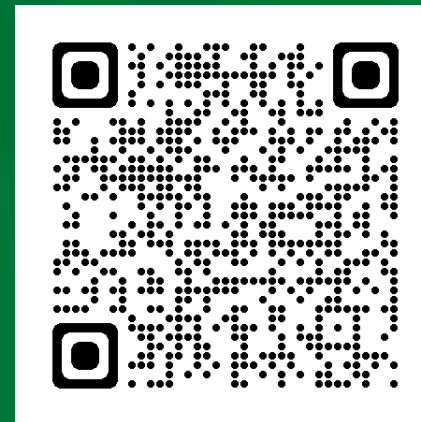
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**MANN +
HUMMEL**