PMD-X-MAPRO

Cross-company material data and material simulation in production

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Yoav Nahshon (Fraunhofer IWM)

Motivation of PMD-X-MAPRO: Linking PMD & Manufacturing-X

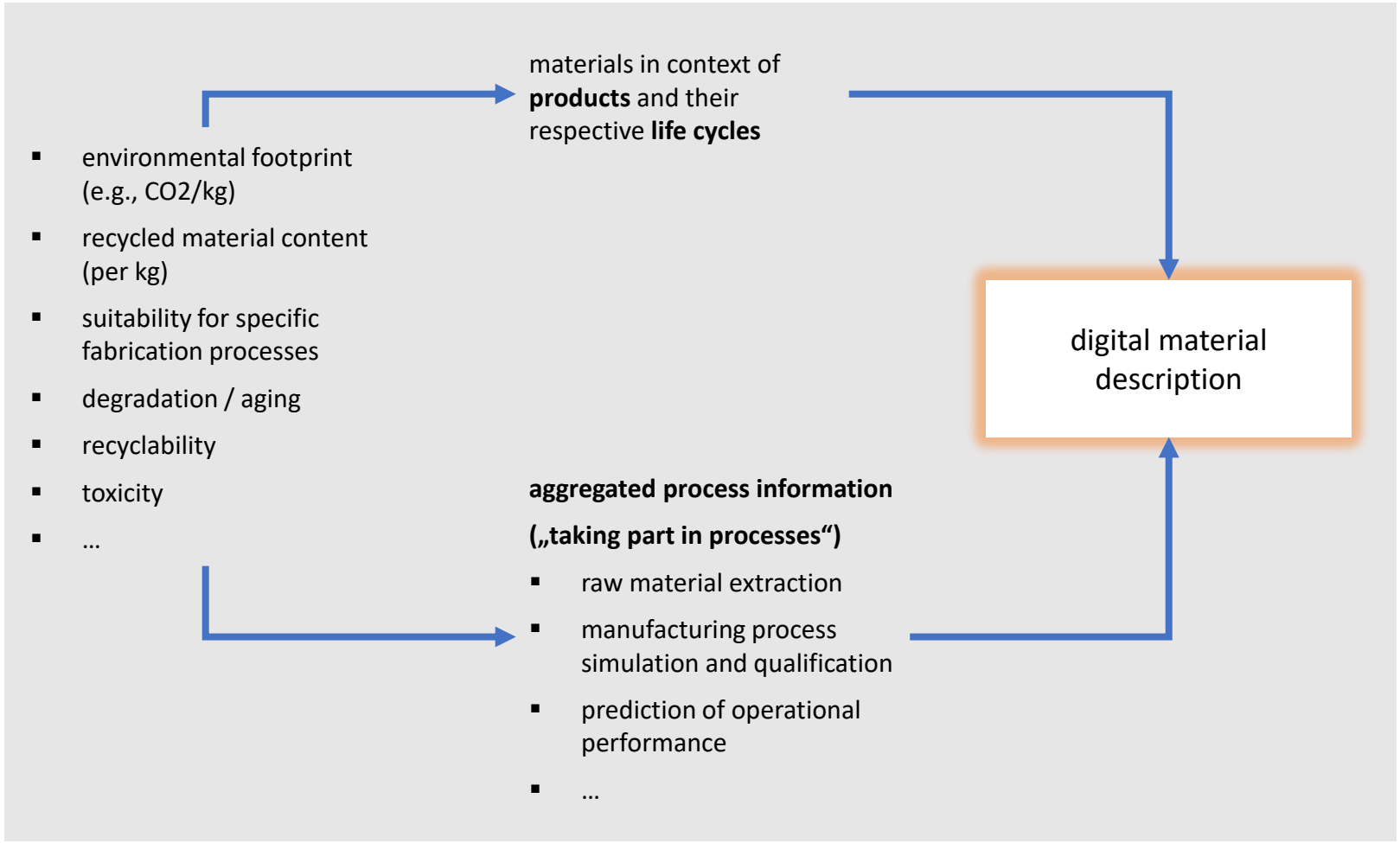
Status Quo

- Manual and error-prone data handling leads to inefficiency, like for instance handling of simulation data and material compliance data
- Finding required information takes too long, no linking of different data set
- Duplication of information and missing context / semantics leads to misunderstandings

Vision

- Combining the added value of the Manufacturing-X world (data sovereignty) with the added value of the PMD world (FAIR and linked data)
- Generating powerful insights by combining and linking data from multiple sources, enabler for getting recommendations driven by AI by providing AI-readiness
- Drastically reduce cost and enable new business models

PMD-X MAPRO material modelling context



Advantages of ontologies (→ data exploration)

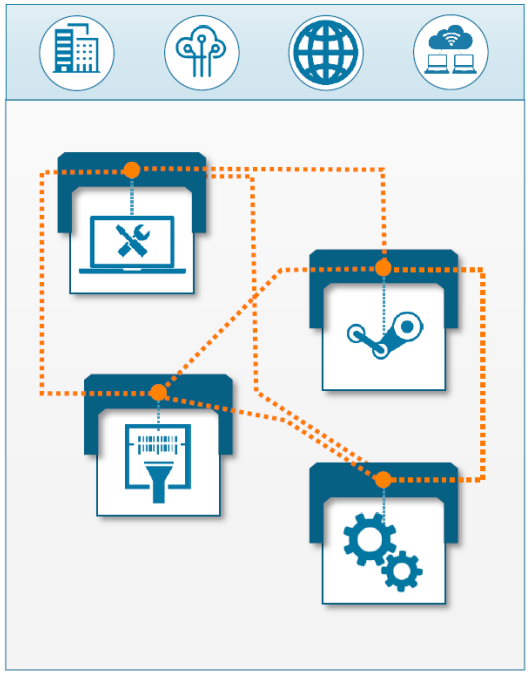
- Universal and well-structured description of knowledge (schema)
- Connection and aggregation of expert knowledge from a wide range of fields (domains) → knowledge graph
- Standardized and automated querying capabilities
- Basis for machine learning and artificial intelligence methods, especially in "small data" scenarios

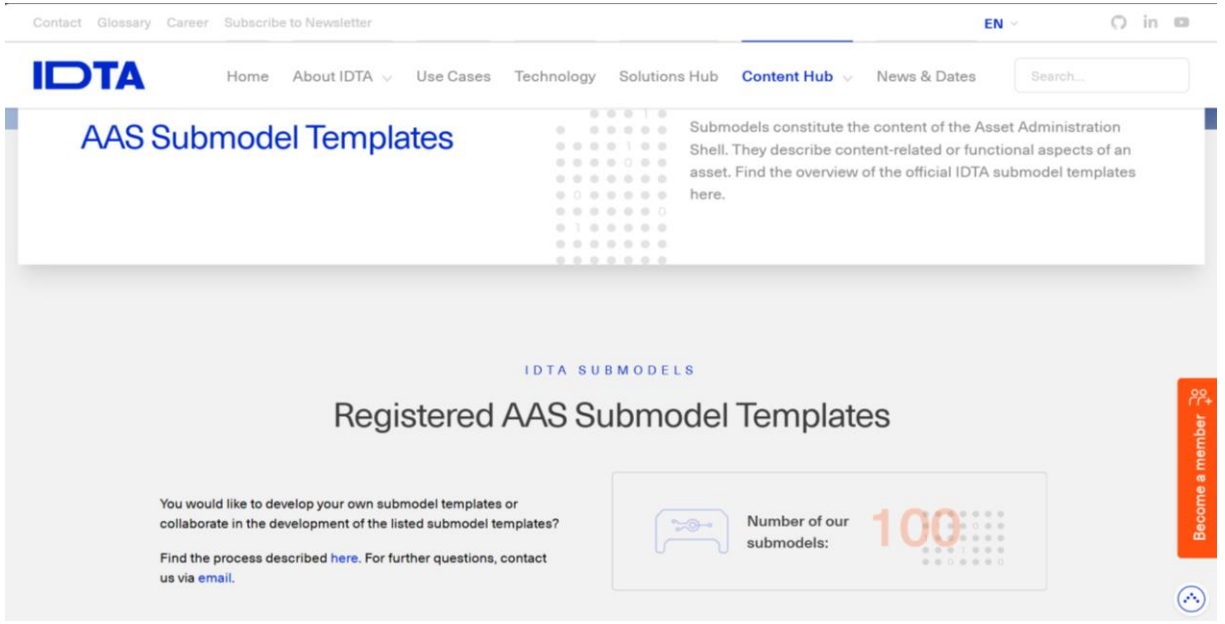
Advantages of Asset Administration Shell (→ data exchange)

- Digital representation of physical objects
- Realizes a uniform and self-describing interface
- Structured data and services based on submodels
- Unify information access through common “language”

What is the Asset Administration Shell?

- Standardized digital twin interface for an asset (hardware, software)
- Contains all relevant information and functionalities of an asset in a structured, machine-readable format
- Enables interoperability between different systems and vendors by following standardized models
- Submodels are derived from standardization process



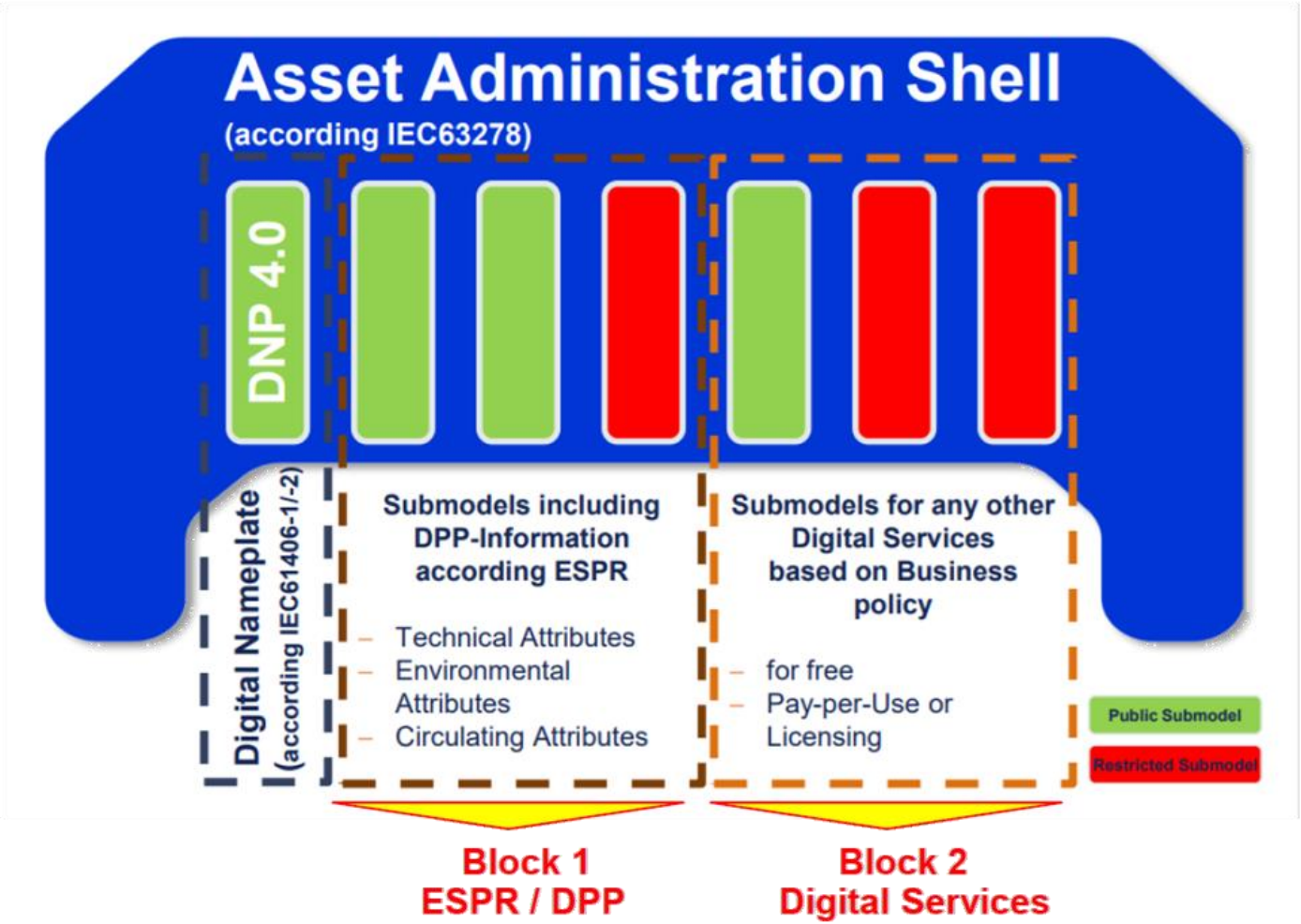


Submodels - IDTA

Image source: Plattform Industrie 4.0

The AAS as Key for Implementing the Digital Product Passport

Digital Product Passport 4.0



Quelle: IDTA Digital Twin Day, Dieter Wegener (Siemens)

The AAS: Standardized and Interoperable

(Technological) Challenge and Vision of PMD-X MAPRO

- Relevant asset data (e.g., material property data) is generated over time by different stakeholders along the life-cylce
  - No central data base/repository
  - One physical assest will have several AAS describing different aspects of it, all linked via asset ID
- New submodel template generation is ongoing and long process as physical assets can have very complex life cycles
- AAS itself is not the data source but rather the standardized data transport technology that enables data spaces and data exchange
  - → no furhter **insight into the asset data** is gained from AAS creation in the first place
  - Data contained in the exisiting data authoring systems needs to be converted into AAS format

PMD-X MAPRO‘s vision

“ontology enriched” AAS

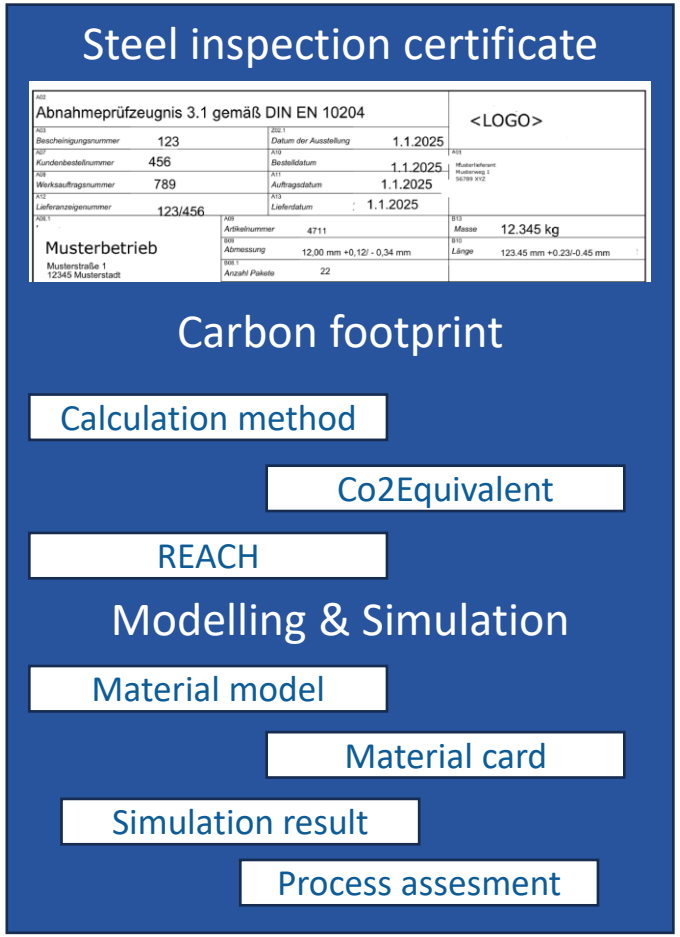
What can be gained from such ontology enriched AAS?:

- Allows to define relevant submodel attributes based on domain ontologies → provide structure of a material submodel or combine information from various submodels
- Through the use of semantic ID and IRIs (i.e., globally unique identifiers) data exchange over longer asset value chains becomes much simpler
- Allows knowledge graph users to automatically create AAS instances without mapping
- Will provide immediate knowledge graph creation even in case of manual data mapping → further promote and motivate use of AAS
- Simple way to validate AAS data according to underlying ontology

Motivation of PMD-X-MAPRO: proof of concept

Specific Use Case for PMD-X-MAPRO to demonstrate the value of the developments

- **Inspection certificates**
  - Status quo: from manual handling to ERP, exchange by paper or PDF
  - Goal: trustable digital workflows for certificate generation from lab to certificate, digital exchange across companies including feedback
- **Sustainability information like carbon footprint and material compliance information**
  - Status quo: manual handling and collection of sustainability information, data provenance by manual documentation, challenges to get data from supplier, materials compliance partially over server applications
  - Goal: seamless communication between companies, exchange of sustainability information including data provenance
- **Modelling and Simulation**
  - Status quo: no data exchange in the current customer relationships
  - Goal: enable new customer relations and business models

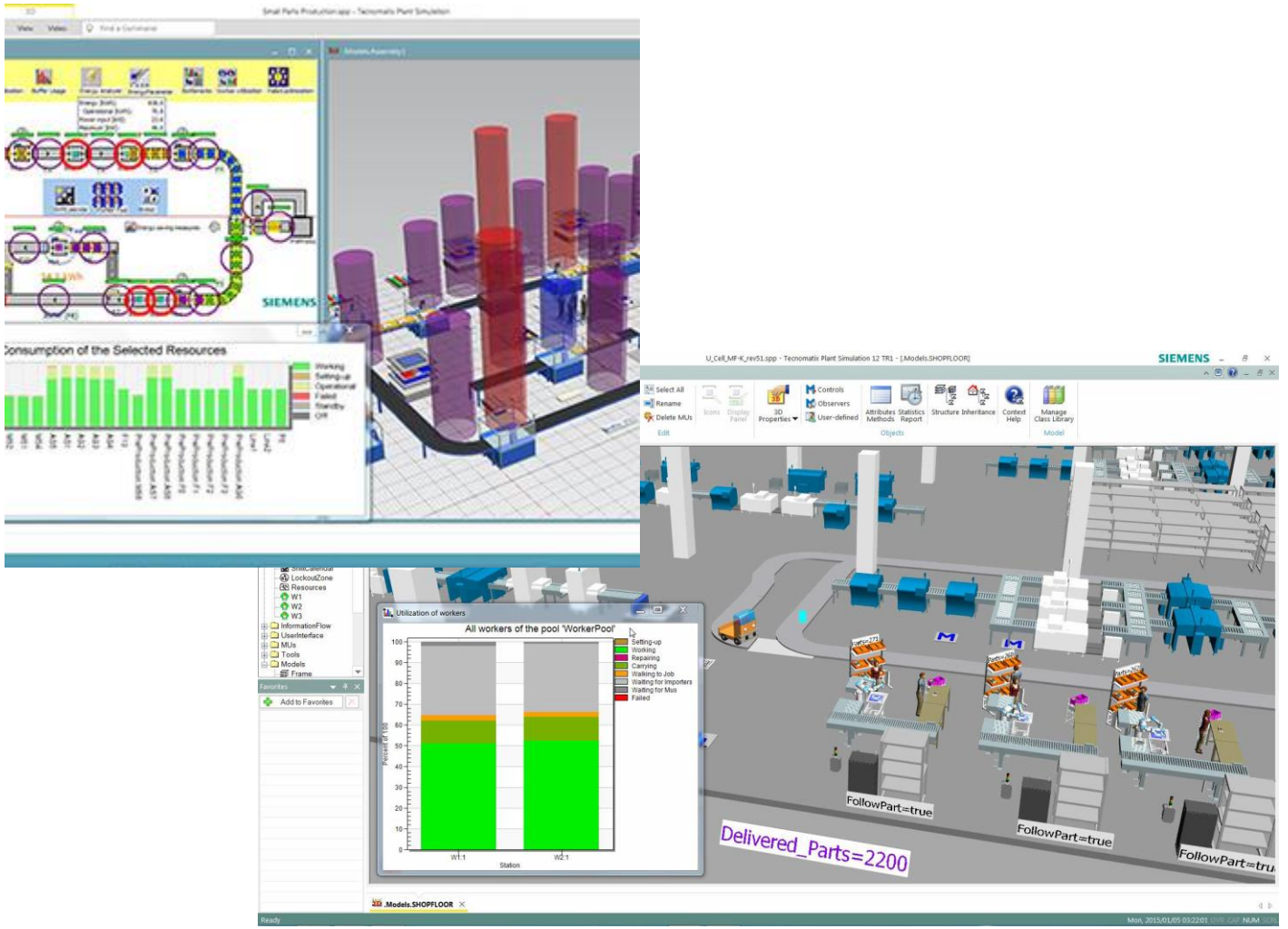


Process Ready Material Twin

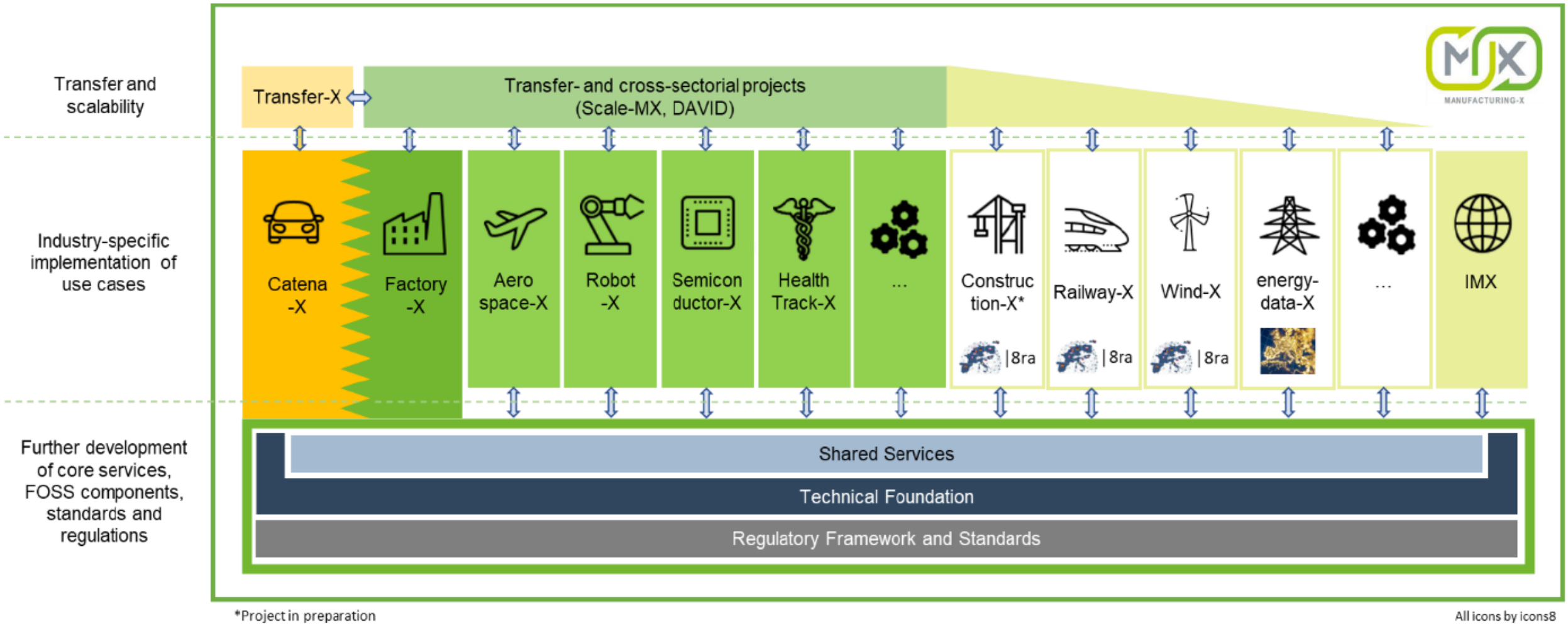
Pro-active simulation/planning of manufacturing process parameter adaptations based on batch specific material property data exchanged via M-X dataspace

- Extraction of relevant material property data from AAS and infusion into simulation process
- Storage of simulation results in proprietary knowledge graph and direct conversion into AAS format
- Automation of simulation runs

Requires material modelling, process modelling and integration with application ontology



The World of Manufacturing-X



Source: https://www.bundeswirtschaftsministerium.de/Redaktion/EN/Dossier/manufacturing-x.html

Manufacturing-X Port

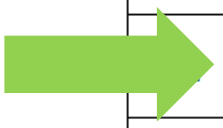
- M-X Port describes approaches for integration

	Layer	Purpose
L5	Discovery	. . . is used to find business partners, data assets (e.g. devices) or business applications.
L4	Access & Usage Control	. . . is used to ensure, that data providers can define the data access and usage as well as restrict the access and usage of the provided data.
L3	Gate	. . . is used to exchange data in a uniform way.
L2	Converter	. . . provides the semantic model for the data to be exchanged.
L1	Adapter	. . . enables any business application to use the MX-Port.

Manufacturing-X Port: Configuration „Leo“

	Layer	MX-Port “Leo”[3]
L5	Discovery	ID-Link[6]
L4	Access & Usage Control	AAS Security[7]
L3	Gate	AAS - REST
	Converter	AAS Submodels[5]
L1	Adapter	Application specific

PMD



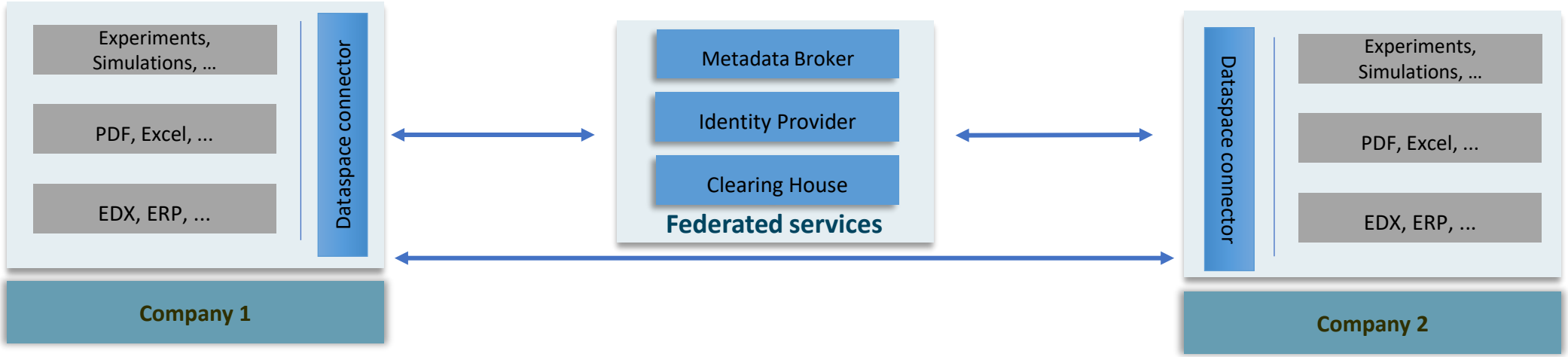
Manufacturing-X Port: Configuration „Leo“

PMD

	Layer	MX-Port “Hercules”[3]
L5	Discovery	Data Space Protocol / Decentral Claims Protocol[4]
L4	Access & Usage Control	
L3	Gate	AAS - REST
L2	Converter	AAS Submodels[5]
L1	Adapter	Application specific

Why Federated + Semantic?

- **Federated dataspaces** ensure trust, sovereignty, and controlled data exchange

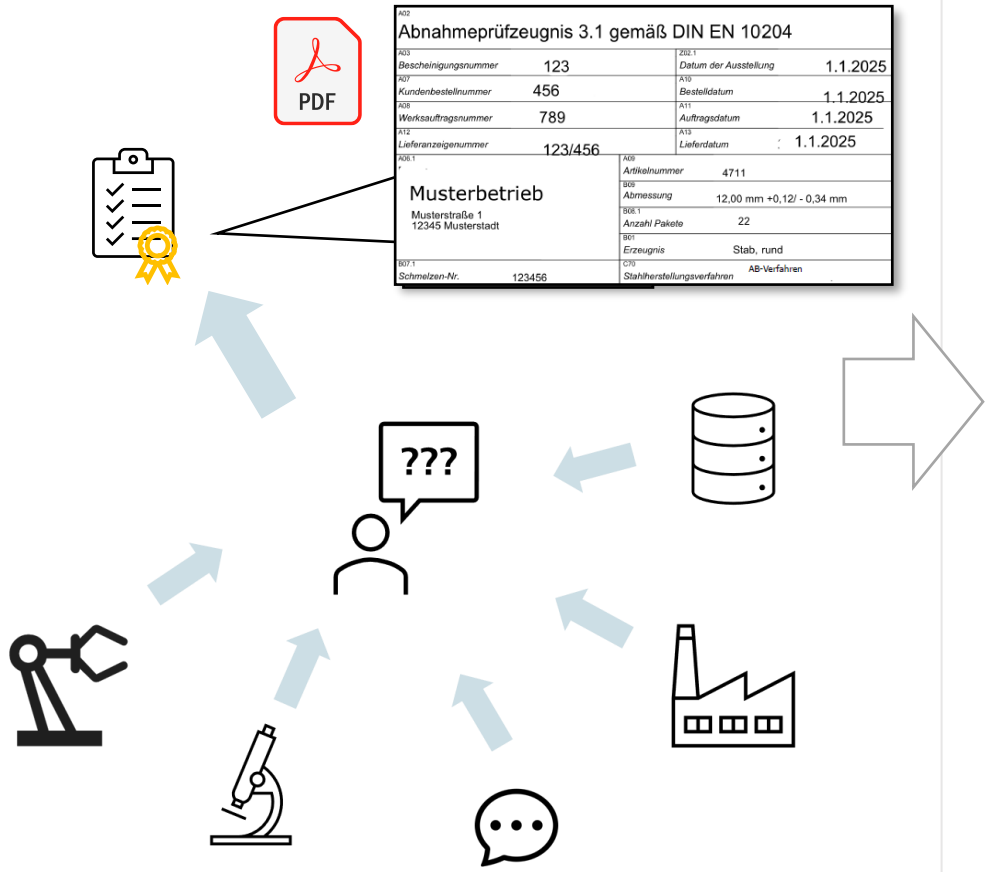


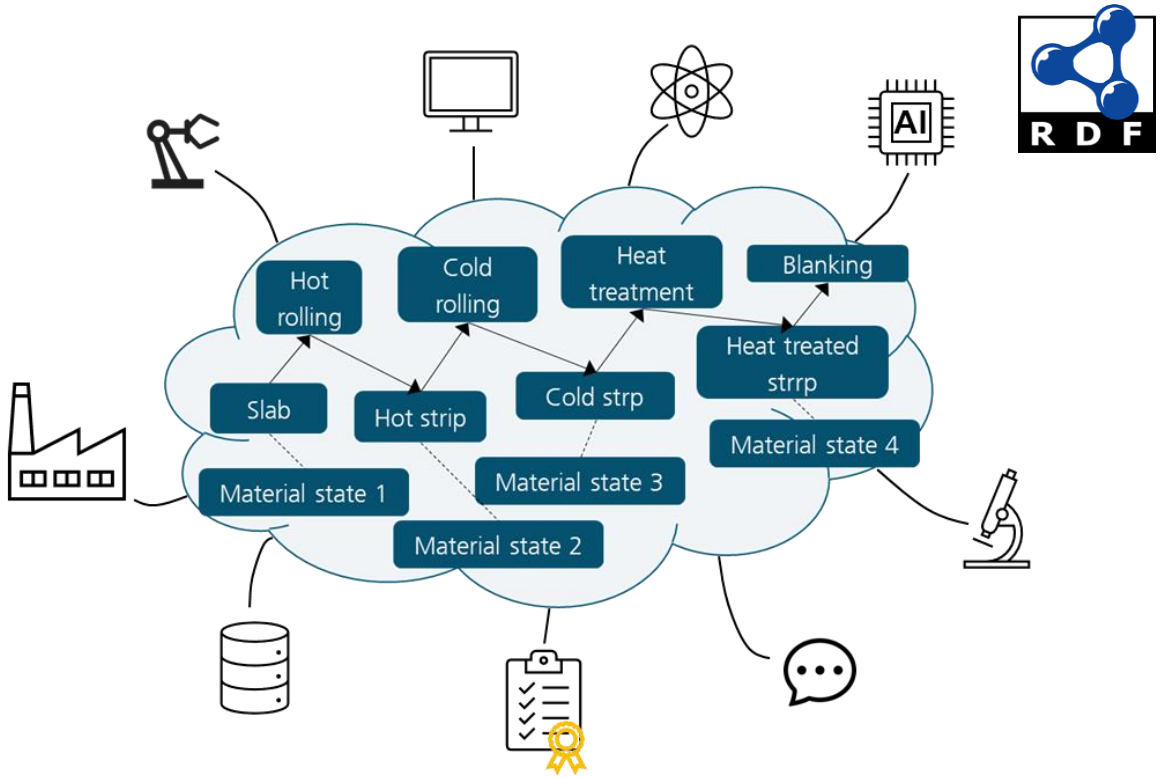
- **Semantic technologies** provide meaning, structure and machine interpretability
- Particularly useful for **data linking**: Key for detecting dependencies and generating data-driven insights

→ Goal: A Federated, Semantic Dataspace

Use Case: Inspection Documents of Steel Products

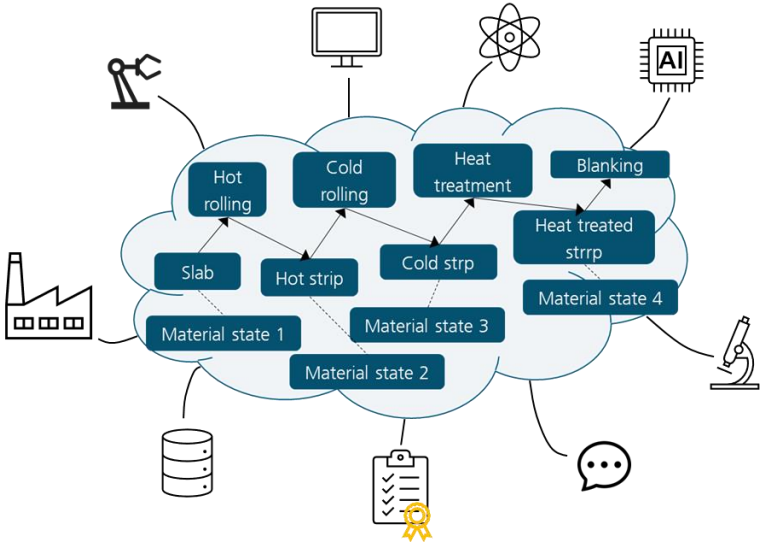
Purpose: Shows that delivered material complies with the order requirements, based on testing





Application example:
Easily detect deviations between specified and measured values (soll / ist)

Use Case: Inspection Documents of Steel Products



KG2AAS

GitHub

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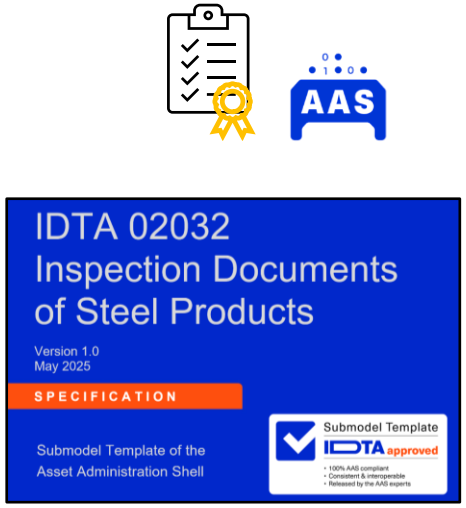
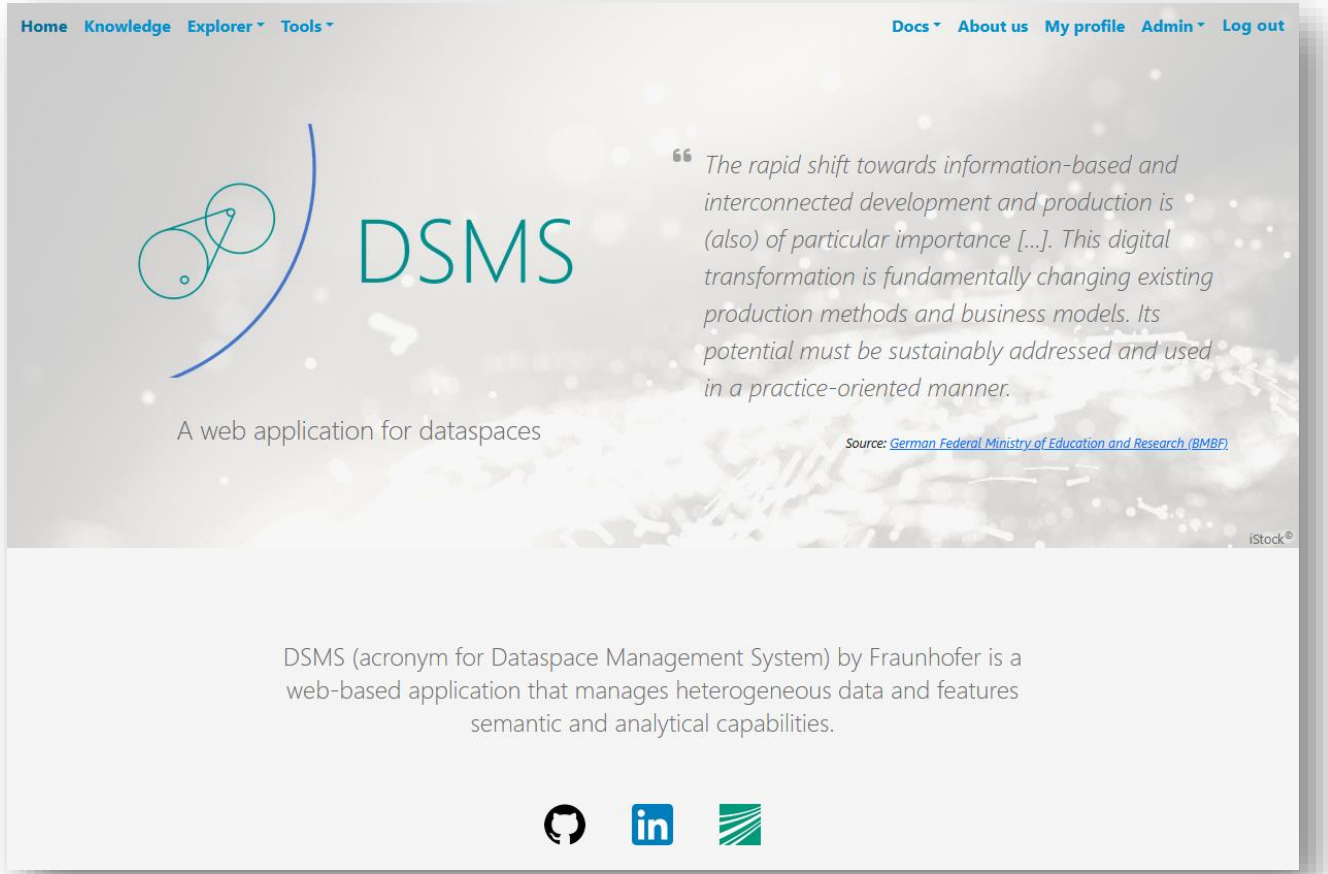
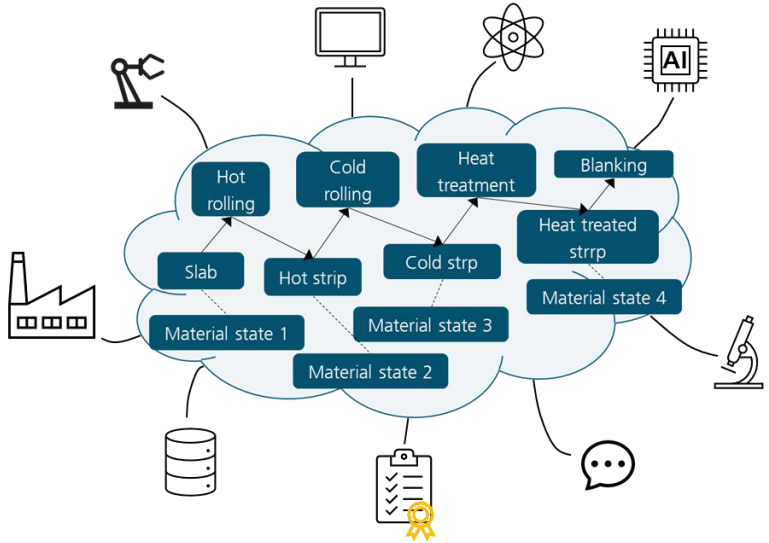


StahlDigital dataspace based on semantic driven PMD technologies

PMD-X/StahlDigital instance with PMD-Dataportal connection





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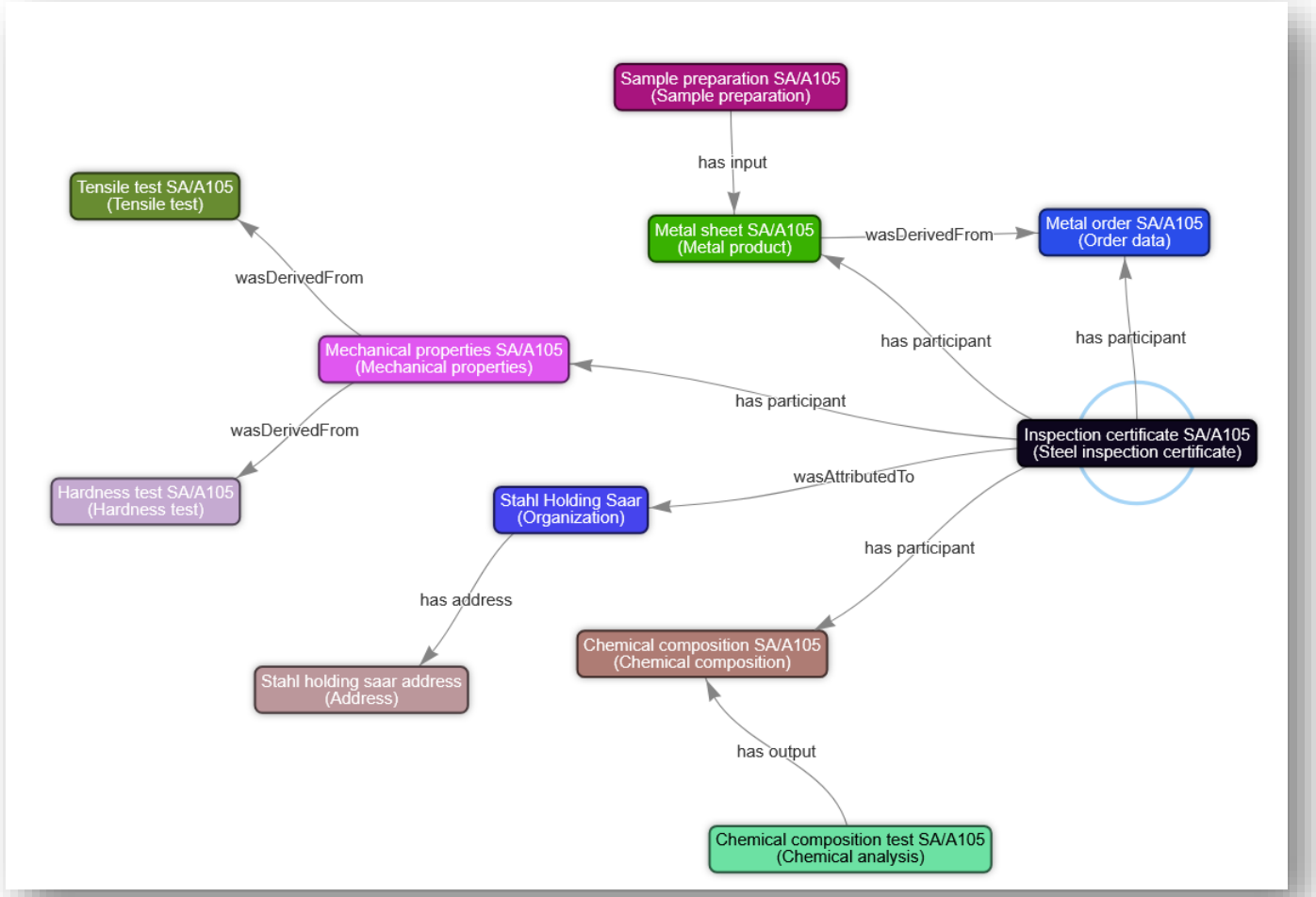

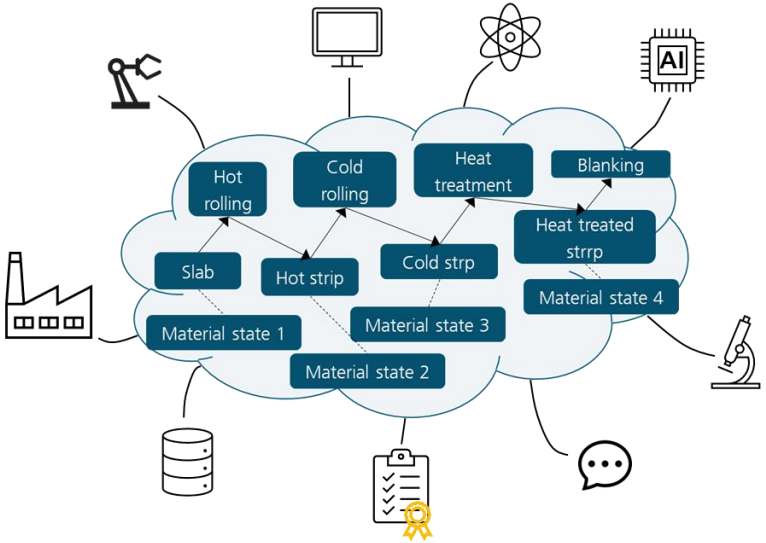

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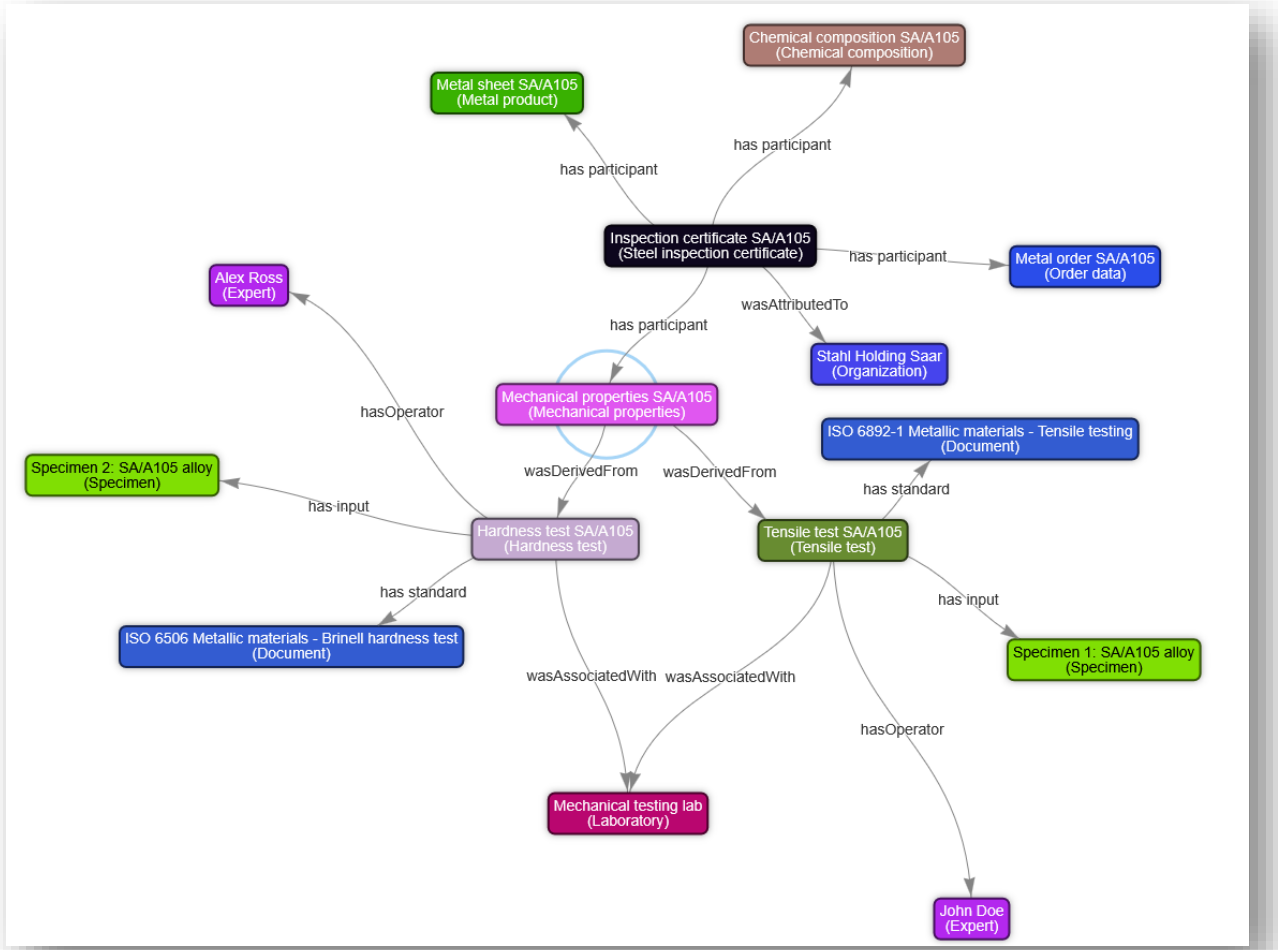

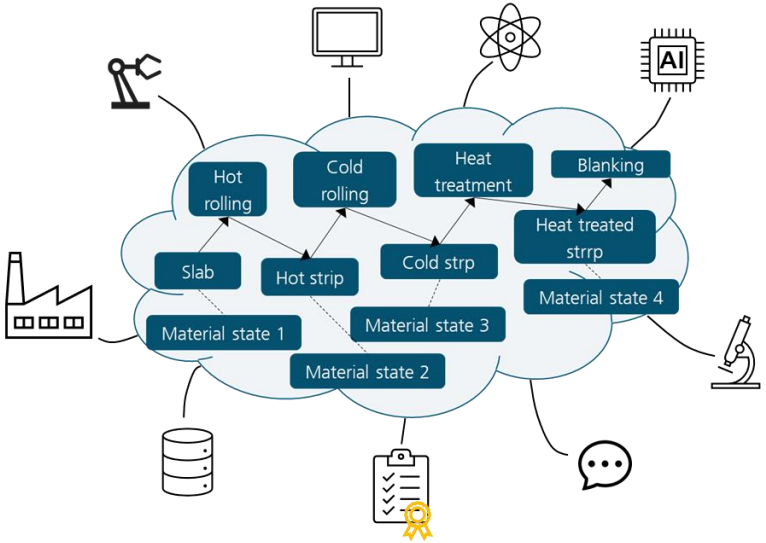

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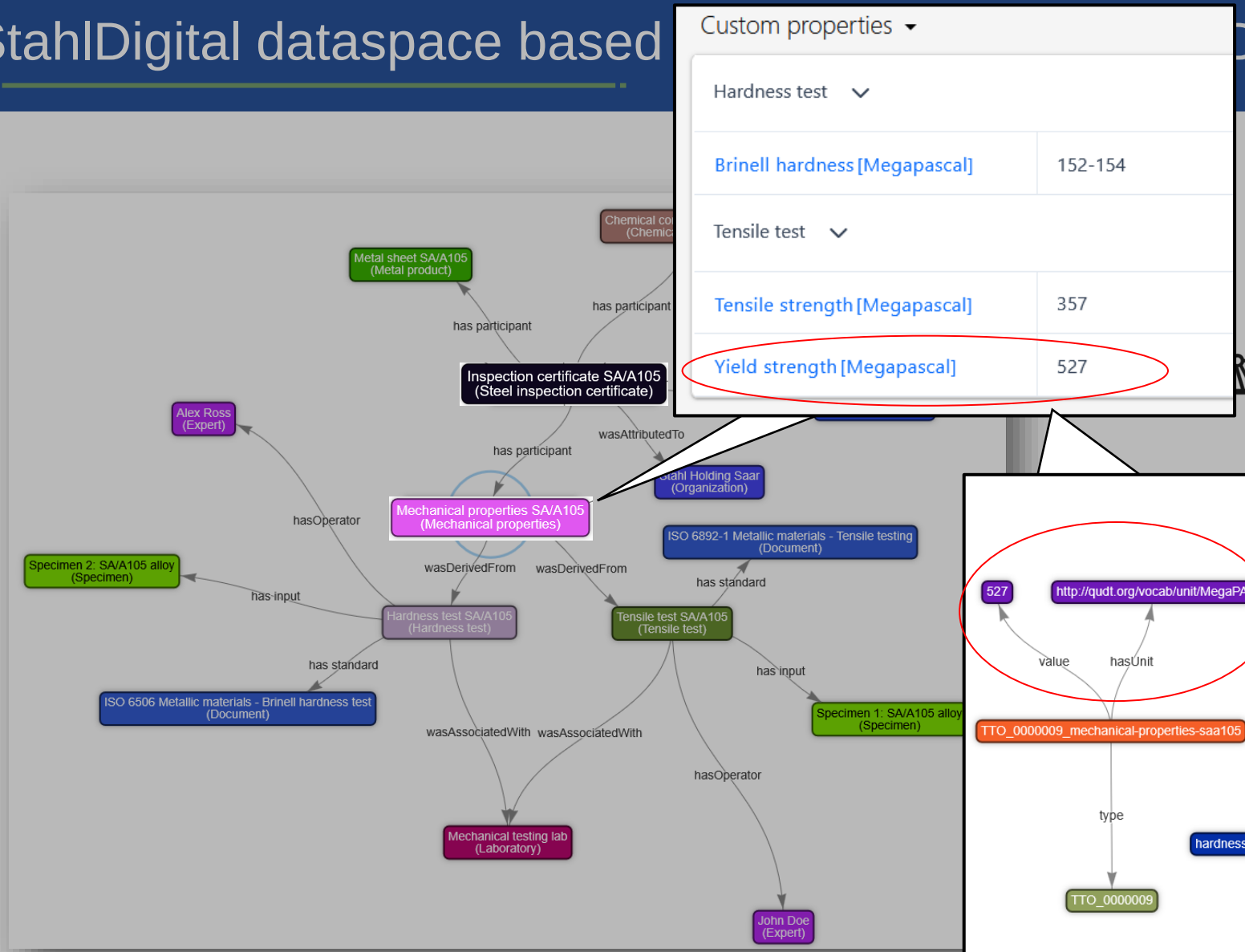

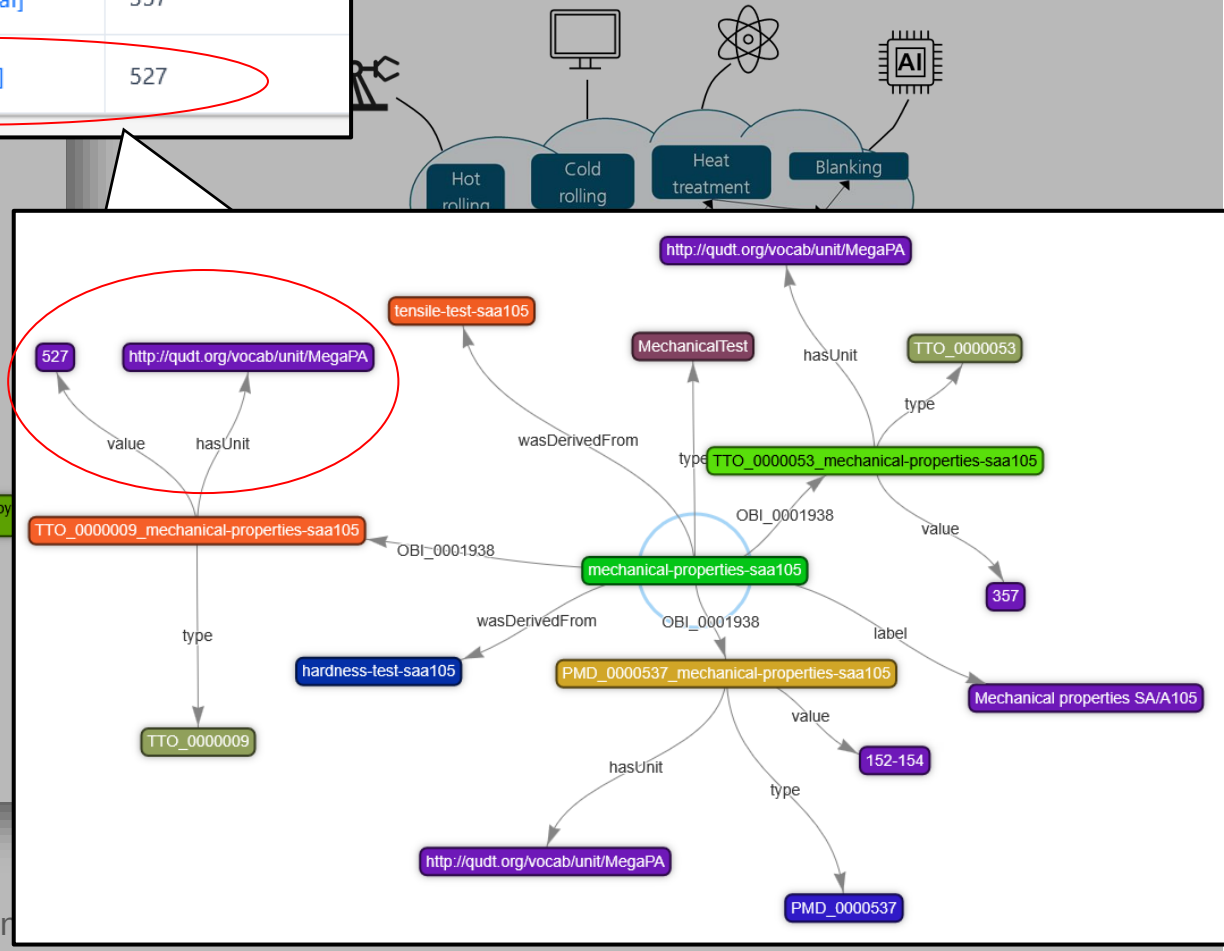

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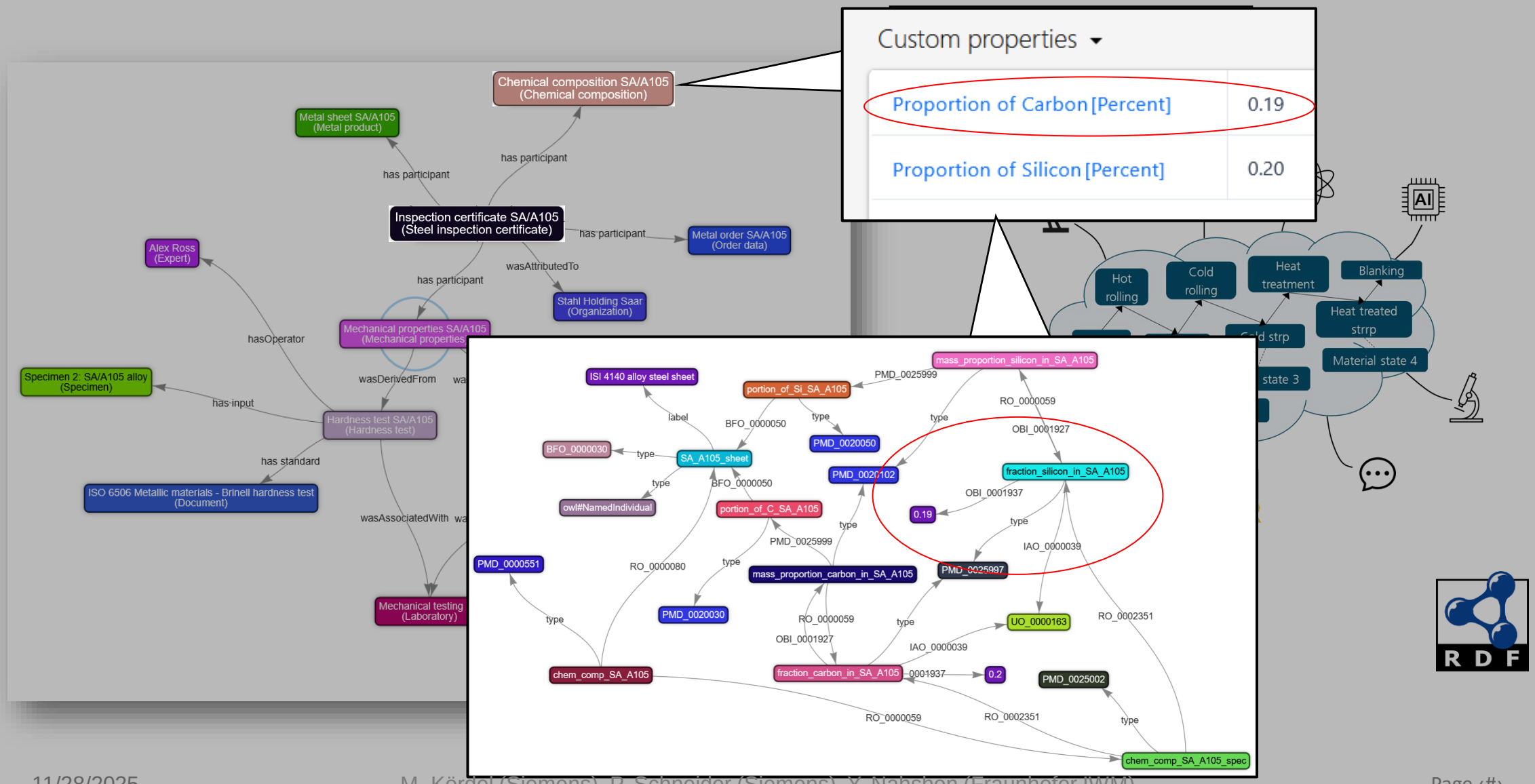

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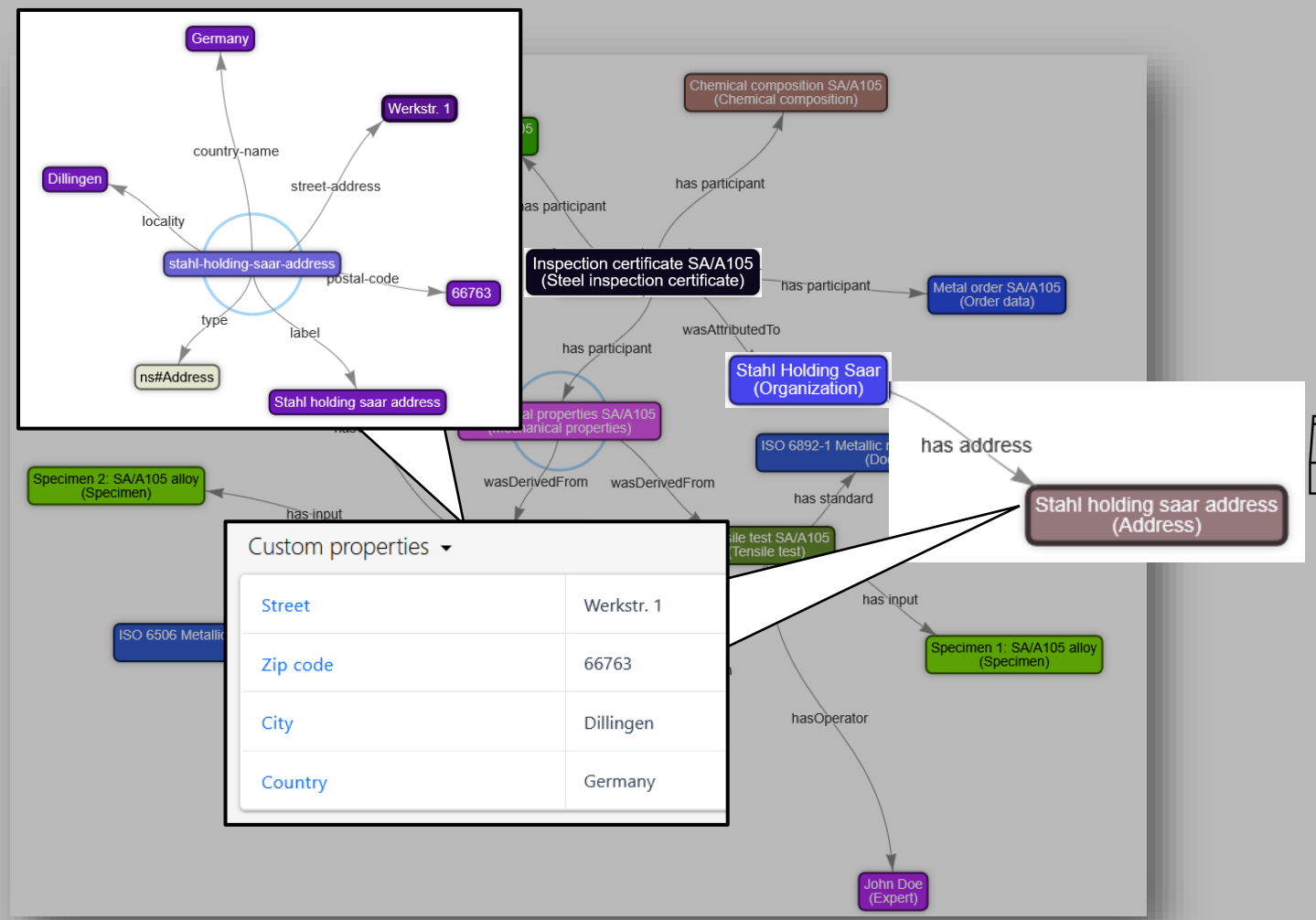
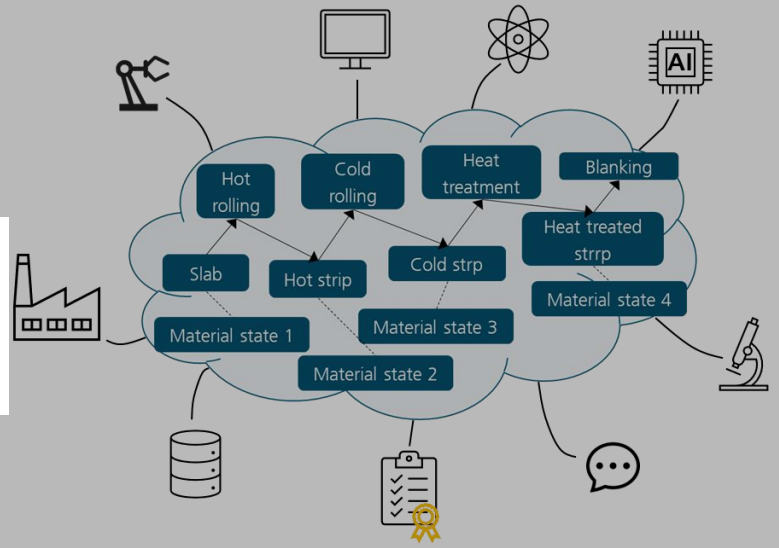
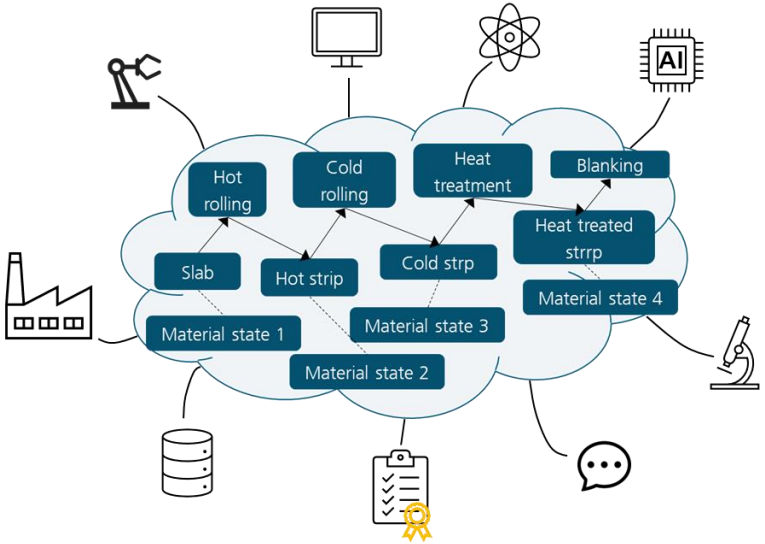




Use Case: Inspection Documents of Steel Products



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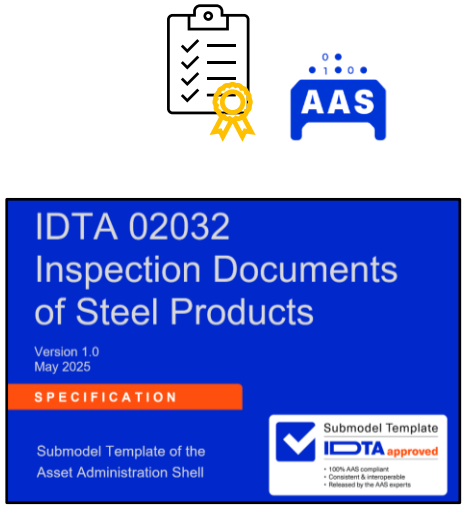

AAS according to Submodel: Inspection Documents of Steel Products

AAS in JSON format:

KG2AAS

8de5e175-ea5e-40c9-9ba9-62649720f898_AAS.json


```
{
  "assetAdministrationShells": [
    {
      "idShort": "InspectionDocumentsOfSteelProductsAAS",
      "displayName": [
        {
          "language": "en",
          "text": "Instance - Inspection Documents of Steel Products v1.0"
        }
      ],
      "id": "https://pmdx.materials-data.space/8de5e175-ea5e-40c9-9ba9-62649720f898/AAS",
      "assetInformation": {
        "assetKind": "Instance",
        "globalAssetId": "https://pmdx.materials-data.space/8de5e175-ea5e-40c9-9ba9-62649720f898/AssetInfo",
        "assetType": "Type",
        "defaultThumbnail": {
          "path": "/aasx/files/IDTA-02032-1-0_Submodel-Inspecon-Documents-of-Steel-Products-Title.png",
          "contentType": "image/png"
        }
      },
      "submodels": [
        {
          "type": "ModelReference",
          "keys": [
            {
              "type": "Submodel",
              "value": "https://pmdx.materials-data.space/8de5e175-ea5e-40c9-9ba9-62649720f898/Submodel"
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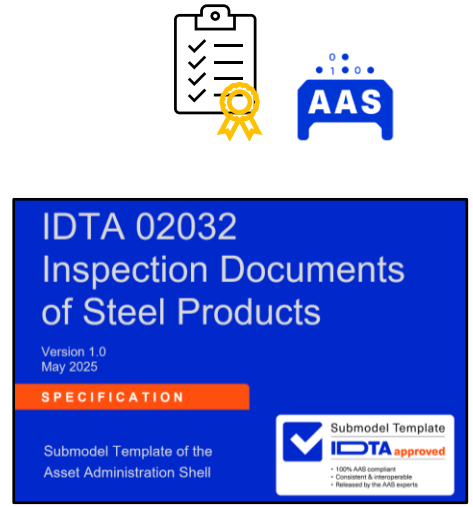
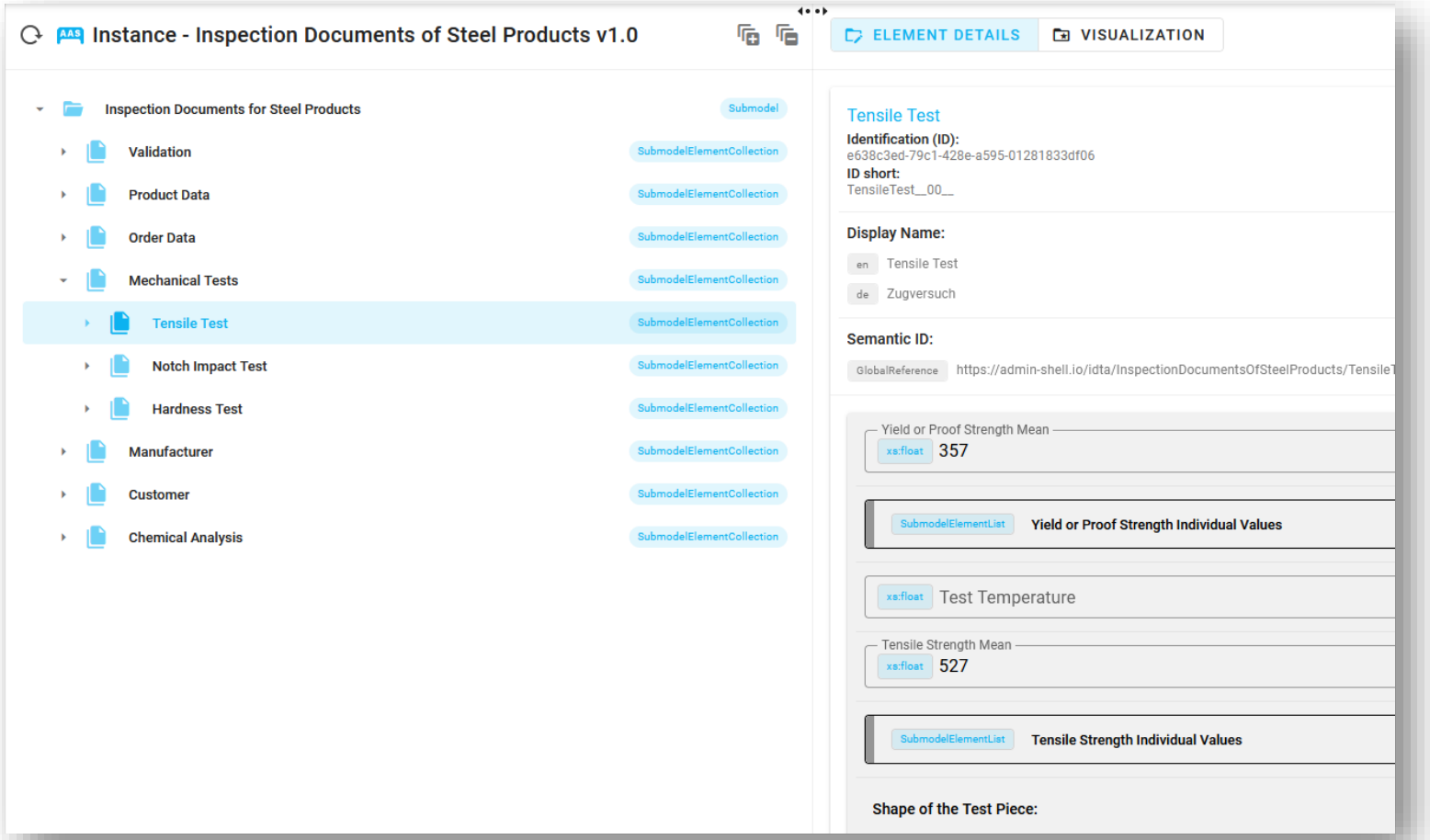
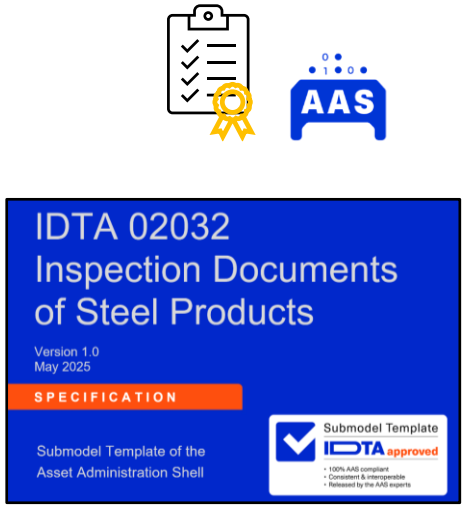


AAS according to Submodel: Inspection Documents of Steel Products

Imported AAS in JSON format into BaSyx





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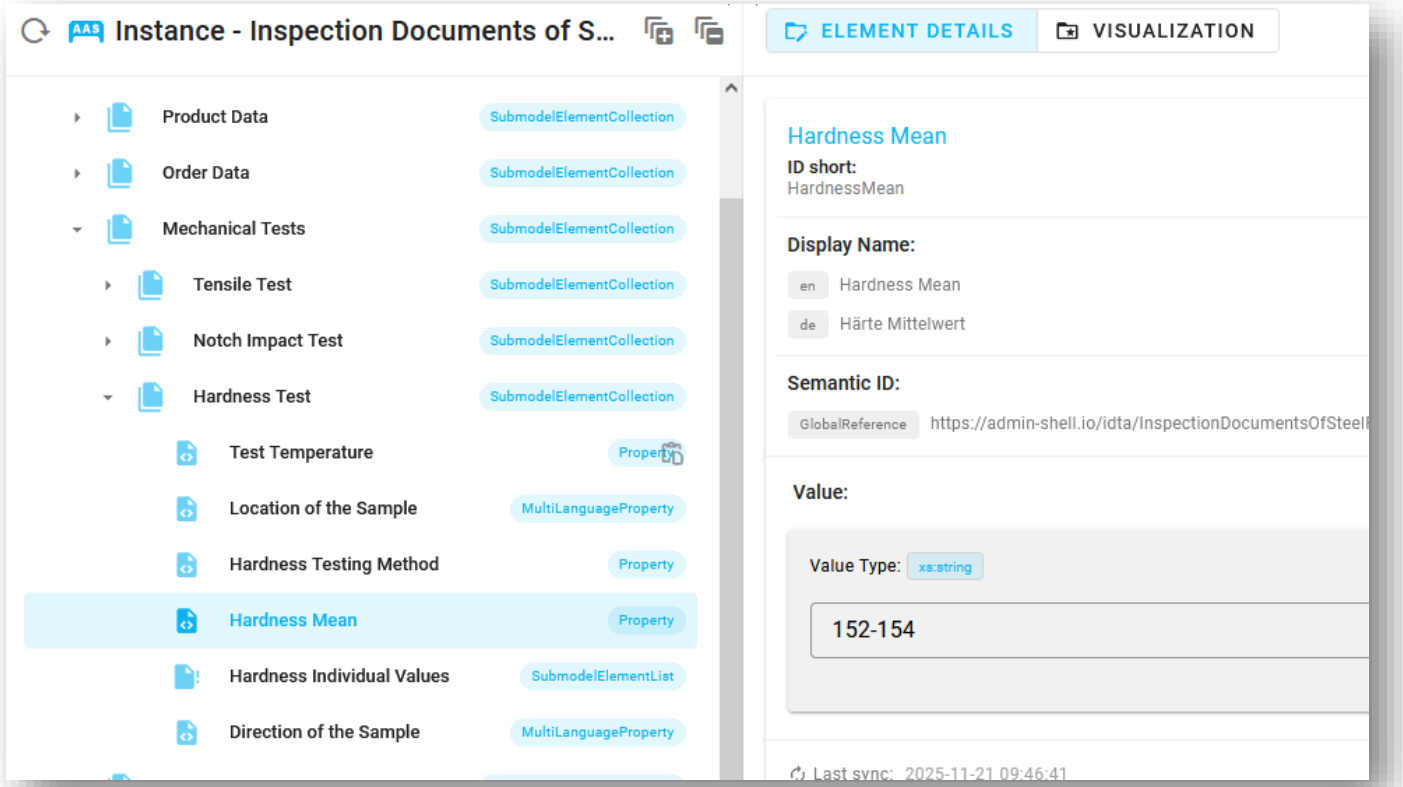

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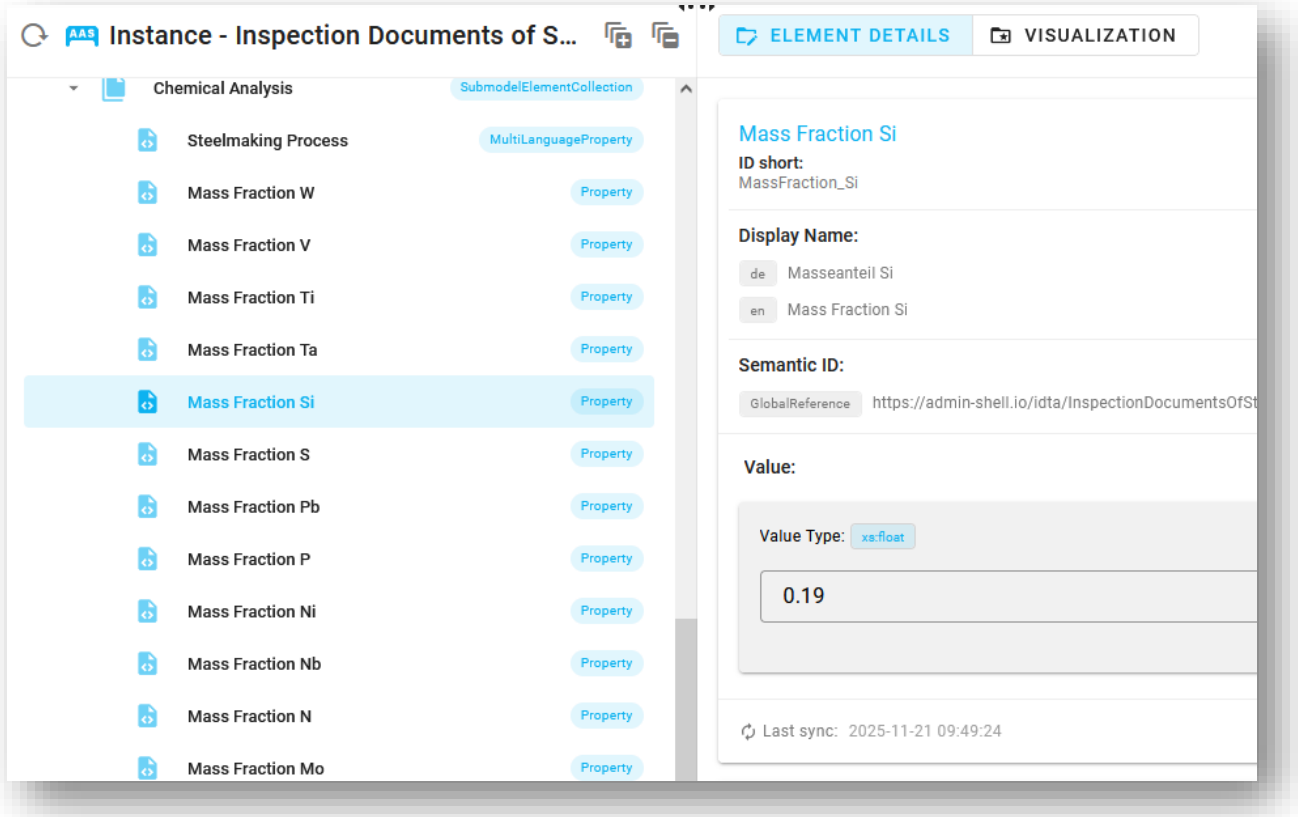

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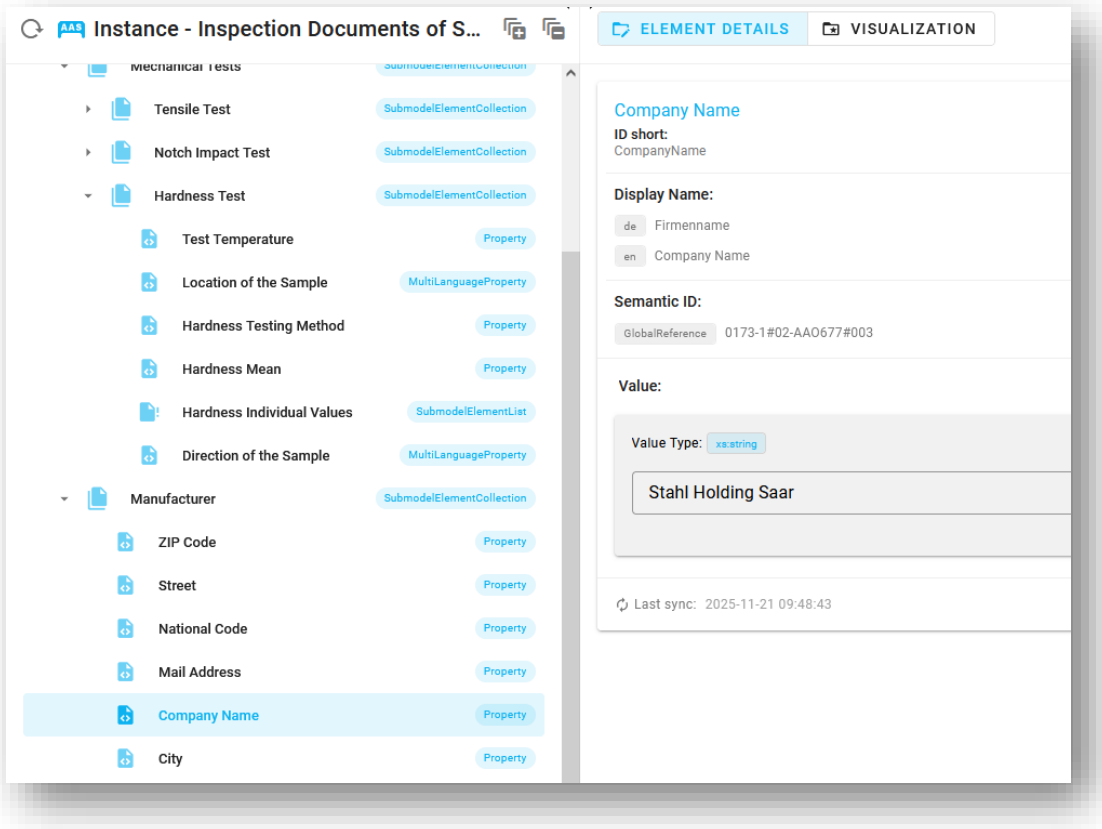
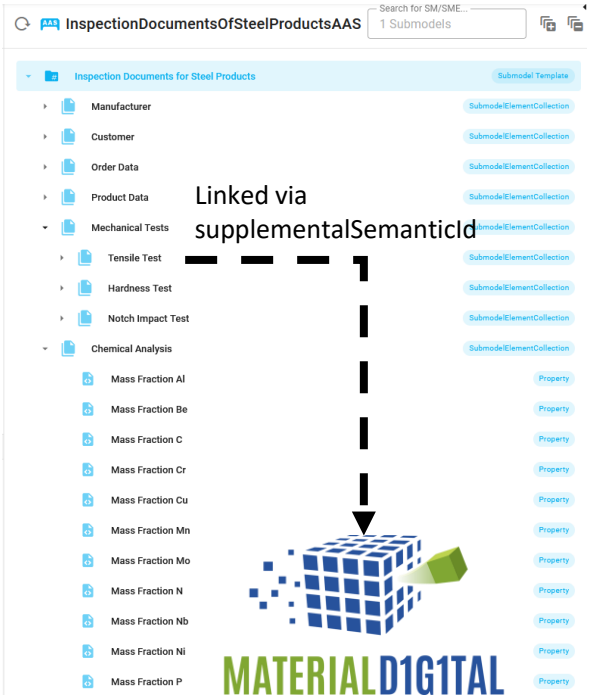


Integrating the PMD Ontology with Submodels



Sharing 3.1 Certificates via Manufacturing-X

Abnahmeprüfzeugnis 3.1 gemäß DIN EN 10204

<LOGO>

Bescheinigungsnummer	123
Kundenbestellnummer	456
Werksauftragsnummer	789
Lieferanzeigenummer	123/456
Datum der Ausstellung	1.1.2025
Bestelldatum	1.1.2025
Auftragsdatum	1.1.2025
Lieferdatum	1.1.2025

Musterbetrieb
Musterstraße 1
12345 Musterstadt

Artikelnummer	4711
Abmessung	12,00 mm +0,12/ - 0,34 mm
Anzahl Pakete	22
Masse	12.345 kg
Länge	123.45 mm +0.23/-0.45 mm
Erzeugnis	Stab, rund
Schmelzen-Nr.	123456
Stahlherstellungsverfahren	AB-Verfahren

Stahlbezeichnung, Bestelltext, Lieferzustand des Erzeugnisses

gemäß Liefervorschrift. **Musterbetrieb**

Chemische Zusammensetzung [Gew.-%], H_2 & O_2 [ppm]; Schmelzanalyse

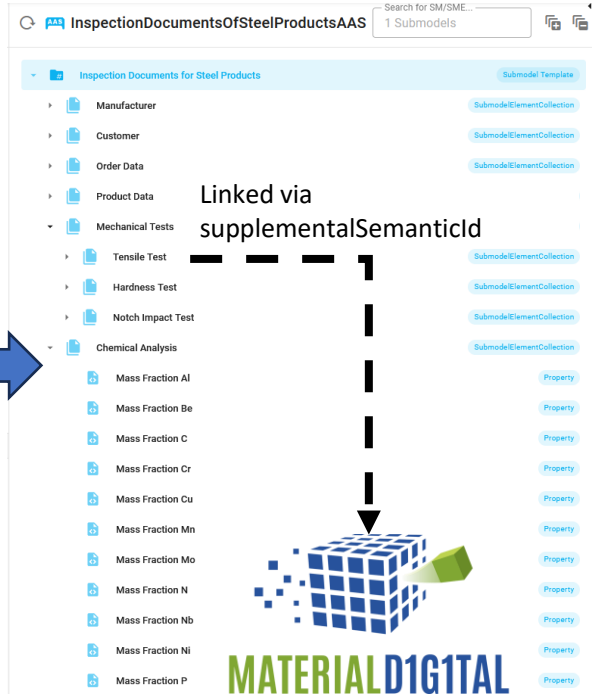
	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	N	Sn
Ist	0,123	0,123	0,123	0,123	0,123	0,123	0,123	0,123	0,123	0,123	0,123	0,123

Härtbarkeit gem. EN ISO 642 — Abstand [mm] — Einheit [HRC]

	1,5	3,0	5,0	7,0	9,0	11,0	13,0	15,0	20,0	25,0	30,0	35,0	40,0
Ist	45,6	45,6	45,6	45,6	45,6	45,6	45,6	45,6	45,6	45,6	45,6	45,6	45,6

Mechanische Werte im Lieferzustand

	HBW 10/3000
Prüfnorm	DIN EN ISO 6506
Einheit	HBW
Min	123
Max	456



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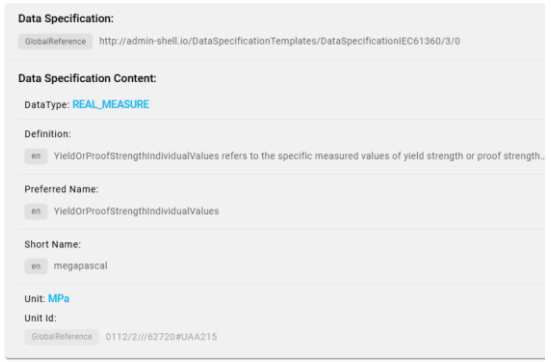
L4	Access & Usage Control	AAS Security[7]
L3	Gate	AAS - REST
L2	Converter	AAS Submodels[5]
L1	Adapter	Application specific

Connecting the PMD-X-MAPRO to the PMDCo W

StahlDigital

- Standard
- StressExponent_n
- strip
- strip tension
- strip width
- SwitchingPoint
- Temperature
- TemperatureSensor
- Tensile Test
- TensionAtWinder%20
- Test
- Testing machine
- TestingRate2
- TestNumber
- TextileCount%20
- ThermalConductivity
- ThermalExpansionCoefficient
- time increment step
- Time series
- Time series simulation
- Total Elongation

AAS-vocabulary



Selected alignment of missing terms

PMDCo

- independent continuant
  - immaterial entity
  - material entity
    - chemical entity
    - fiat object part
    - manufacturer
    - object
    - object aggregate
    - organization
    - portion of matter
      - material
        - engineered material
          - ceramic
          - composite material
          - functional material
          - glass
          - metal
          - polymer
        - mineral
        - natural organic material
      - pure substance
    - specimen
- specifically dependent continuant
  - quality
    - extensive quality
    - half-life
    - intensive quality
    - relational quality
  - realizable entity
    - behavioral material property
      - accoustic property
      - deteriorative property
      - electrical property
      - magnetic property
      - mechanical property
      - morphological property
      - optical property
      - stiffness
      - temporal property
      - thermal property

MAPRO App. Ontology

Tailored extensions with new terms

Take existing StahlDigital ontology and AAS-Vocabulary

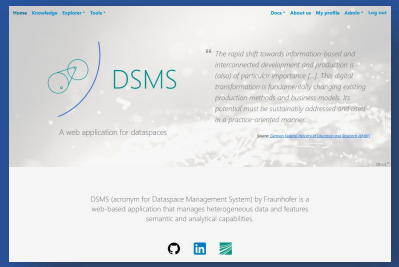
- Started with BAM Hackathon (13.10 – 15.10)
- Goal of aligning **selected** terms of the exisitng Stahldigital ontology to PMDCo 3.0.0-rc1
- **Straight forward**, since StahlDigital is bottom-up created from documents. It is a comprehensive terminology.
- Take into account the side condition that the PMDco is already heavy steel-sided, makes things simpler
- Add needed terms (classes/properties)
- Use modelling patterns d the provider patterns

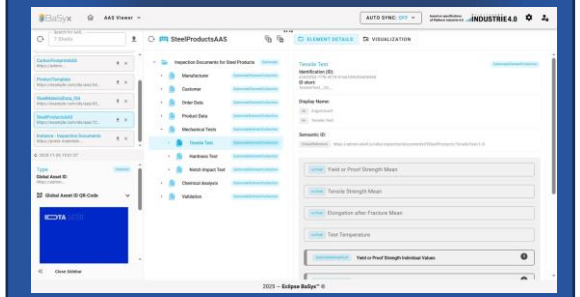
Achievements in the first months

User stories defined

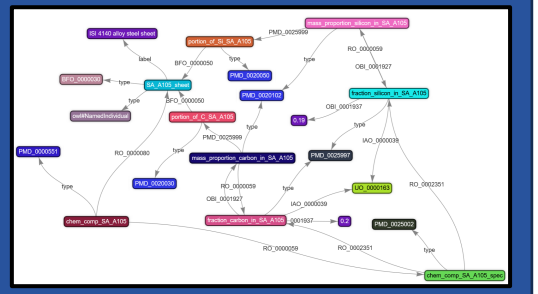
- Steel inspection certificate
- Carbon footprint data
- Process planning/simulation and simulation data
- Recycling information

PMD data instance and X-dataspace instanciated

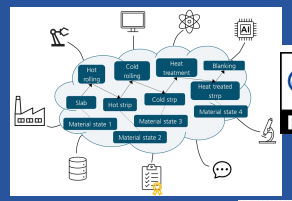




PMDco conformable domain specific knowledge graph



Transformation from KG to AAS including ontology enrichment of AAS



KG2ASS

AAS + MATERIALD1G1TAL + MANUFACTURING-X

Interoperable Data that is **Exchanged** via a **Trusted Environment**

Summary

- Combination of PMD and Manufacturing-X world enables sharing Interoperable Data via a Trusted Environment
- AAS enables easy integration of ontologies like PMD via reference
- Standardized submodels of IDTA enable easy data sharing over dataspaces
- Integration with Manufacturing-X and Catena-X enables seamless sharing regardless of chosen dataspace
- Semantic technologies and linking of data is a powerful enabler for generating data-driven insights and recommendations and promoting AI-readiness
- A semantic federated dataspace creates synergy: the combined impact is greater than the sum of its parts