Capturing the Meaning of Industrial Data

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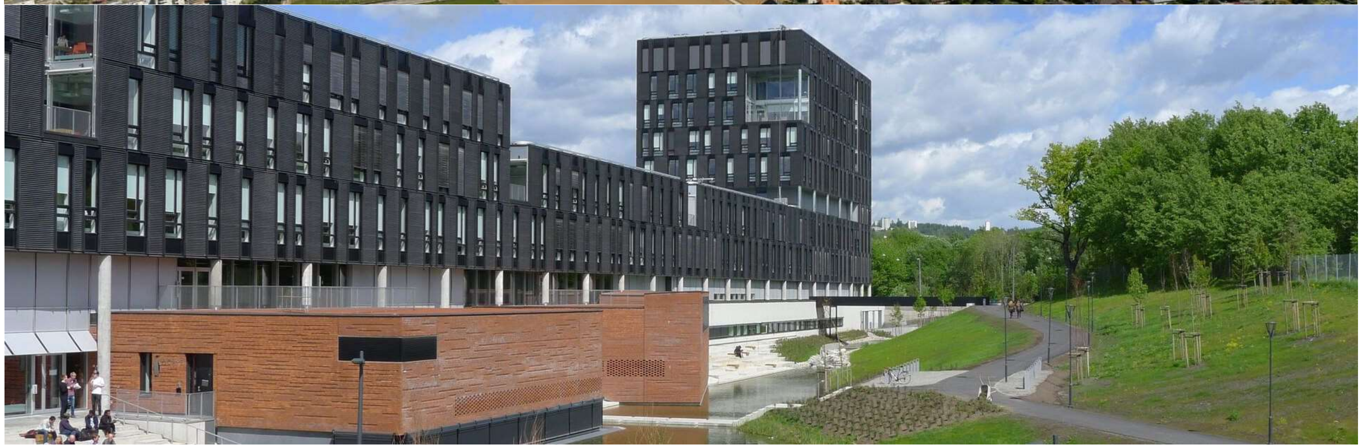
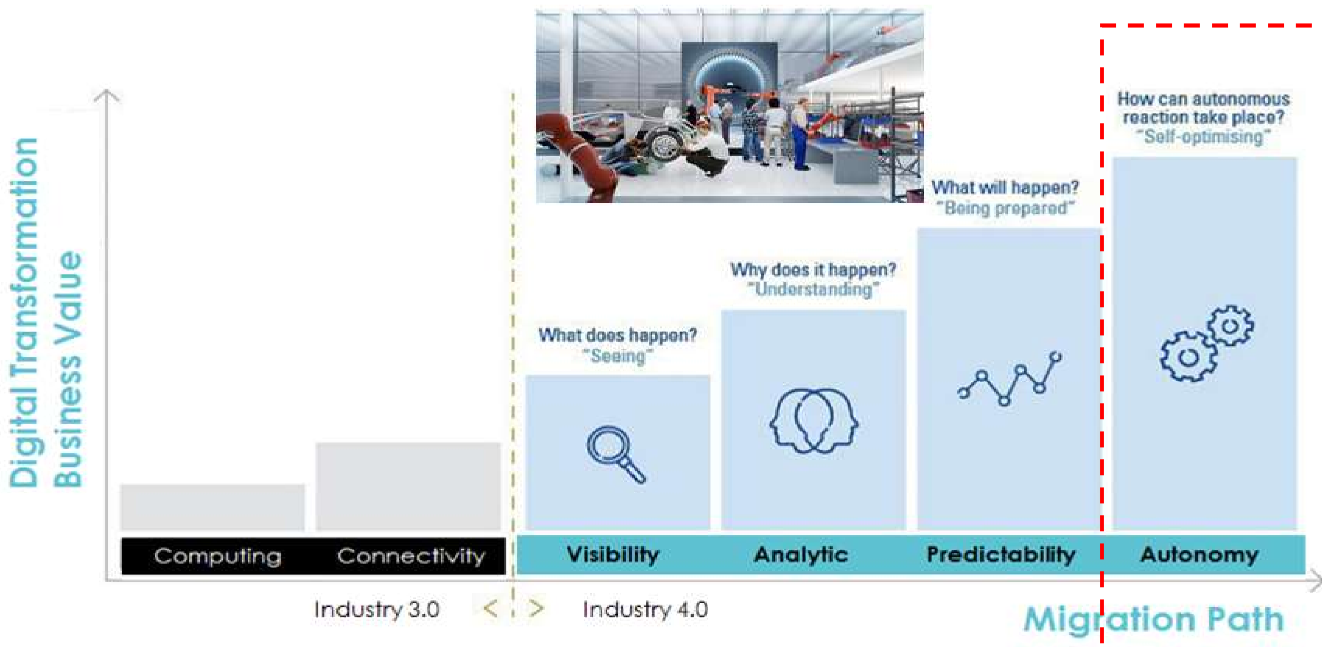


École polytechnique fédérale de Lausanne

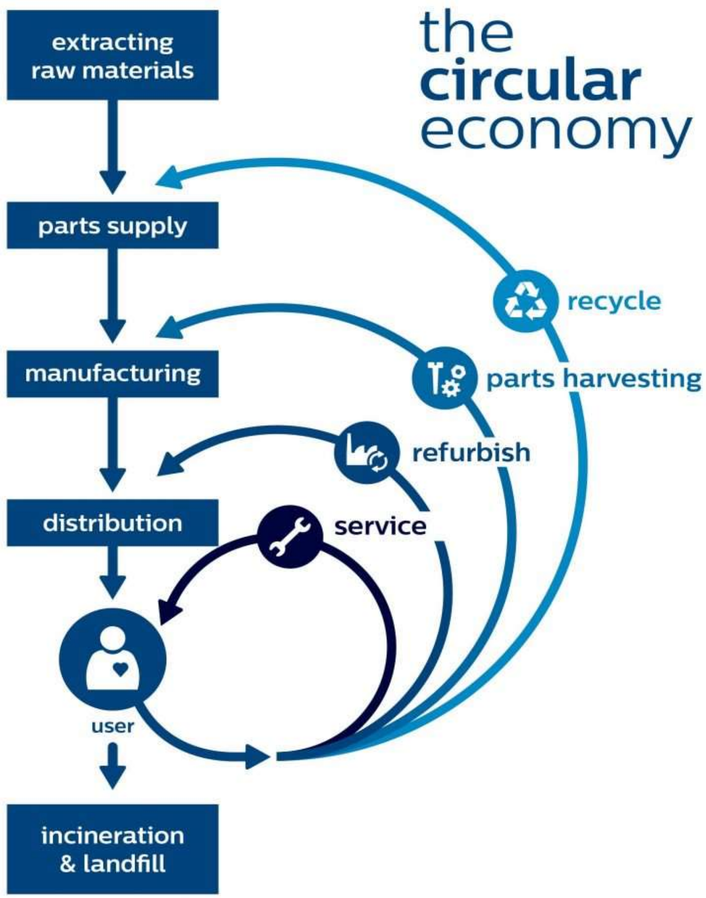
Industry 4.0



Connect & Configure	Monitor & Visualize	Analyze & Predict	Cognitive
• Physical assets, IIoT etc. • Connect data sources • Collect, aggregate, explore	• Data visualization • Monitoring platform • Statistical analysis	• Model-based analysis • Machine/Deep learning • Prediction/recommendation	• Complex & unpredicted behaviors • Sensing & reasoning • Decision-making etc.

UN Sustainable Development Goals - SDGs

The new context: Circular Economy



Source http://www.zerowastemontenegro.me/circular-economy

Extraction	– Raw Materials
Material Supply Chain	+ Reduce material inputs + Replace with renewable materials
Design & Manufacture	+ Design for quality, durability and longevity + Use safe chemistry and healthy materials
Distribution & Use	○ Reuse ○ Repair ○ Rent & resell
End of first file	○ Remanufacture ○ Recycle
Disposal	– Waste to landfill

Source: WMF Report 2021

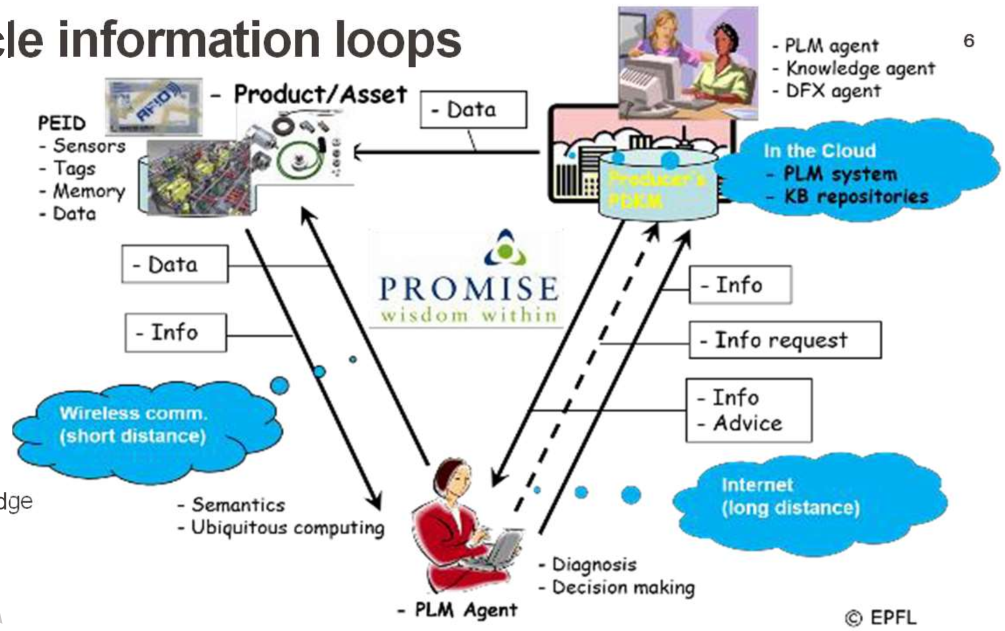
The emergence of Product Embedded Information Devices

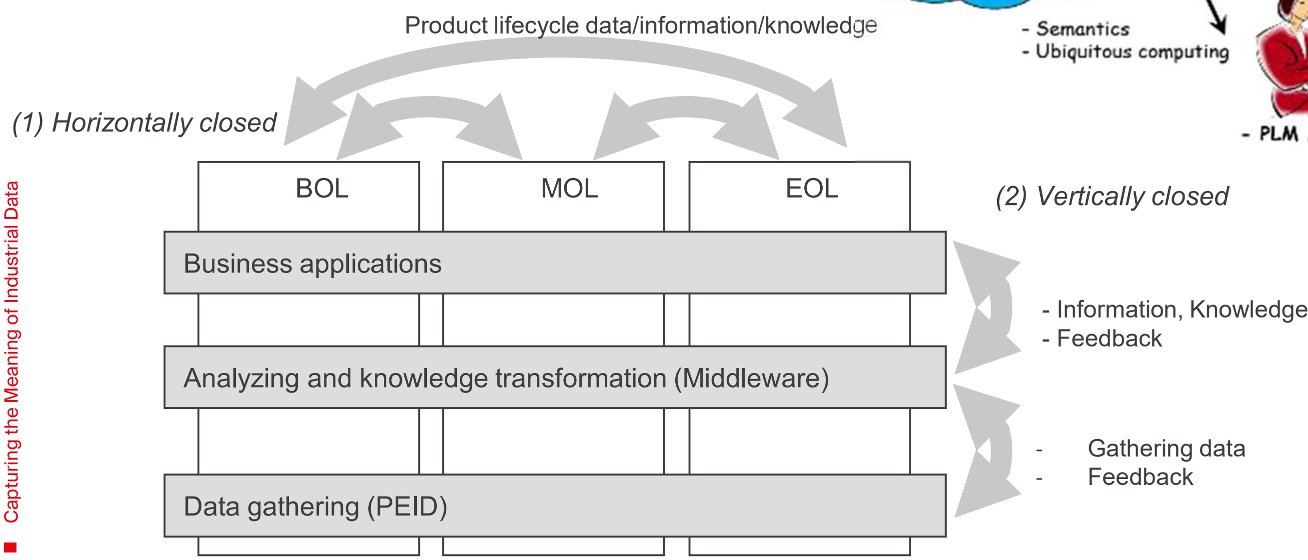
- Sensors (sensing)

- Memory chips (memory)

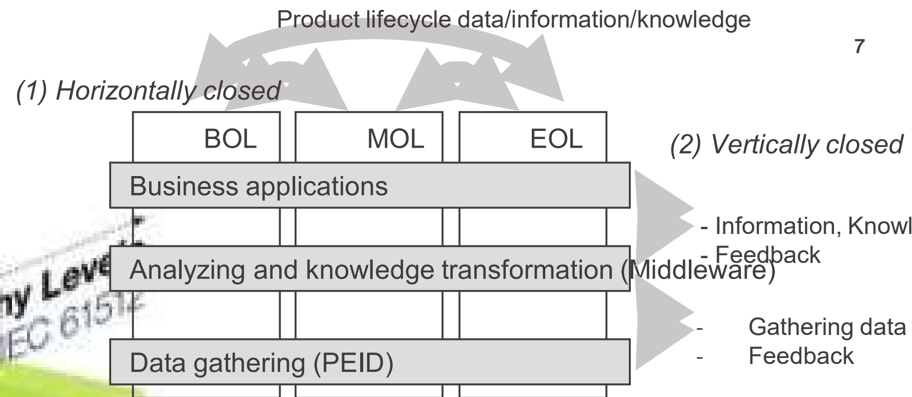
- Micro-processors + Software (logic)
- Barcodes, RFID, … (identity)
- Bluetooth, WiFi, IoT, … (communication)

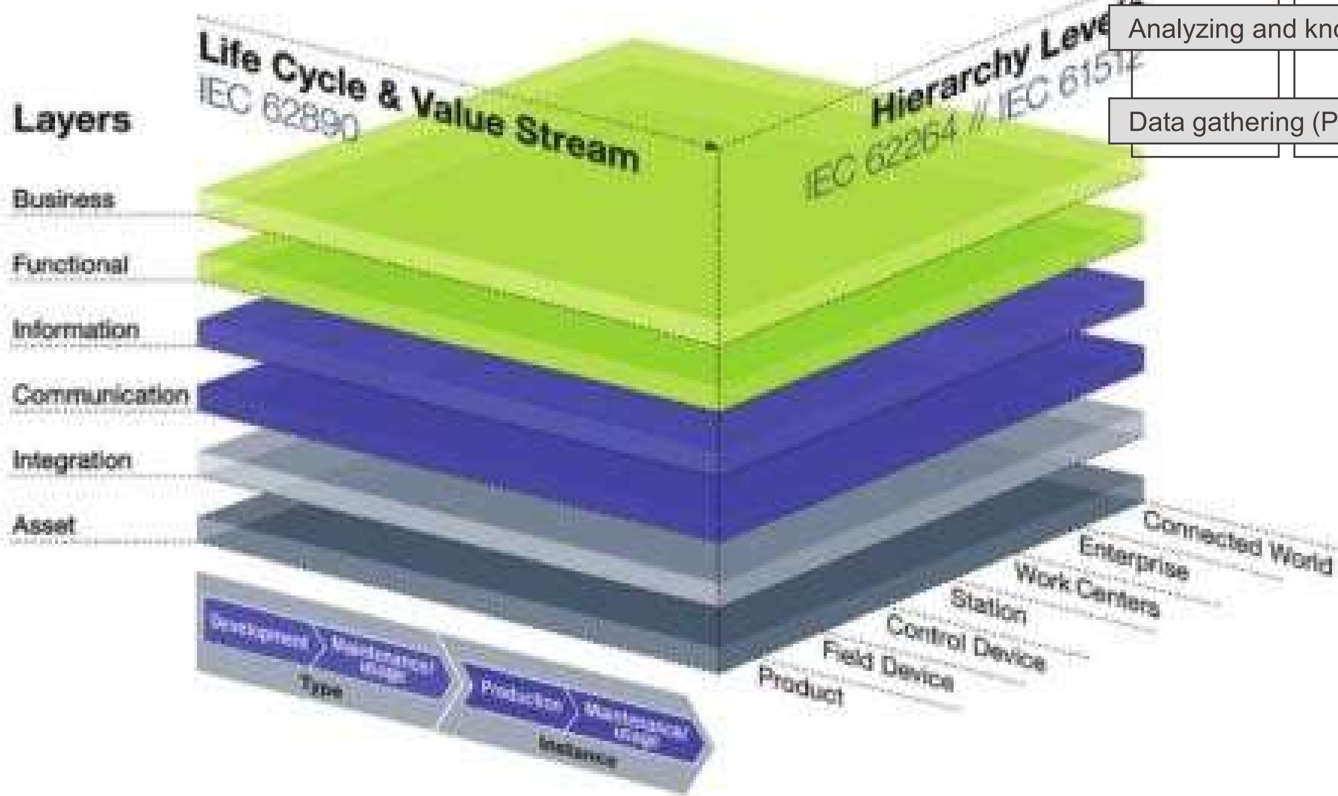
PROMISE: Closing the lifecycle information loops





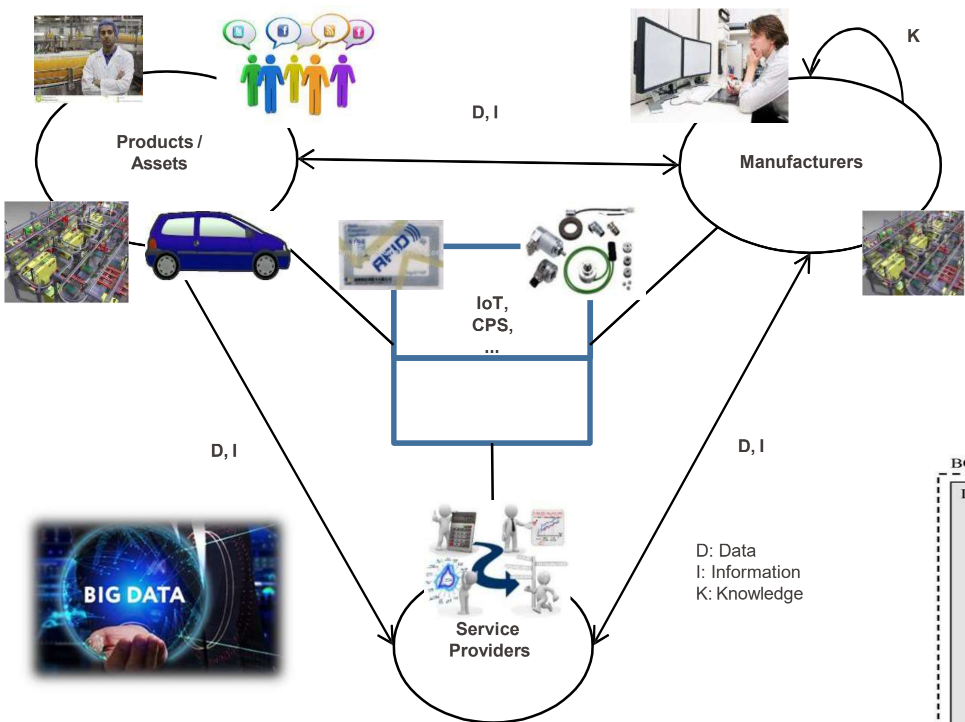
Industry 4.0 - RAMI 4.0 as enabler of Closed Loop Lifecycle Management



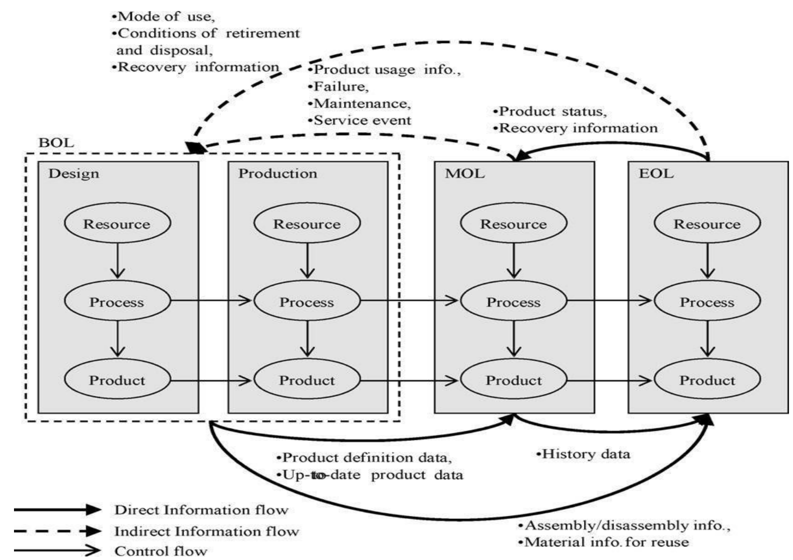


ICT4SM

It is all about Big Life Cycle Data Transformations



- Closed-Loop Life cycle
  - Data-Information-Knowledge Transformations
- Semantic Model-Based Systems Engineering for Industrial Data Analytics



LinkedDesign   Z-Fact0r   Z-Bre4k   Boost 4.0 BIG DATA FOR FACTORIES   QU4LITY

Data Sharing for Manufacturing

WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

White Paper

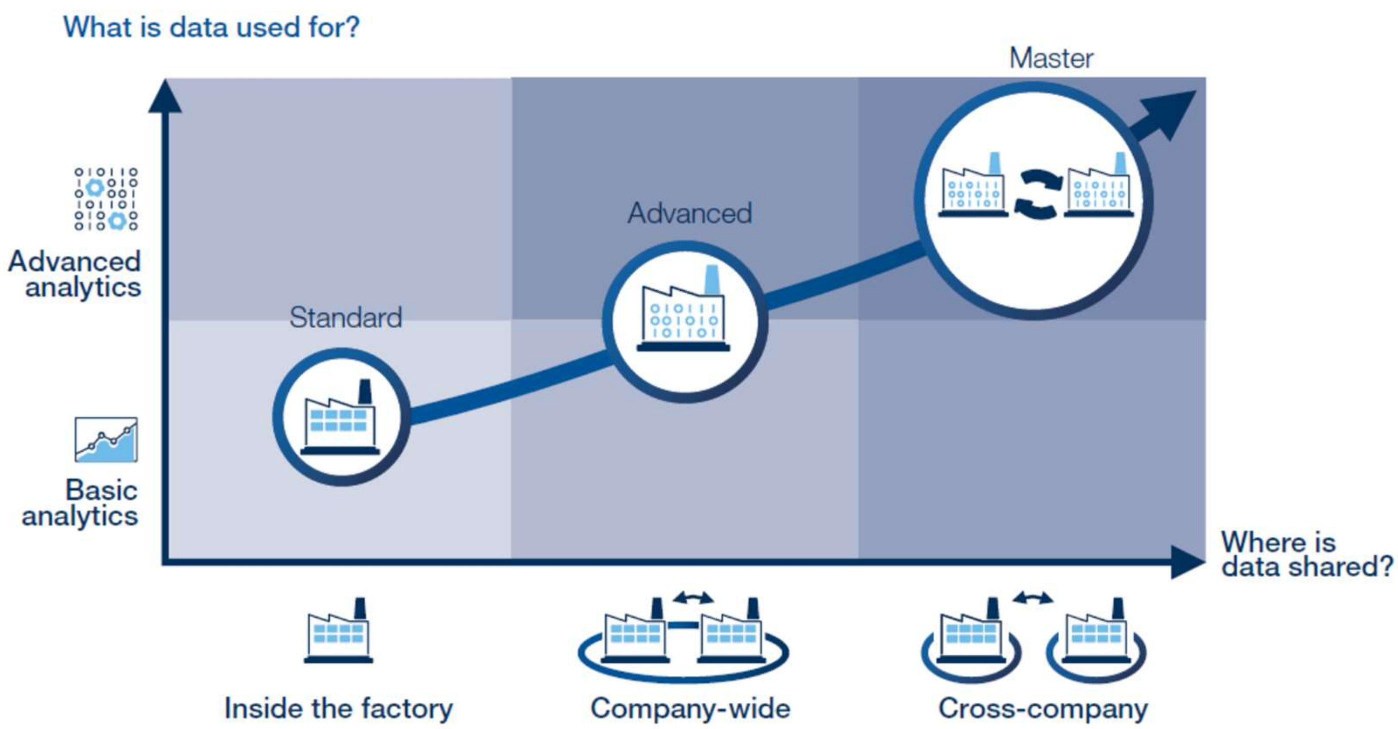
Share to Gain:
Unlocking Data Value in Manufacturing

In collaboration with Boston Consulting Group

January 2020

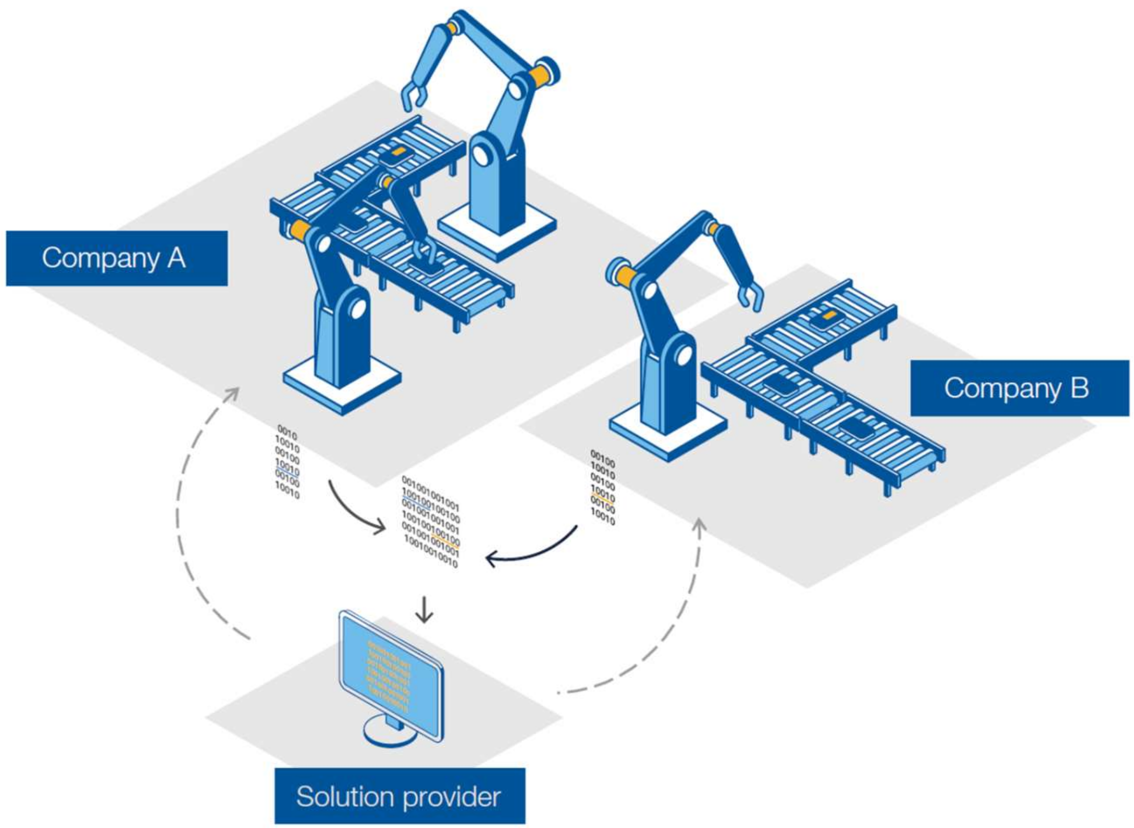
http://www3.weforum.org/docs/WEF_Share_to_Gain_Report.pdf

Data Sharing for Manufacturing



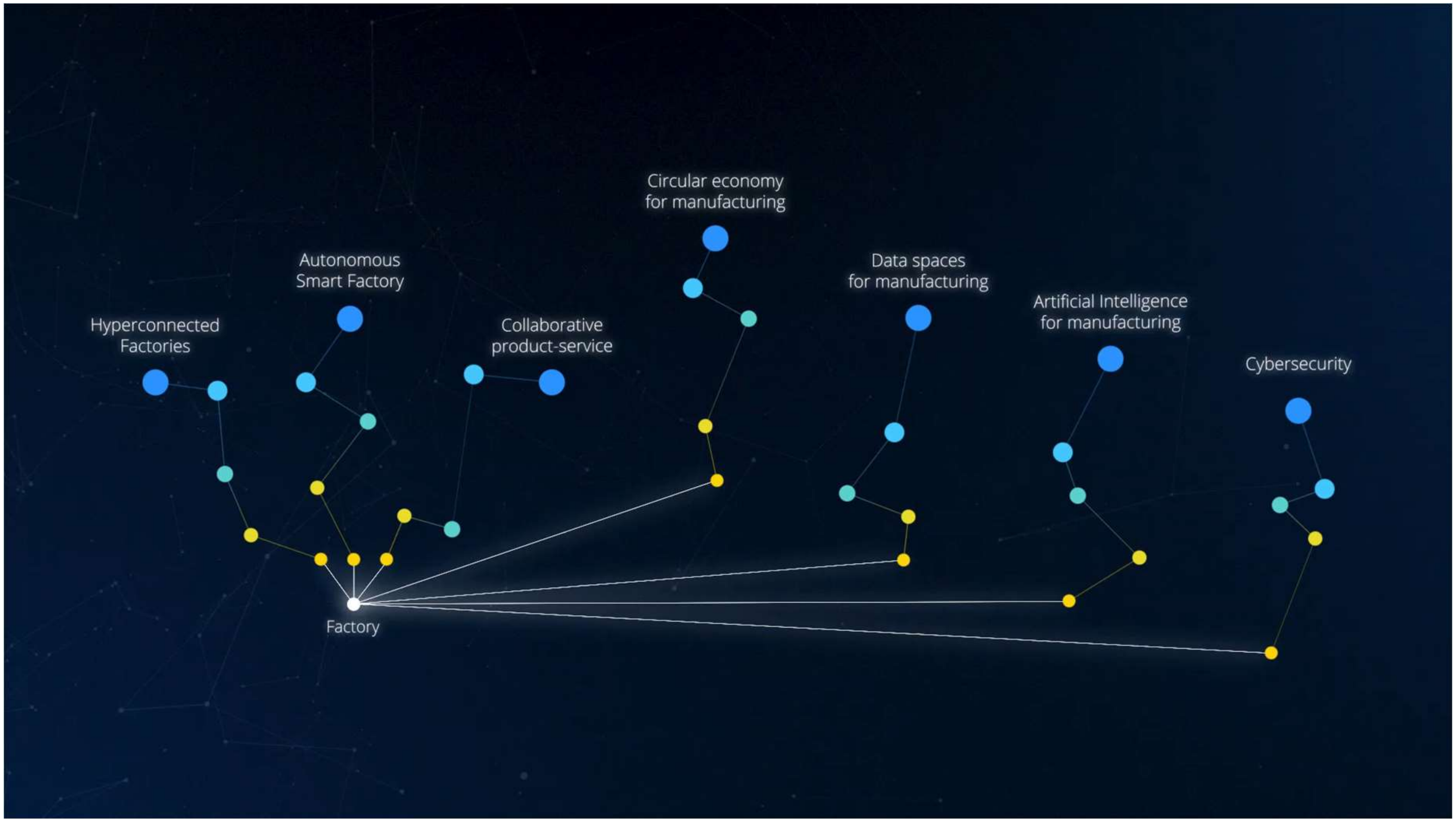
http://www3.weforum.org/docs/WEF_Share_to_Gain_Report.pdf

Enhance Asset Optimization



http://www3.weforum.org/docs/WEF_Share_to_Gain_Report.pdf

Connected Factories

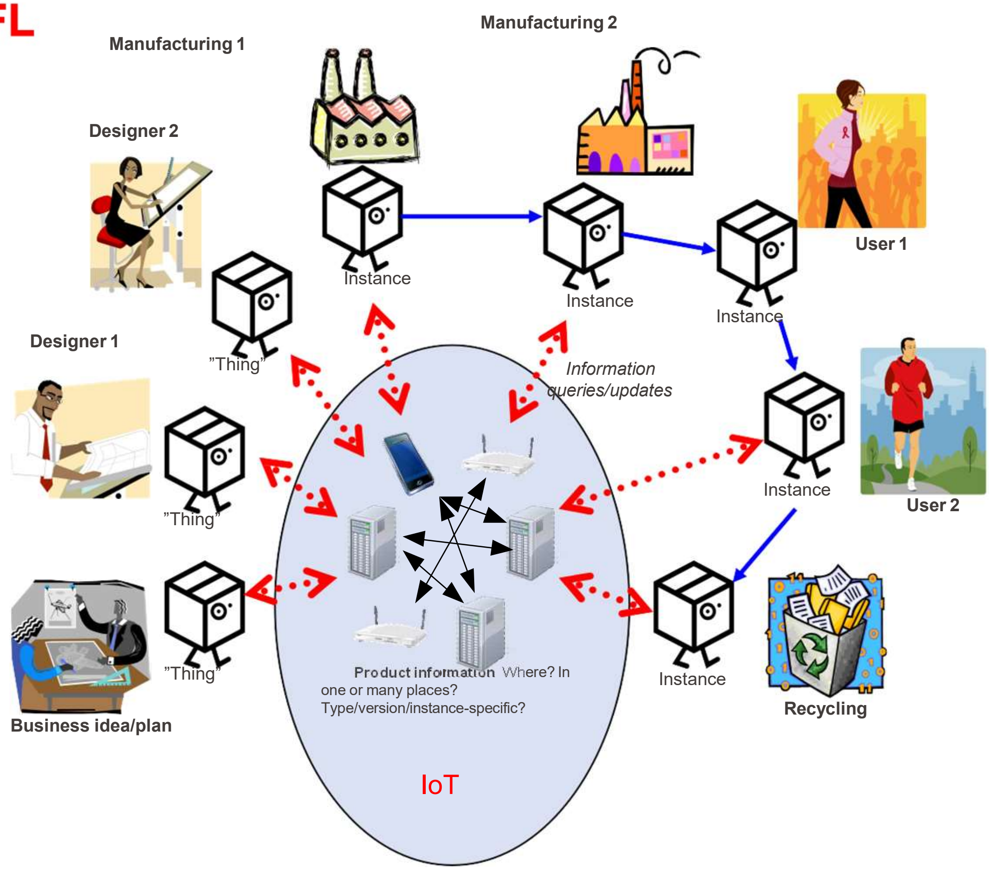


https://youtu.be/AT78aMMyS2s

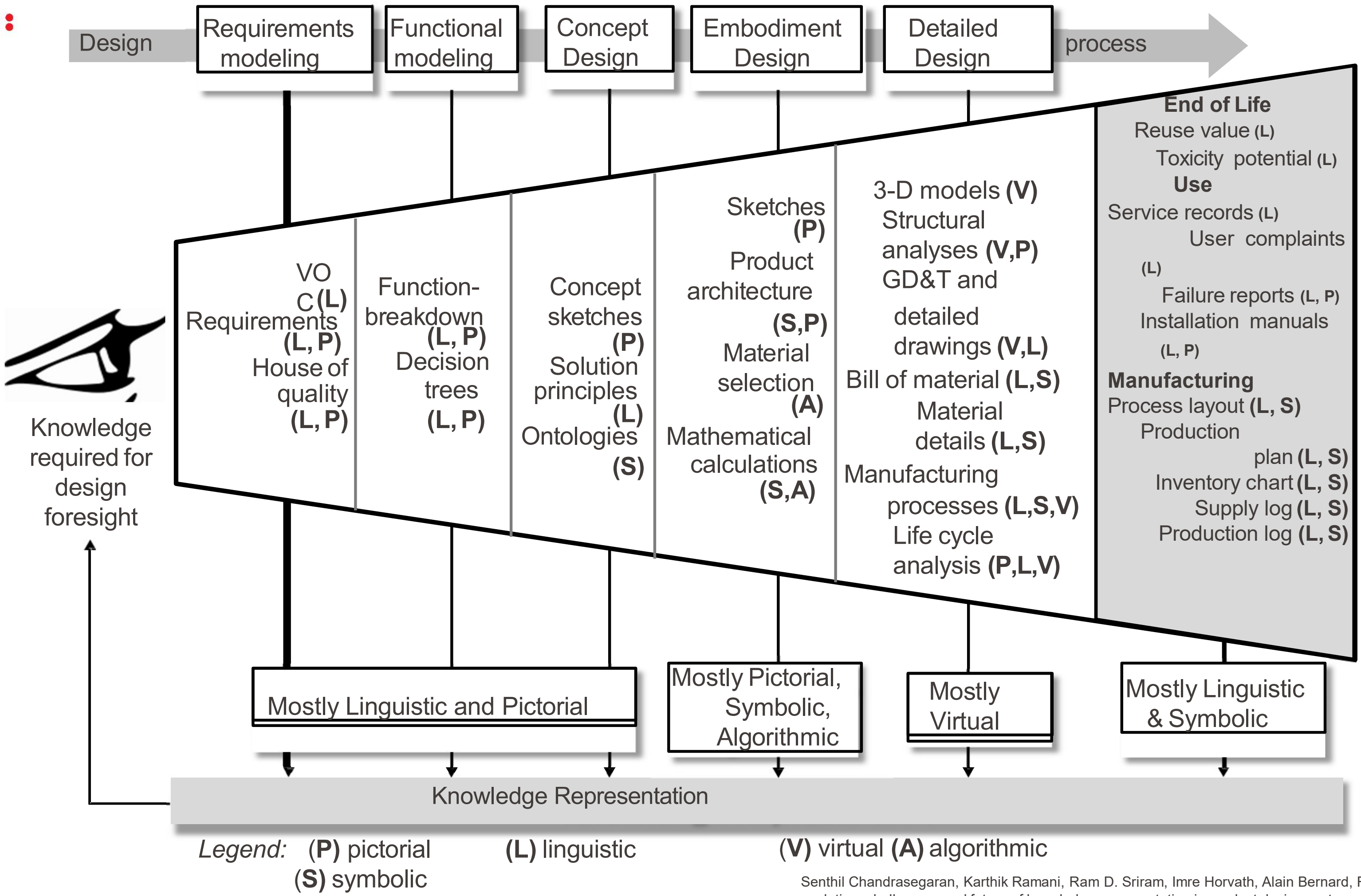
Agenda

- Role of Data in Circular Economy Context
- **Semantic Modelling and MBSE**
- Cognitive Digital Twin concept
- Application case of Airbus
- IMF & CDT in new EU projects

Systems of Systems: Closed Loop Lifecycle Management



- **Lifecycle view**: IoT is about managing **all information** about **any Product/Thing**
- Information is **Distributed over Systems** (devices, servers, applications, ...)
- Information is **Distributed over Organizations** (companies, individuals, authorities, …)
- Product (and its parts) are **unique instances**
- How to manage **identities**, **access rights**, …?
- **IoT** should provide necessary capabilities for **Closed Loop Lifecycle Management**



Senthil Chandrasegaran, Karthik Ramani, Ram D. Sriram, Imre Horvath, Alain Bernard, Ramy Harik, Wei Gao The evolution, challenges, and future of knowledge representation in product design systems Computer-Aided Design Volume 45, Issue 2, February 2013, Pages 204-228.

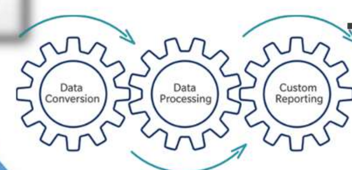
Characteristics of Data

Data Source

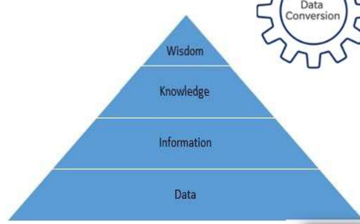
Value

Context

Transformation



Interpretation



Visualisation

The Meaning of Data

Body temperature

38.5 °C

Oven temperature

Ontologies allow the interpretation of the right meaning of data

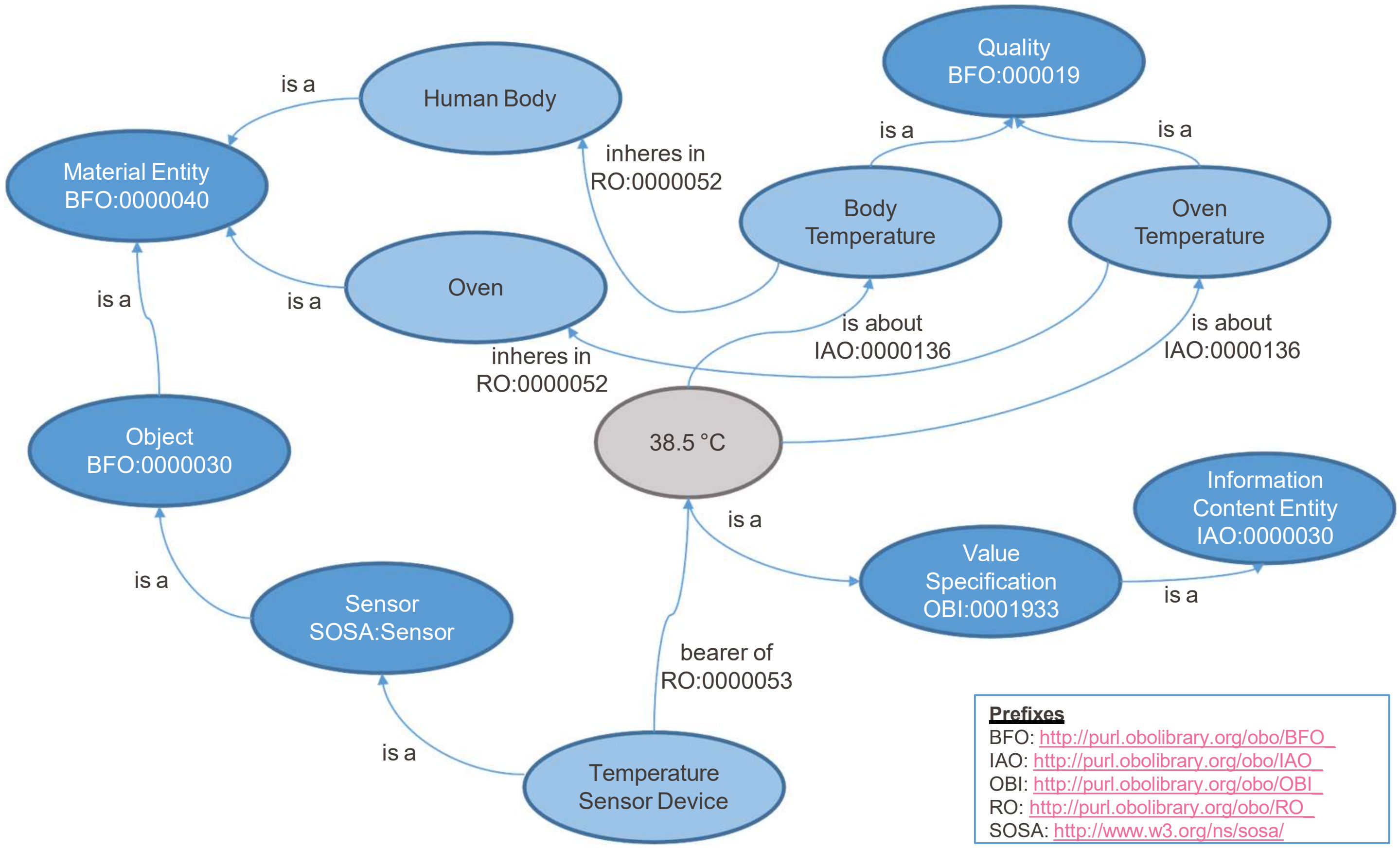
Reasoning

Domain disambiguation

Data Silos

Essay by Verscheure & Kiritsis in 2018 WMF Report: https://www.worldmanufacturingforum.org/report/

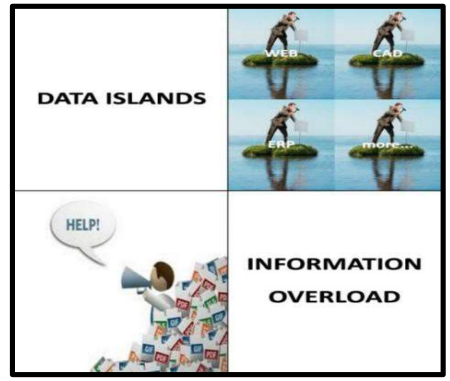
The Meaning of Data

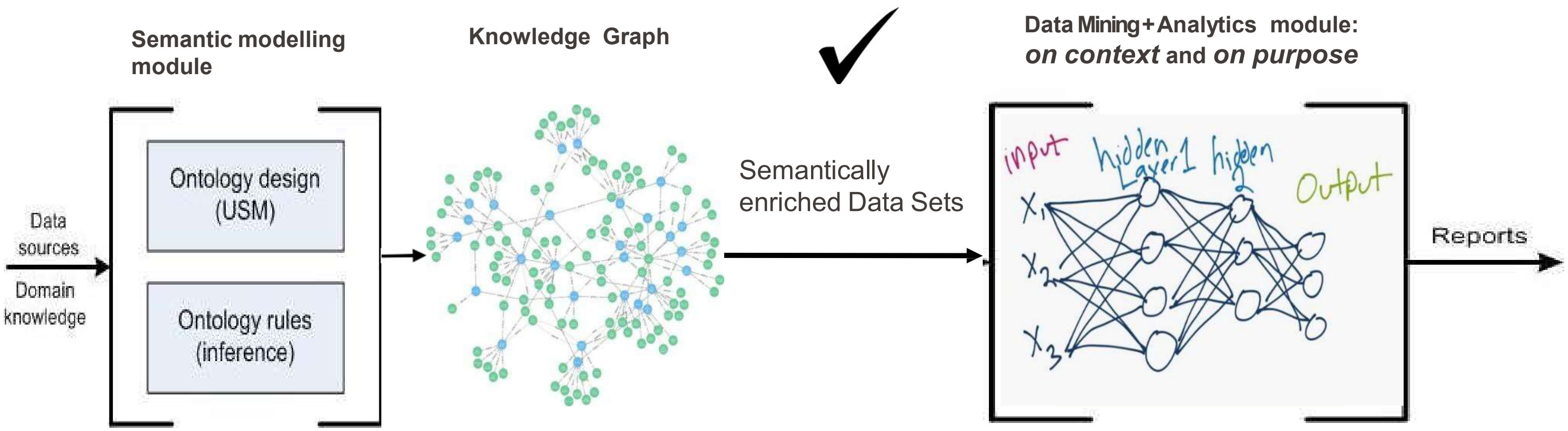


Prefixes
BFO: http://purl.obolibrary.org/obo/BFO_
IAO: http://purl.obolibrary.org/obo/IAO_
OBI: http://purl.obolibrary.org/obo/OBI_
RO: http://purl.obolibrary.org/obo/RO_
SOSA: http://www.w3.org/ns/sosa/

Ontologies & Big Data

- **Challenges:**
  - Scattered data in several sources, systems and services
  - Different actors with multidisciplinary skills

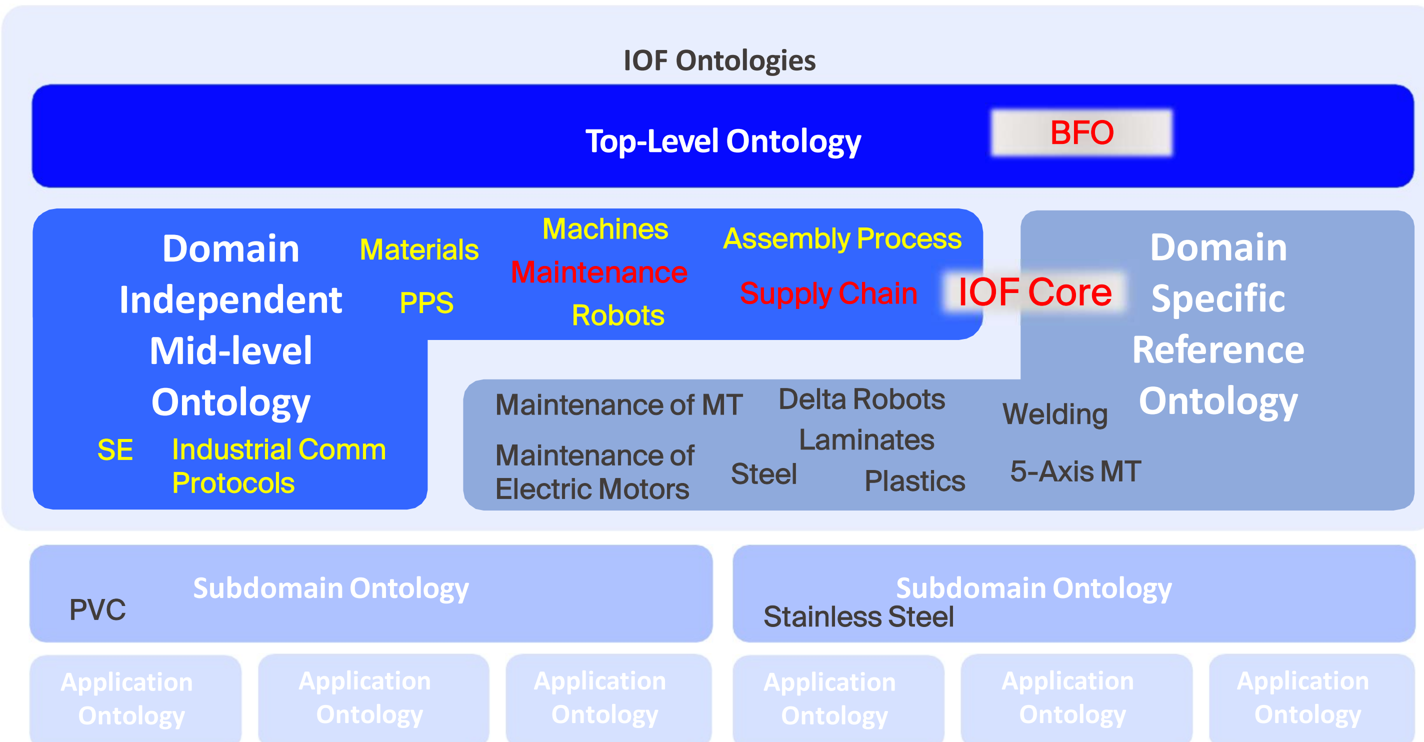




Ontology - Industrial Ontologies Foundry (IOF)

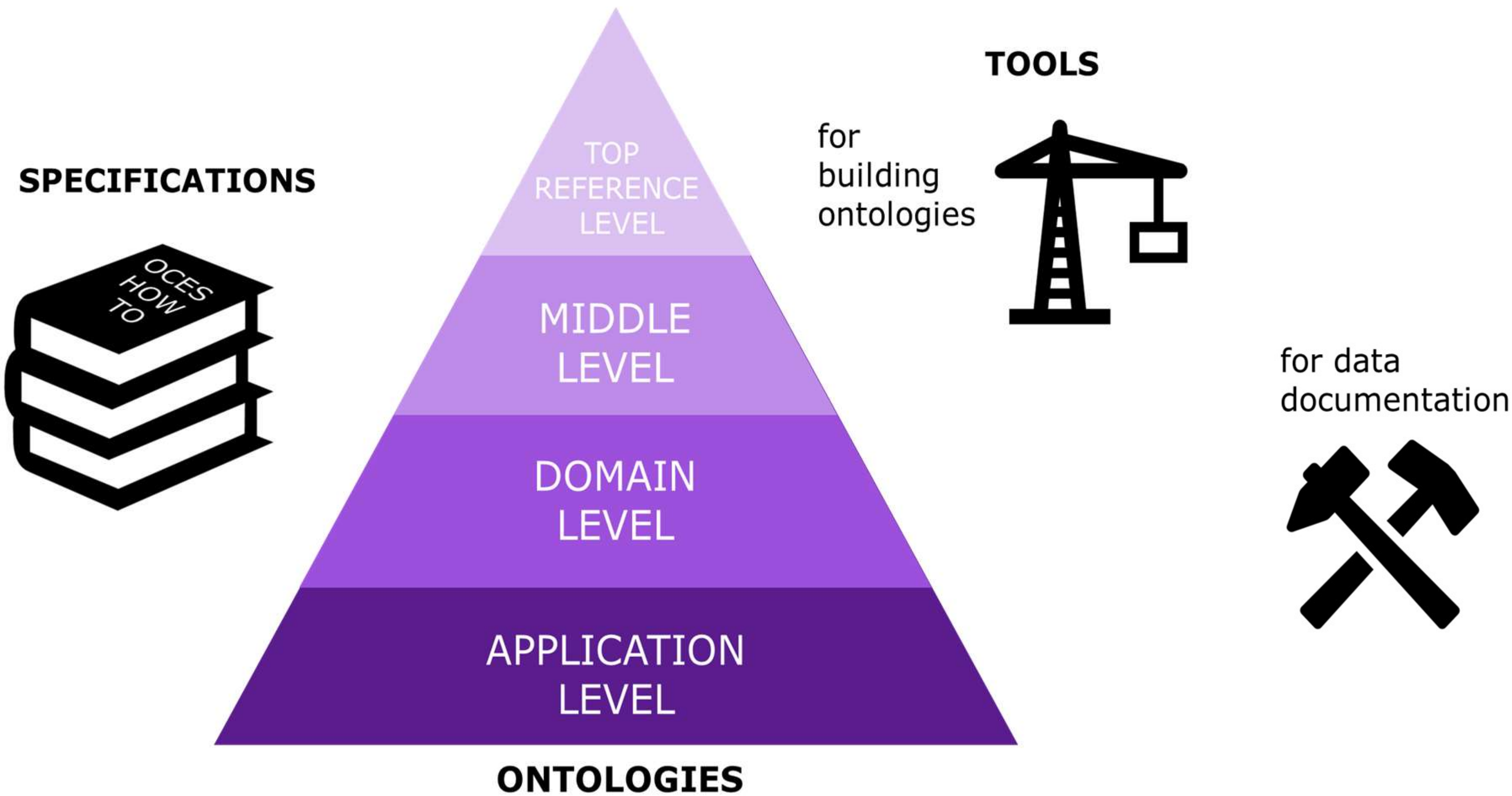
https://www.industrialontologies.org/

- aiming to create a set of open ontologies to support the manufacturing and engineering industry needs and advance data interoperability
- involves government, industry, academic and standards organizations

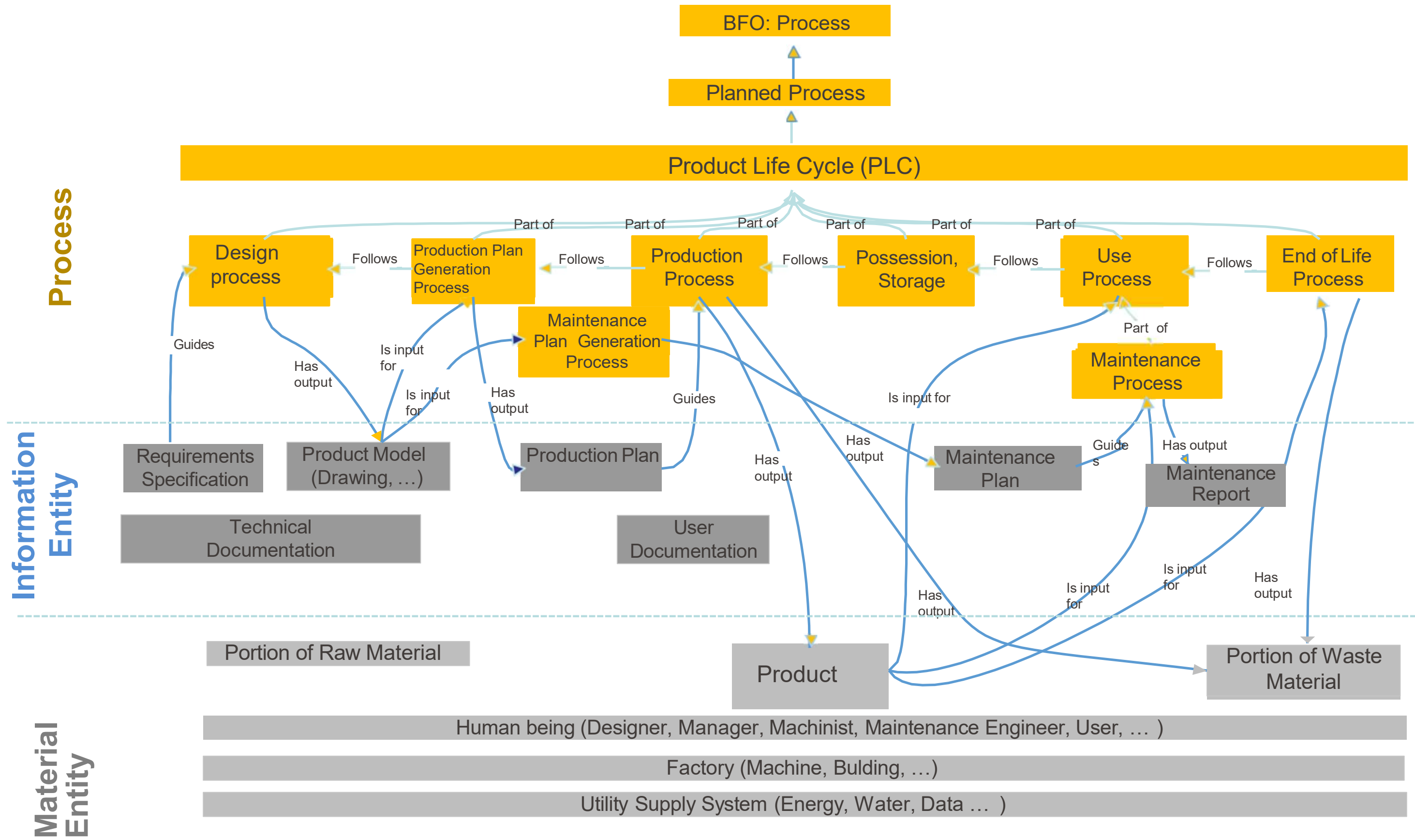


Ontology – OntoCommons EcoSystem

https://ontocommons.eu/

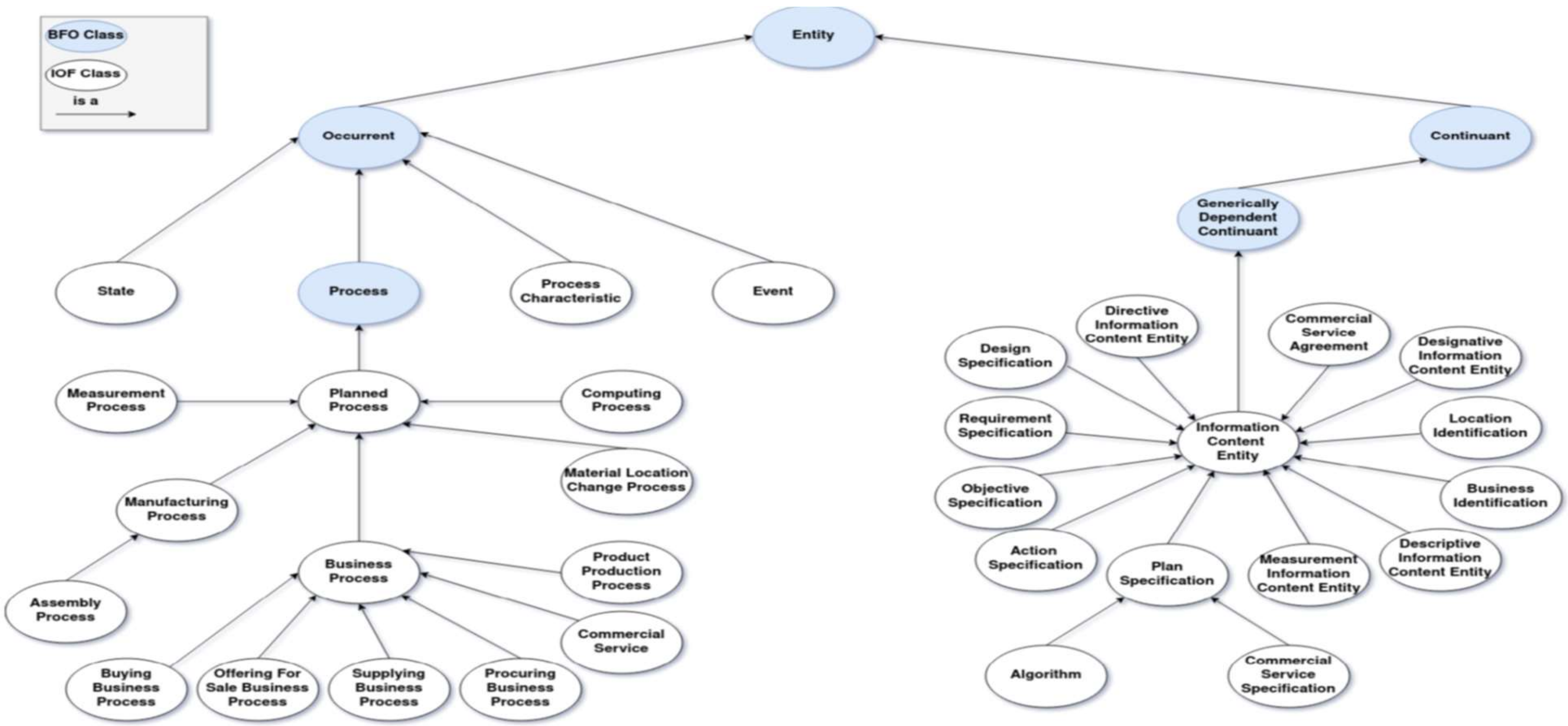


Sketch of a Product Life Cycle Ontology Framework



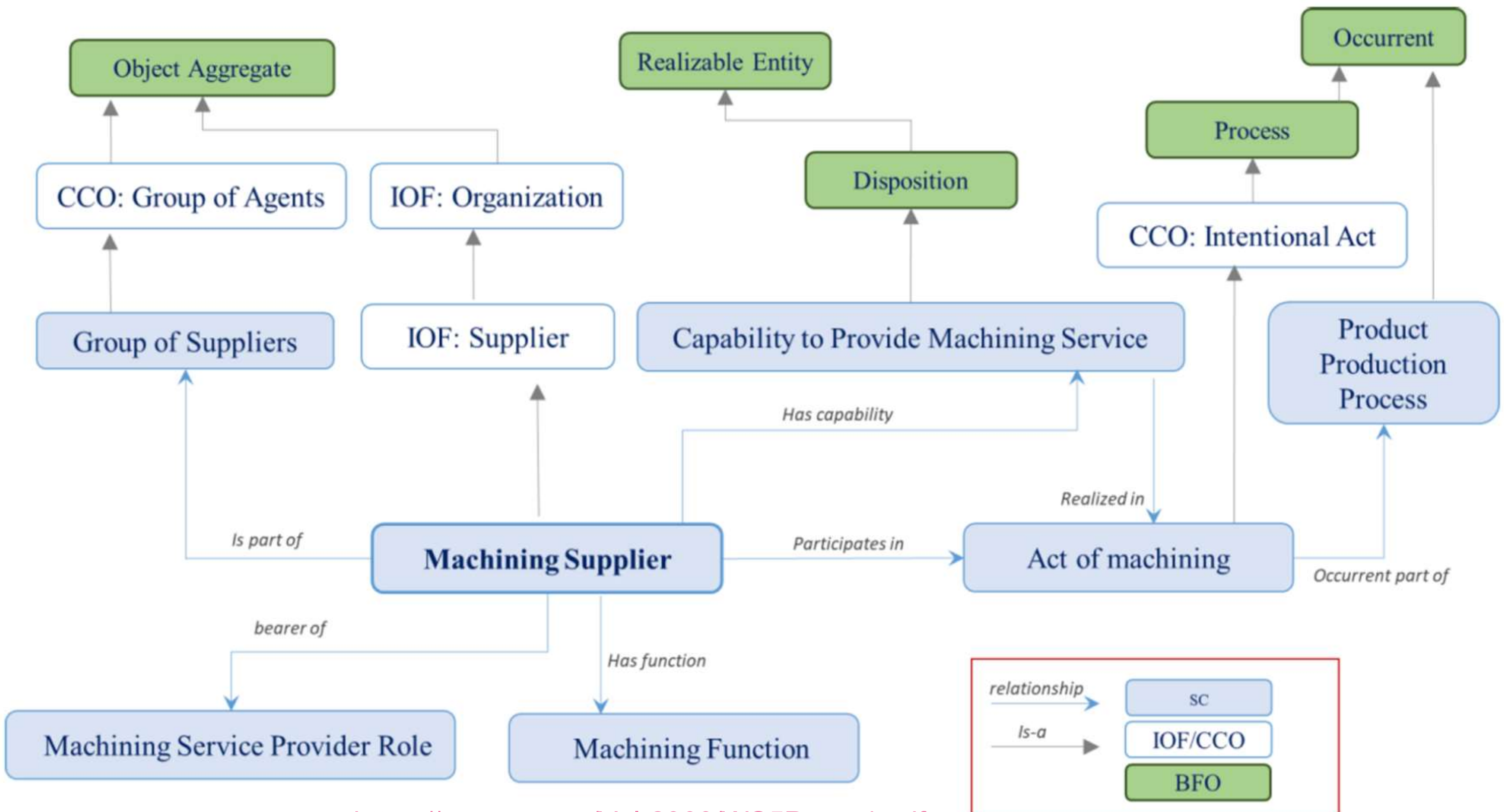
Barry Smith and Dimitris Kiritsis, 2016

IOF Core Ontology



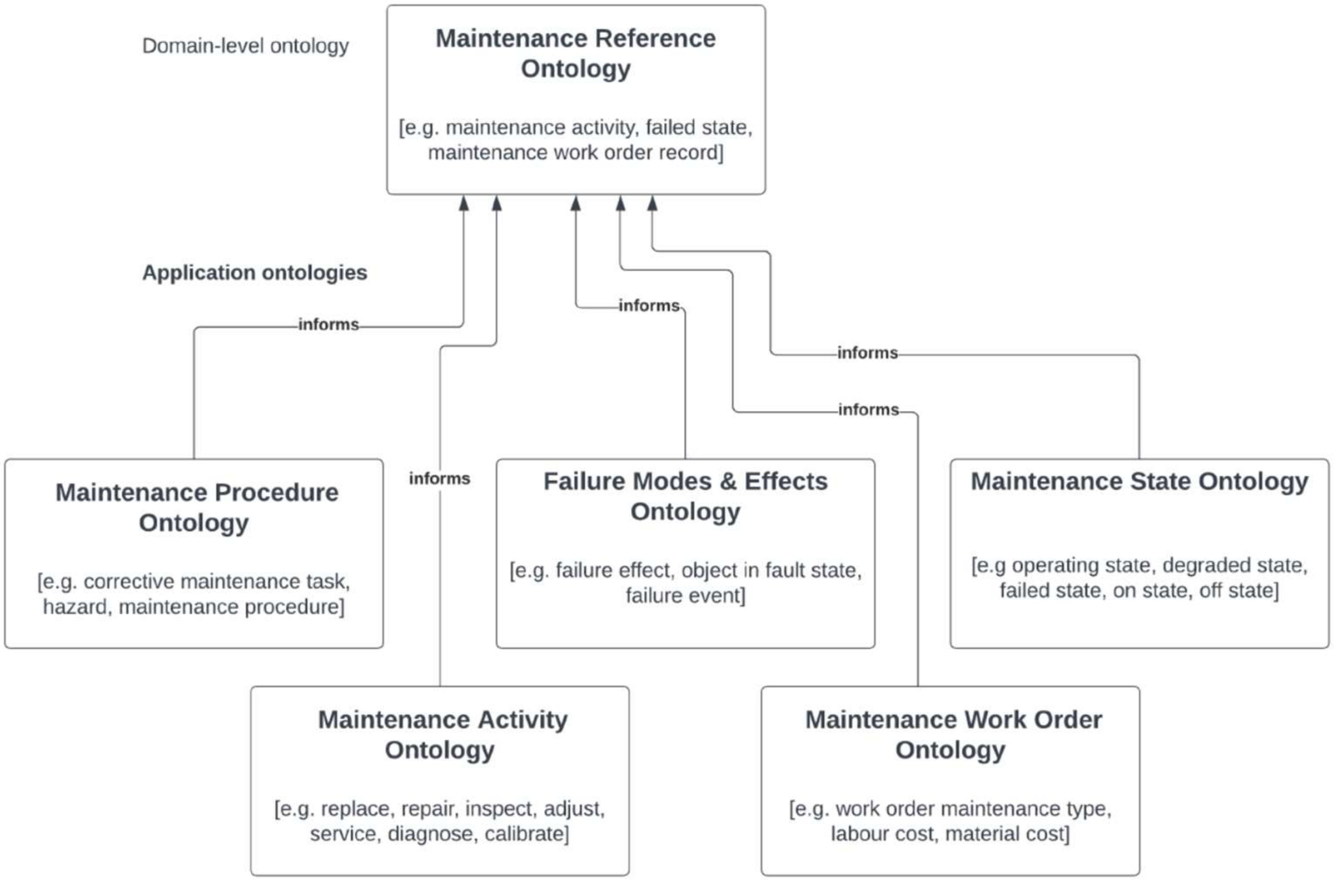
https://ceur-ws.org/Vol-3240/paper3.pdf
https://github.com/iofoundry/ontology/tree/master/core

IOF Supply Chain Ontology



https://ceur-ws.org/Vol-2900/WS5Paper4.pdf
https://github.com/iofoundry/ontology/tree/master/supplychain

IOF Maintenance Ontology



https://github.com/iofoundry/ontology/tree/master/maintenance

Agenda

- Role of Data in Circular Economy Context
- Semantic Modelling and MBSE
- **Cognitive Digital Twin concept**
- Application case of Airbus
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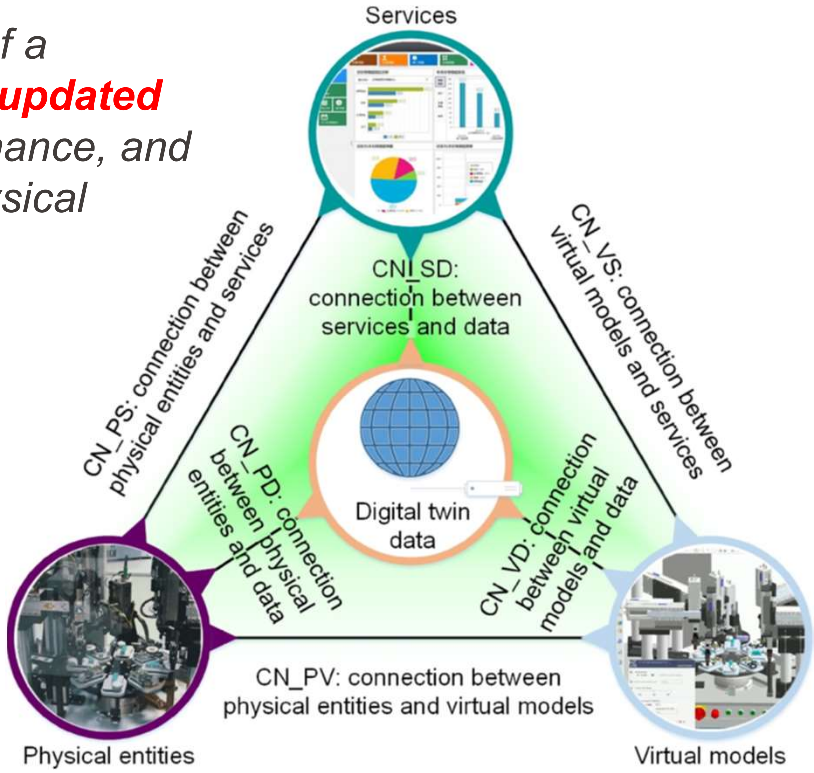
Digital Twin - Concept

- *"A Digital Twin is a **virtual instance** of a **physical system** that is **continually updated** with the latter's performance, maintenance, and health status **data** throughout the physical system's life cycle."*[*a]

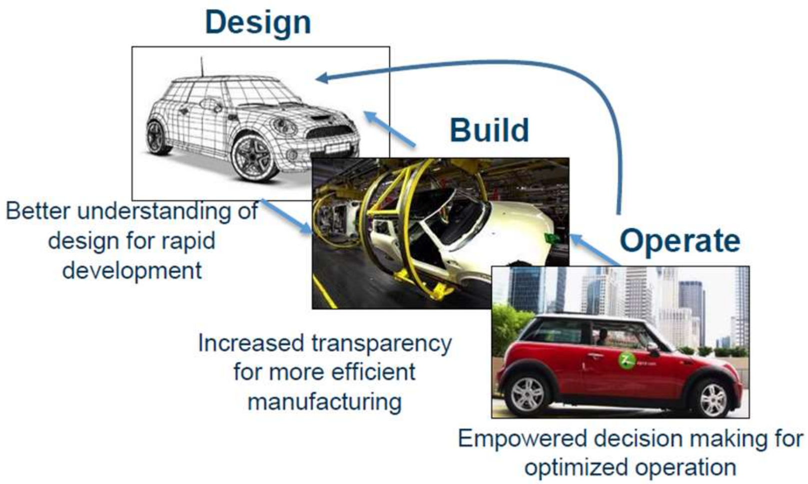
- Key elements:
  - Physical entities
  - Virtual instances
  - DT data
  - Services
  - Connections



Five-dimension digital twin model [*b]

[*a] *Madni et.al., Leveraging digital twin technology in model-based systems engineering, Systems, 2019*
[*b] *Qi et.al., Enabling technologies and tools for digital twin, Journal of Manufacturing Systems, 2019*

Digital Twin and its Challenges



- High complexity of modern industrial systems
- Heterogeneous DT models corresponding to
  - related systems, subsystems and components
  - different lifecycle phases
  - different stakeholders, protocols and standards
- Lack of unified platform for integrating all relevant DT models

- *Madni et.al., Leveraging digital twin technology in model-based systems engineering, Systems, 2019*
- *Fariz Saracevic, IBM, Cognitive Digital Twin, Bosnia Agile Day 2017*
- *https://www.nytimes.com/2017/05/03/magazine/a-look-inside-airbuss-epic-assembly-line.html*

UiO

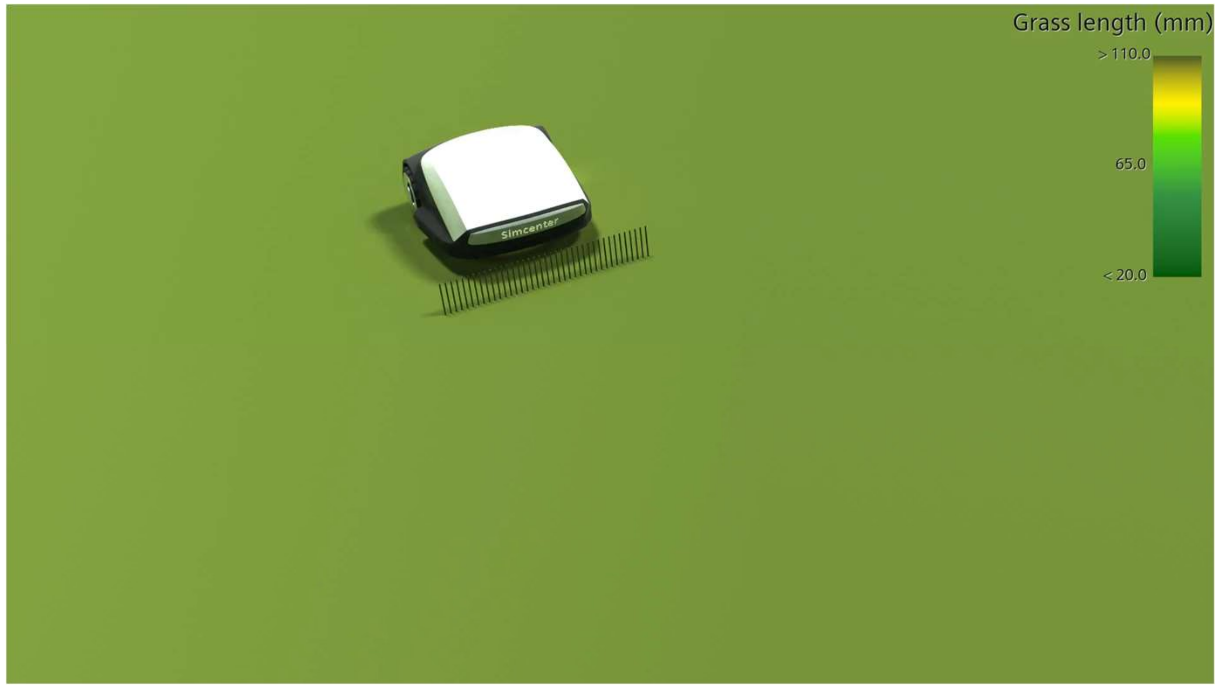
EPFL

Digital Twin for Products

UiO RE4DY MANUFACTURING DATA NETWORKS

https://re4dy.eu/

Design, **simulate**, and verify products digitally, including mechanics and multi-physics, electronics and software management

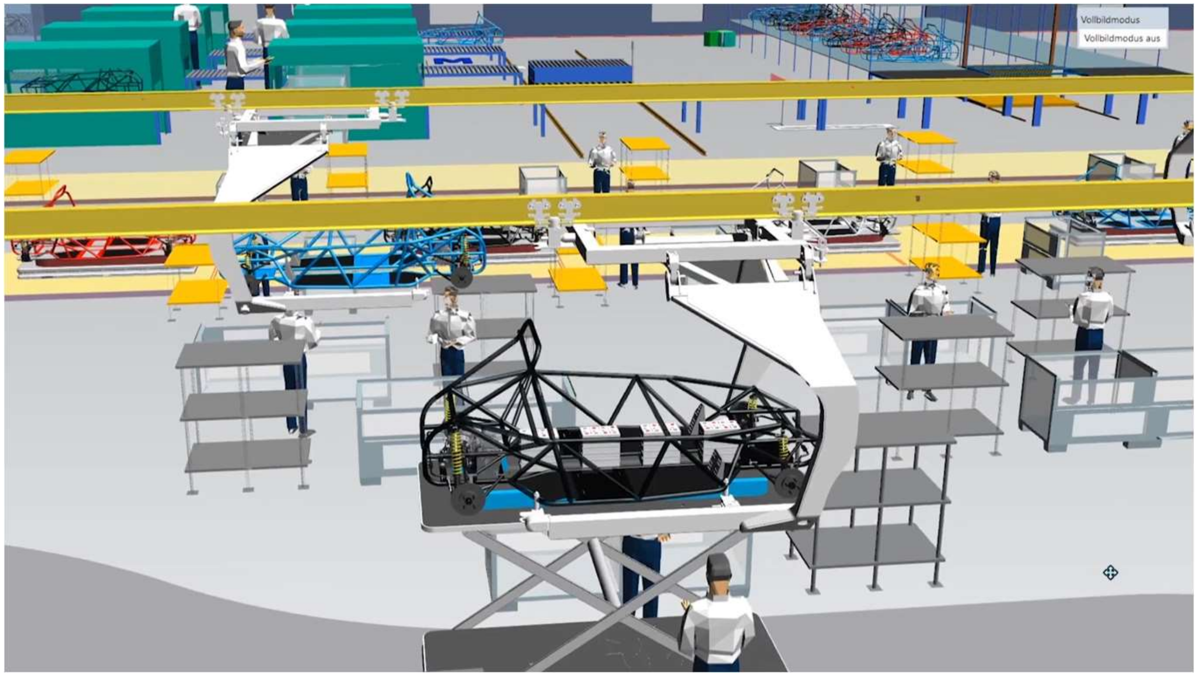


Slide produced by SIEMENS-CH

Digital Twin for Production

https://re4dy.eu/

Plan, simulate, predict and optimize production digitally with PLC code generation and virtual commissioning



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UiO

EPFL

Digital Twin for Performance

UiO

RE4DY

MANUFACTURING DATA NETWORKS

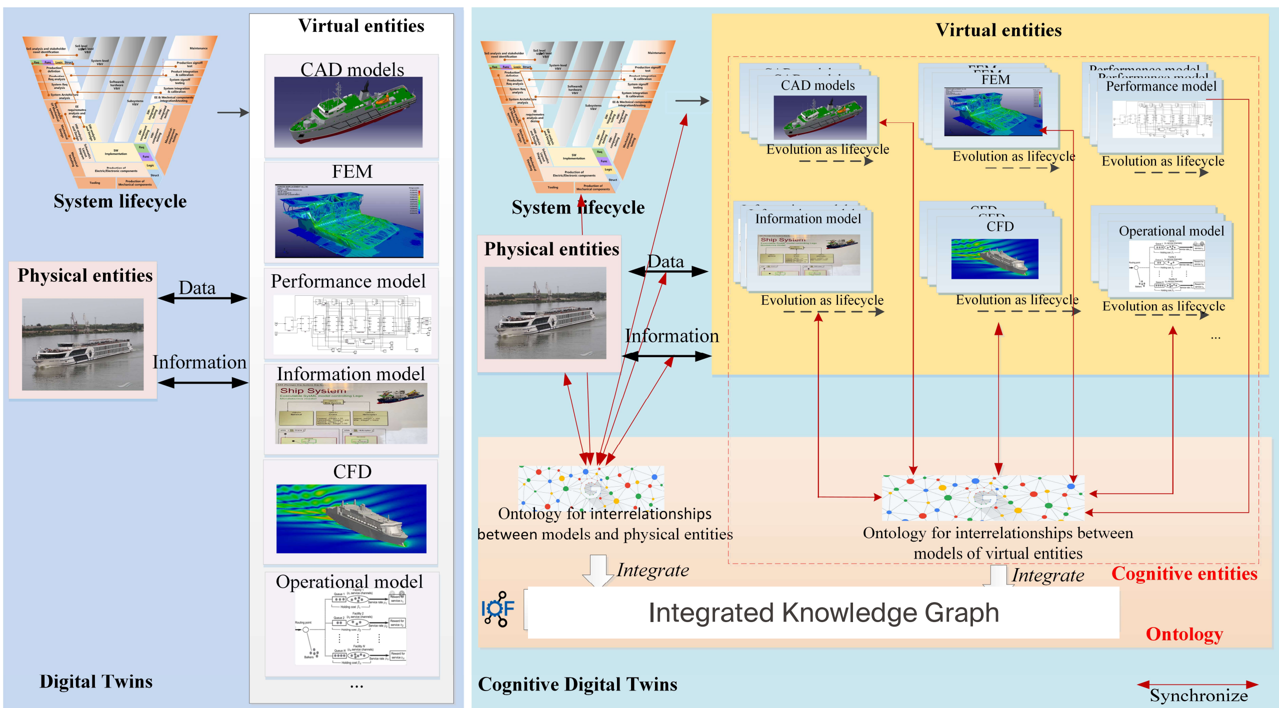
https://re4dy.eu/

Run production efficiently and securely with Totally Integrated Automation. Continuously optimize with data insights.

Slide produced by SIEMENS-CH

Cognitive Digital Twin

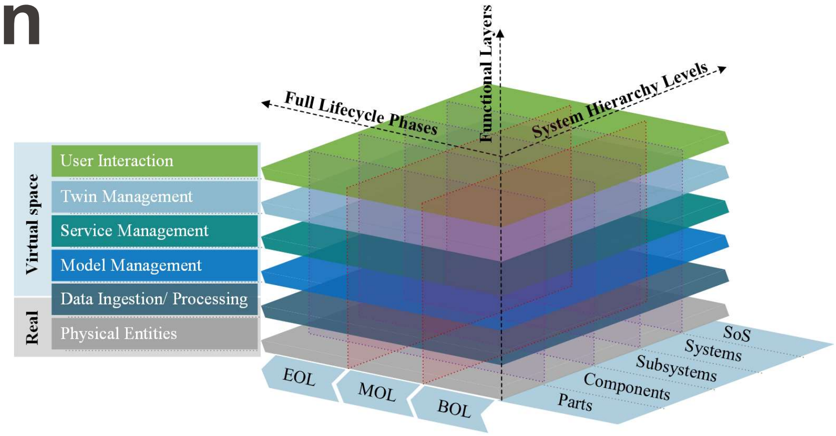
- Cognitive Digital Twin: a digital representation of a physical system augmented with **cognitive capabilities** and enables **autonomous activities**; comprises **semantically interlinked digital models** related to **different lifecycle phases**; **continuously evolves** with the physical system across the entire lifecycle.

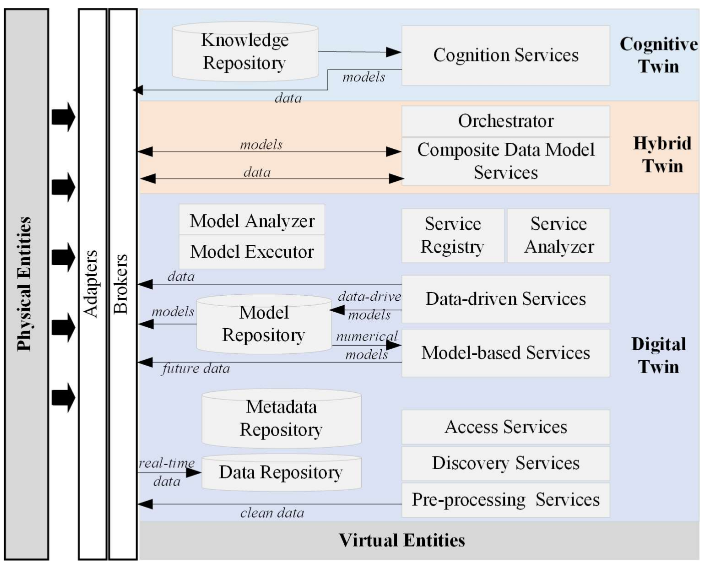


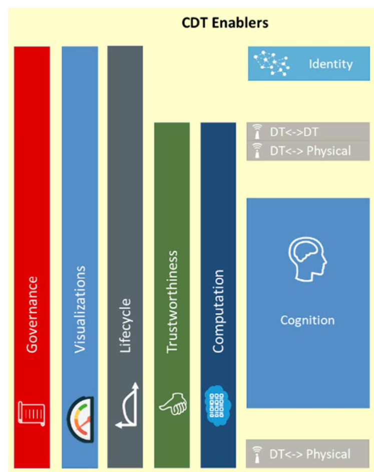
https://www.tandfonline.com/doi/full/10.1080/00207543.2021.2014591

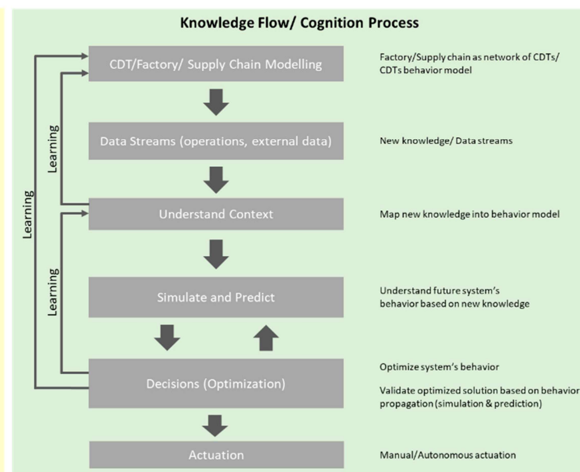
Cognitive Digital Twin

- **Reference Architecture**
  - Full lifecycle phases
  - System Hierarchy levels
  - Functional layers







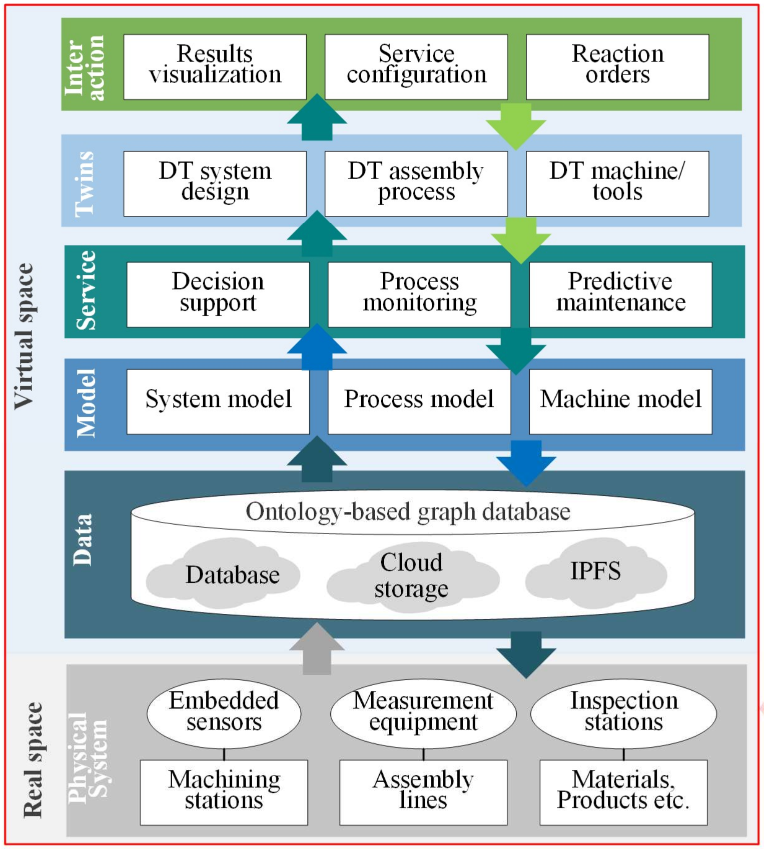


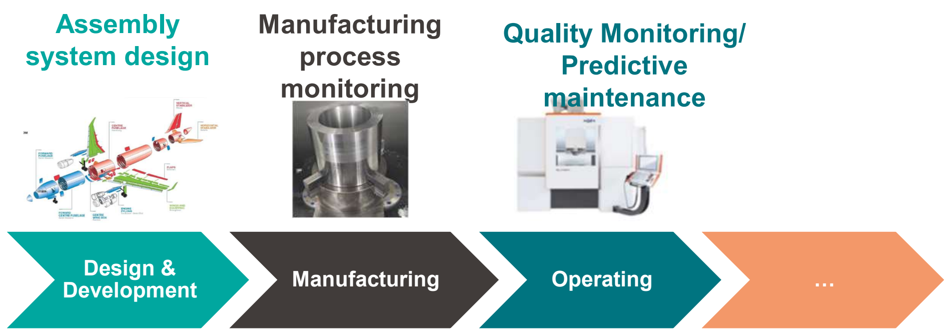
▪ Capturing the Meaning of Industrial Data

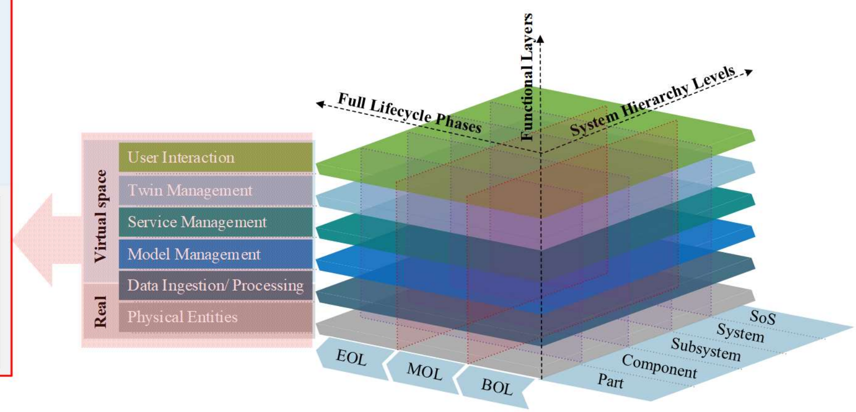
*a Abburu et.al. "COGNITWIN-Hybrid and Cognitive Digital Twins for the Process Industry. 2020
*b Kalaboukas et.al. Implementation of Cognitive Digital Twins in Connected and Agile Supply Networks—An Operational Model. Appl. Sci. 2021, 11, 4103

Application cases

- Multiple lifecycle phases:







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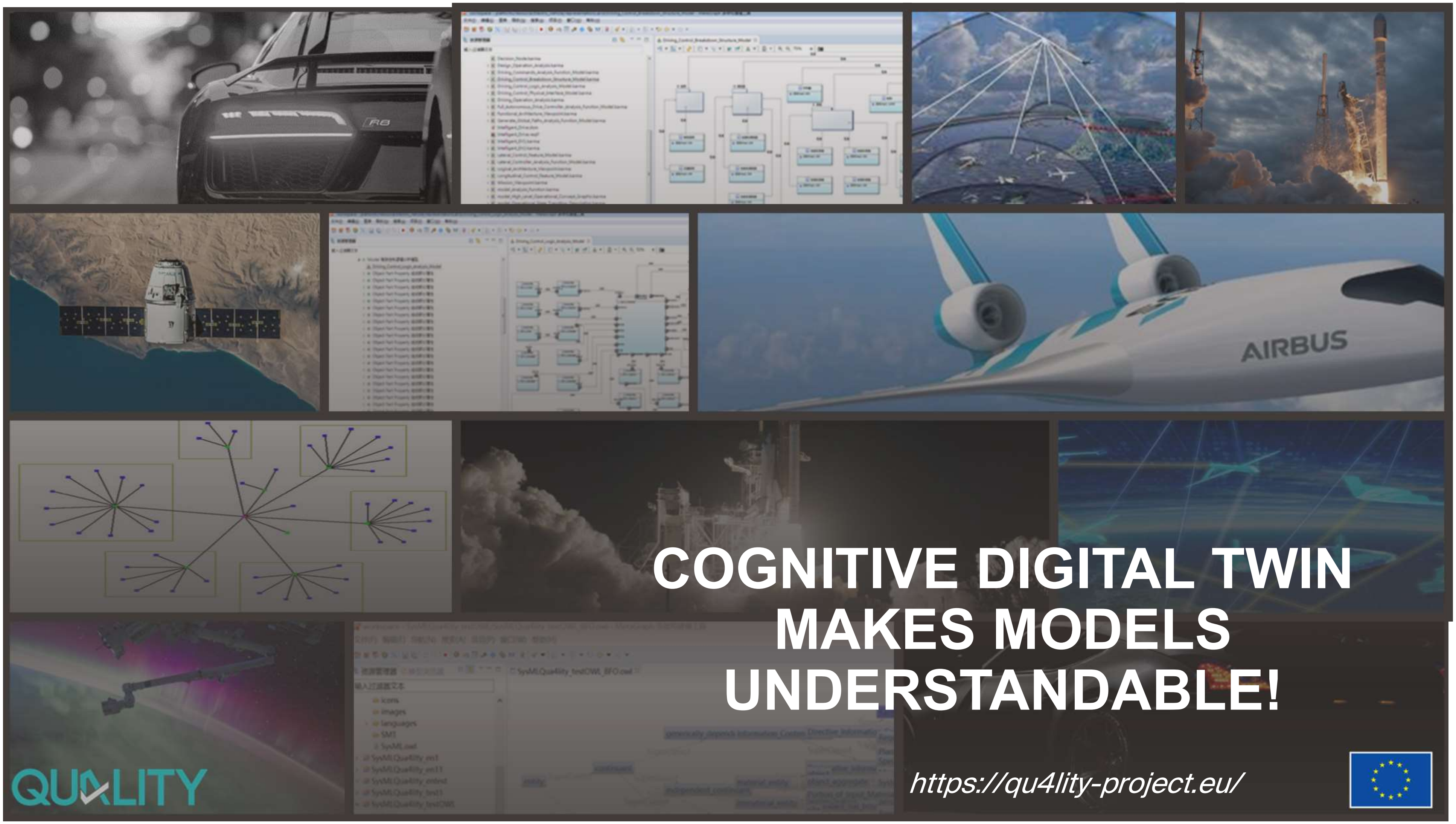
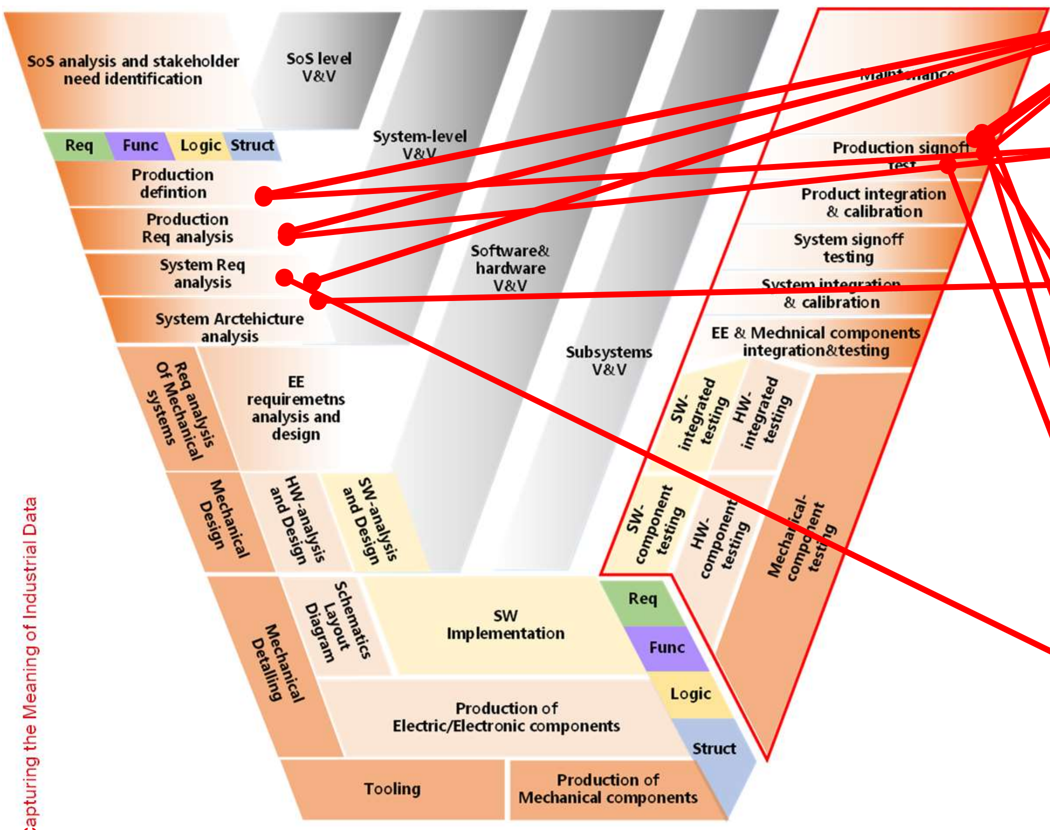

COGNITIVE DIGITAL TWIN
MAKES MODELS
UNDERSTANDABLE!
https://qu4lity-project.eu/
AIRBUS
QU4LITY

DDMS Supporting System lifecycle in AIRBUS



AUTHORITATIVE SOURCE of TRUTH
Ontology is used to represent assembly processes and their virtual models across lifecycle.

REQUIREMENTS
Requirements define the needs of the end users of industrial systems.

ARCHITECTURE
Semantic MBSE is used to implement MOFLP approach for assembly based on ontology.

2D SIMULATION
Discrete event simulation is used for assembly process performance evaluation.

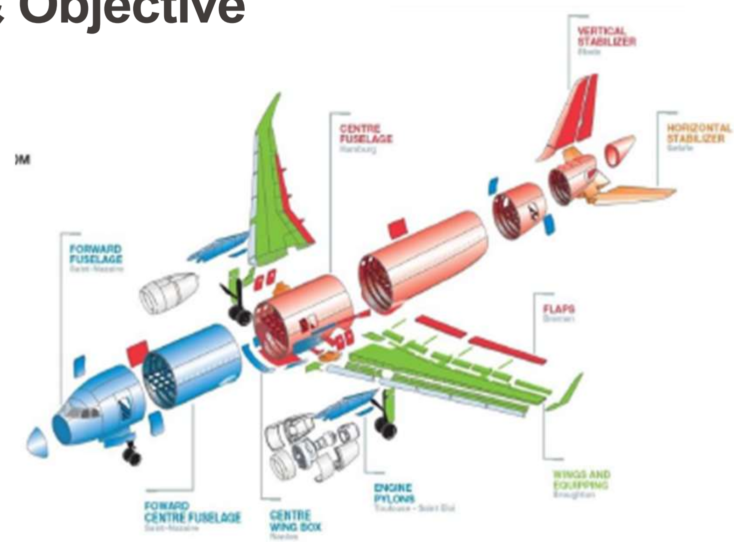
3D SIMULATION
3D factory simulation to verify, validate and optimize manufacturing alternatives.

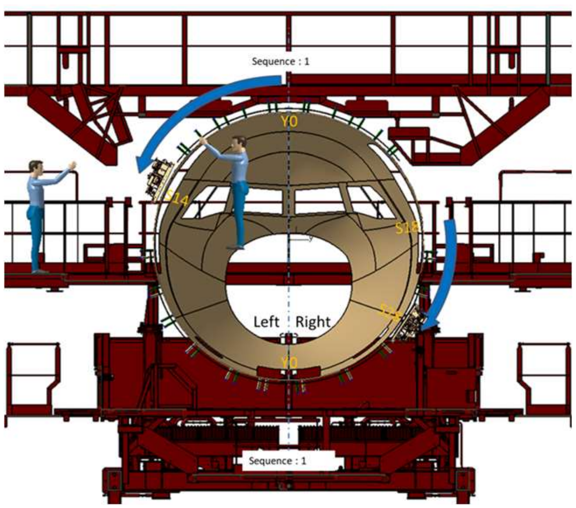
TRADE OFF
Automatic requirement verification is implemented based on the ontology centric trade off.

DDMS: Digital Design, Manufacturing & Services

QU4LITY Airbus Pilot - Context & Objective

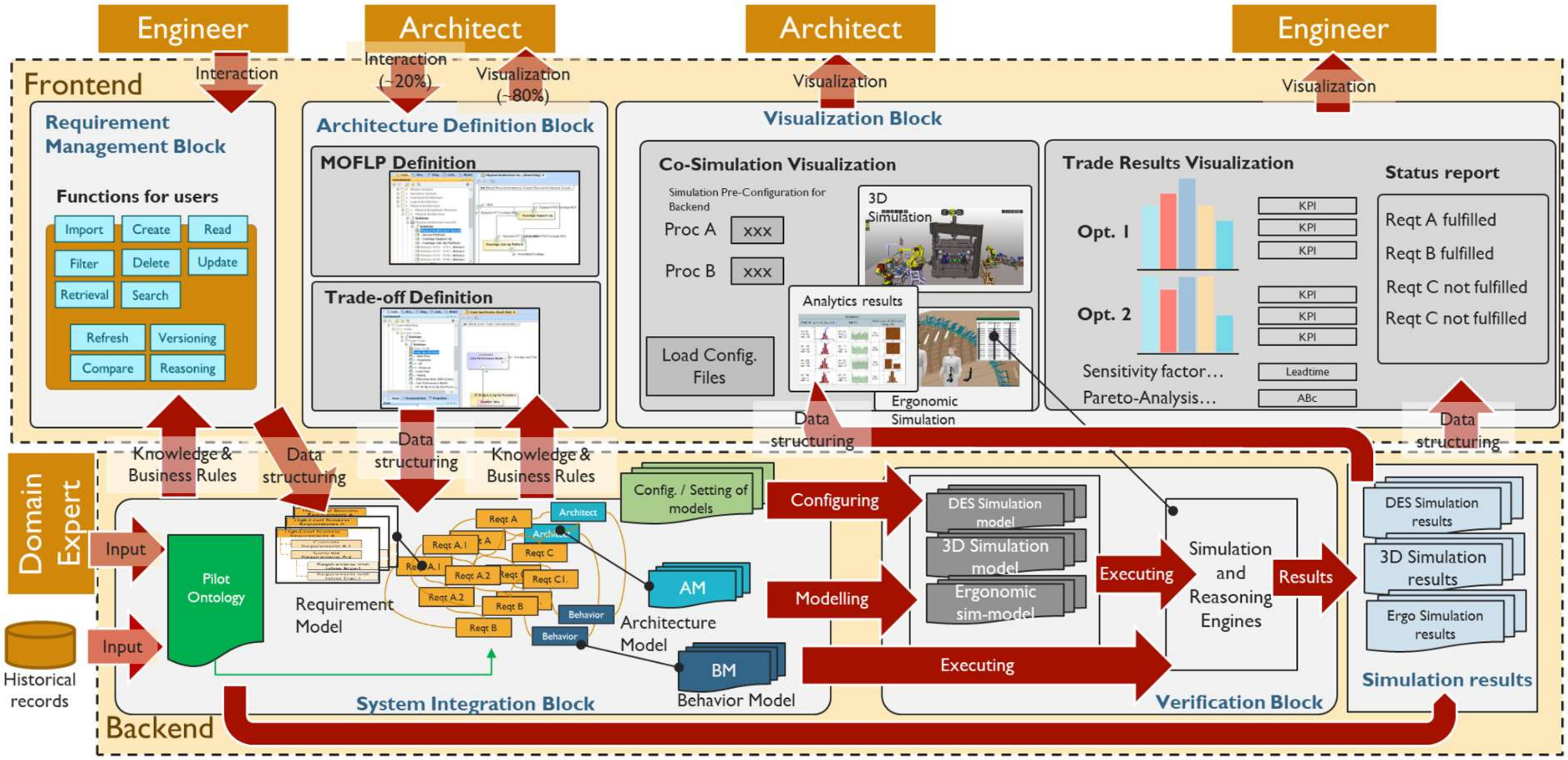
- Enable an **MBSE** and **collaborative design** process between the **Aircraft** and **Industrial System** domains.
- Overcome bottlenecks concerning **knowledge management**, **interoperability** and **decision making** in the design process.





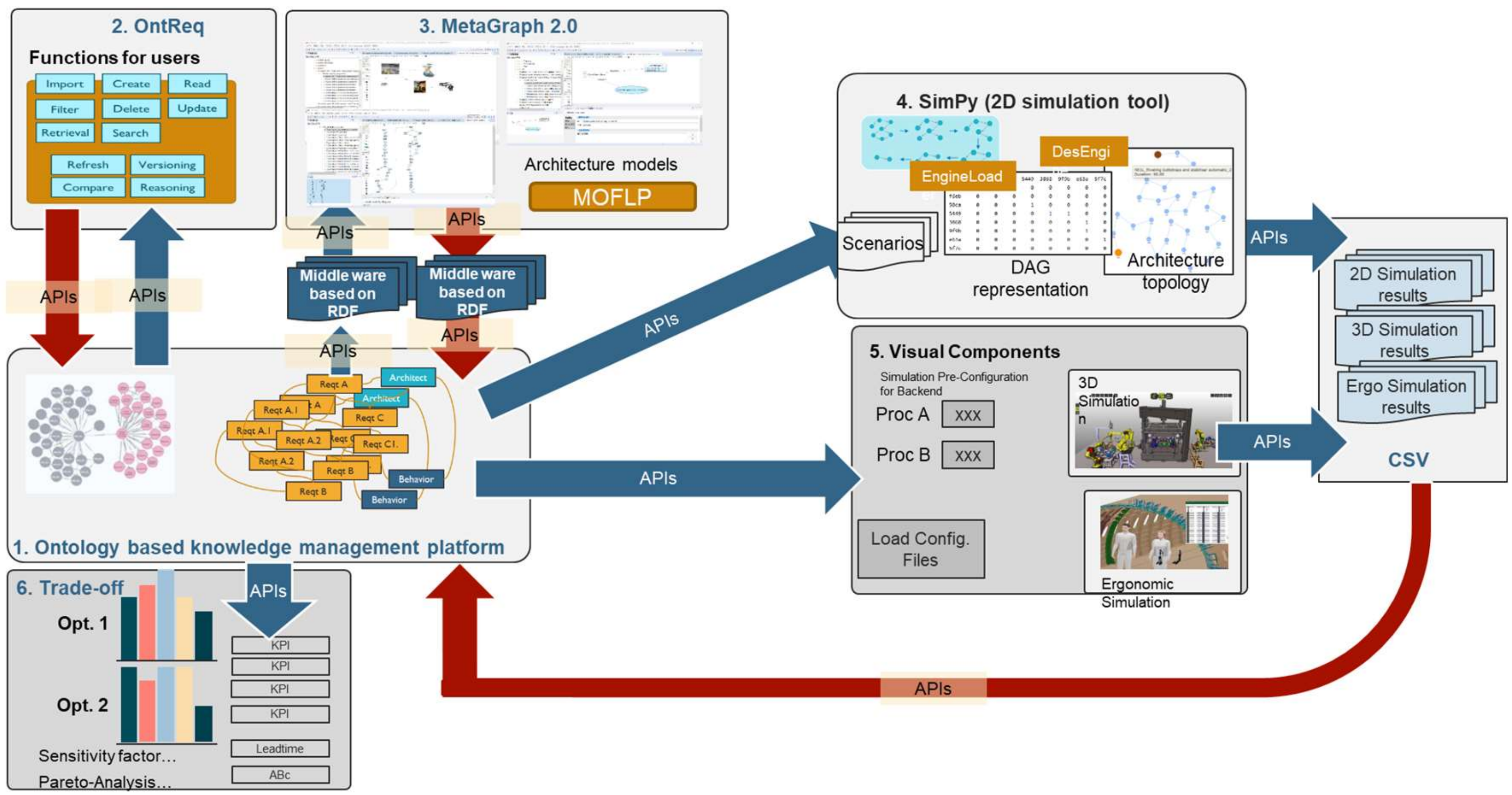
- Use Case: the design process of the Aircraft fuselage Orbital Joint Process, in the Final Assembly Line (FAL) to be reconfigured/redesigned for new industrializations
- MVP5 prototype enables Orbital Joint Process trade-off analysis, by generating and simulating all possible design alternatives based on defined requirement targets.

Prototype Functional Architecture

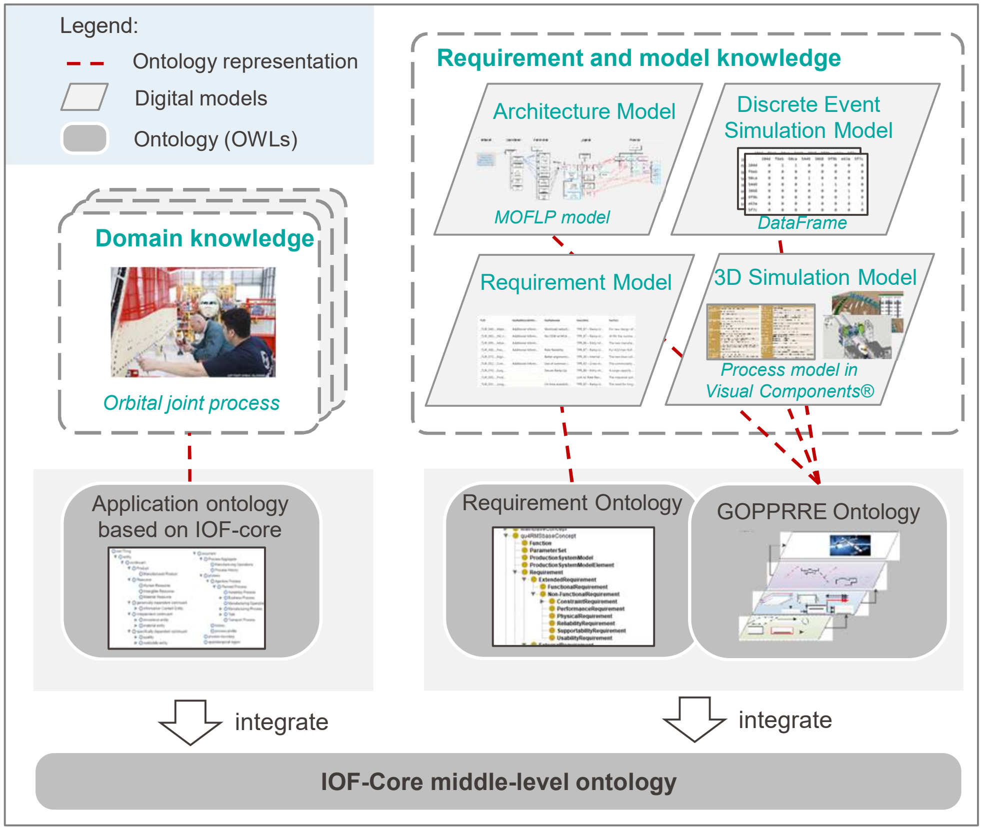


■ Capturing the Meaning of Industrial Data

Tool-chain overview



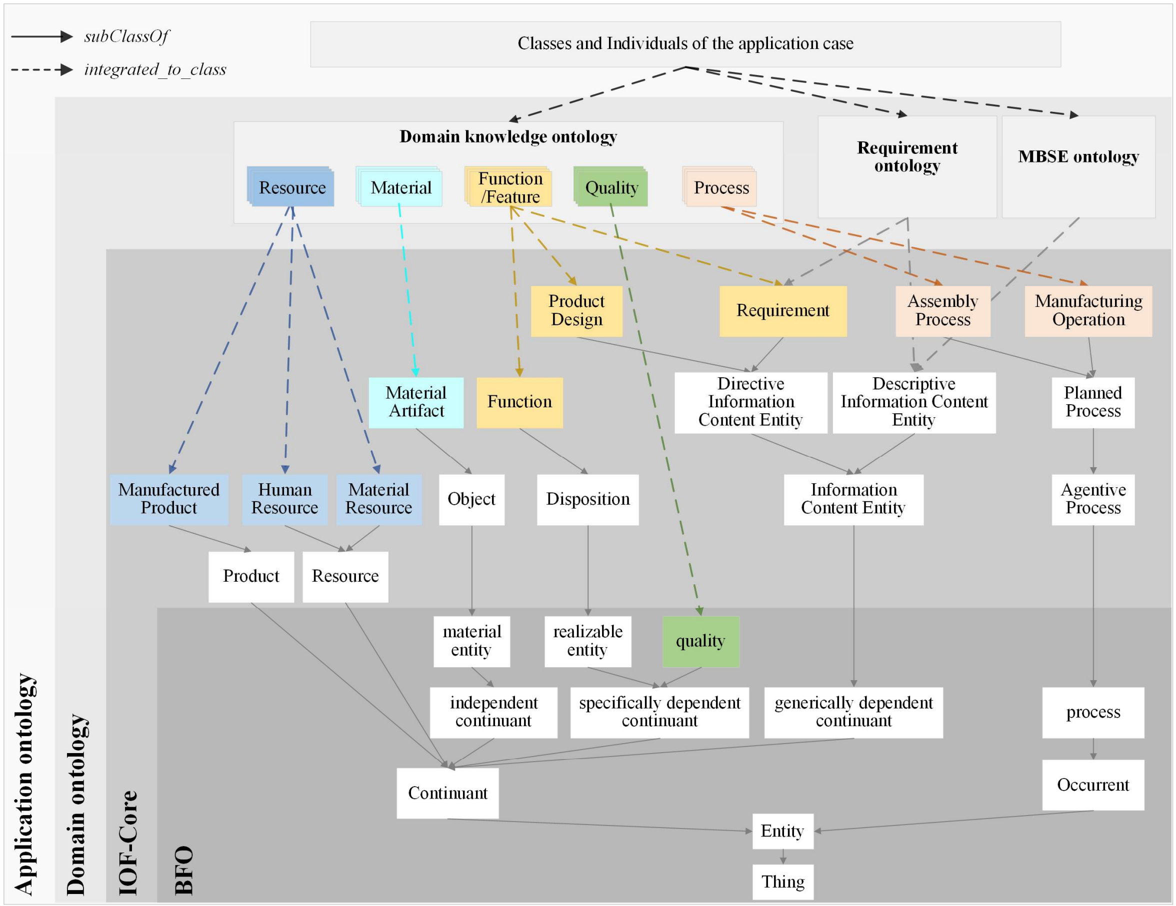
Development of application ontology



- Application ontology is developed to capture domain knowledge, requirement and modelling knowledge.
  - Assembly system application ontology
  - Requirement ontology
  - GOPPRRE ontology (MBSE)
- Three ontologies integrated into the IOF:Core middle level ontology.
- Main knowledge sources:
  - Documented knowledge
  - Expert knowledge

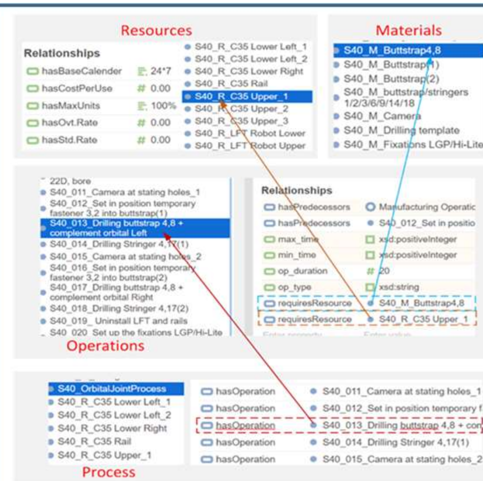
Development of application ontology

- **Application Ontology**
  - Hierarchical strategy
  - Based on IOF Core & BFO



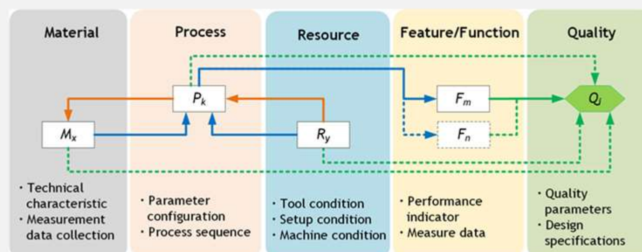
Development of application ontology

- **Application Ontology**
  - Main knowledge sources:



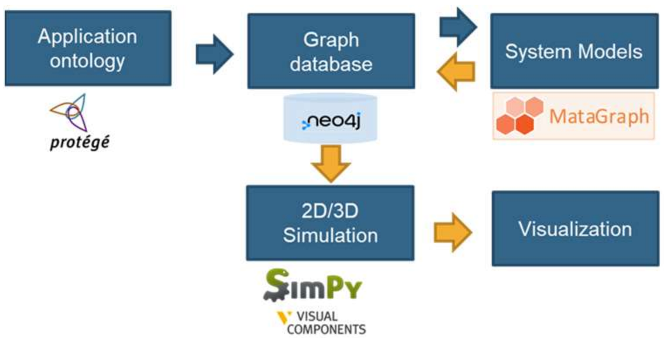
Task Name	Duration	Predecessors	Resource Names
: Drilling Stringer 4,17(2)	50 mins	18	C35 Upper_1
: Deinstall LFT and rails	15 mins	19,31	C35 Upper_1, LFT
: Set up the fixations LGP/Hi-Lite on buttstrap/stringers 1/2/3/6/9/14/18 Left	90 mins	20	C35 Upper_1
: Finalize remaining serial & part of stringers on 1+1 Left	90 mins	21	C35 Upper_1
: Riveting buttstraps and stabiliser L1/2/3/6/9/14/18 Left	75 mins	22	C35 Upper_1
: Inspection L2 C35 Upper INT	15 mins	23	C35 Upper_1
: Load P265 DMT/Fixing the buttstraps L4-5,7-8,10-12,13 Left	95 mins	24FS+10 mins	C35 Upper_1
: S1 2D>18G	35 mins	4	LFT Robot Upper
: S2 2G>18G	35 mins	26	LFT Robot Upper
: S3 20G>1G	15 mins	11	LFT Robot Upper
: S4 20G>1G	80 mins	28	LFT Robot Upper
: S6 20G>1G	15 mins	29	LFT Robot Upper
: S7 20G>1G	80 mins	30	LFT Robot Upper

Knowledge source 1:
Historical Orbital Joint Process specifications.

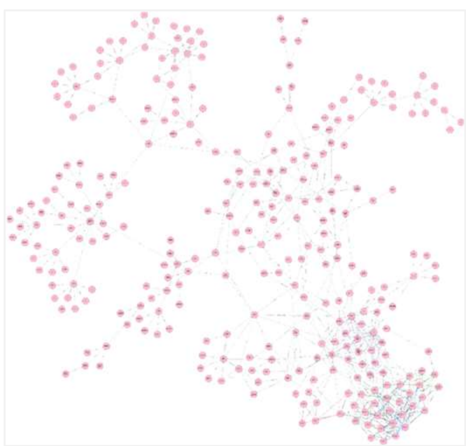


Knowledge source 2:
Domain experts' knowledge.

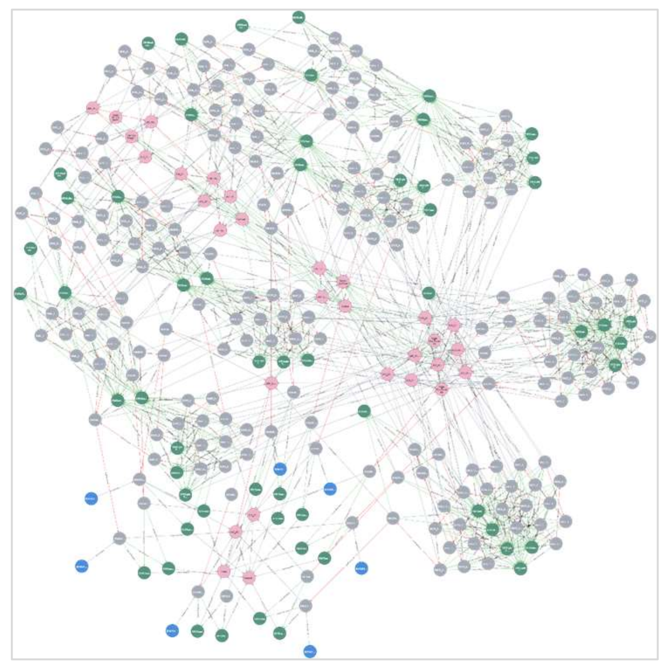
Ontology-based architecture design



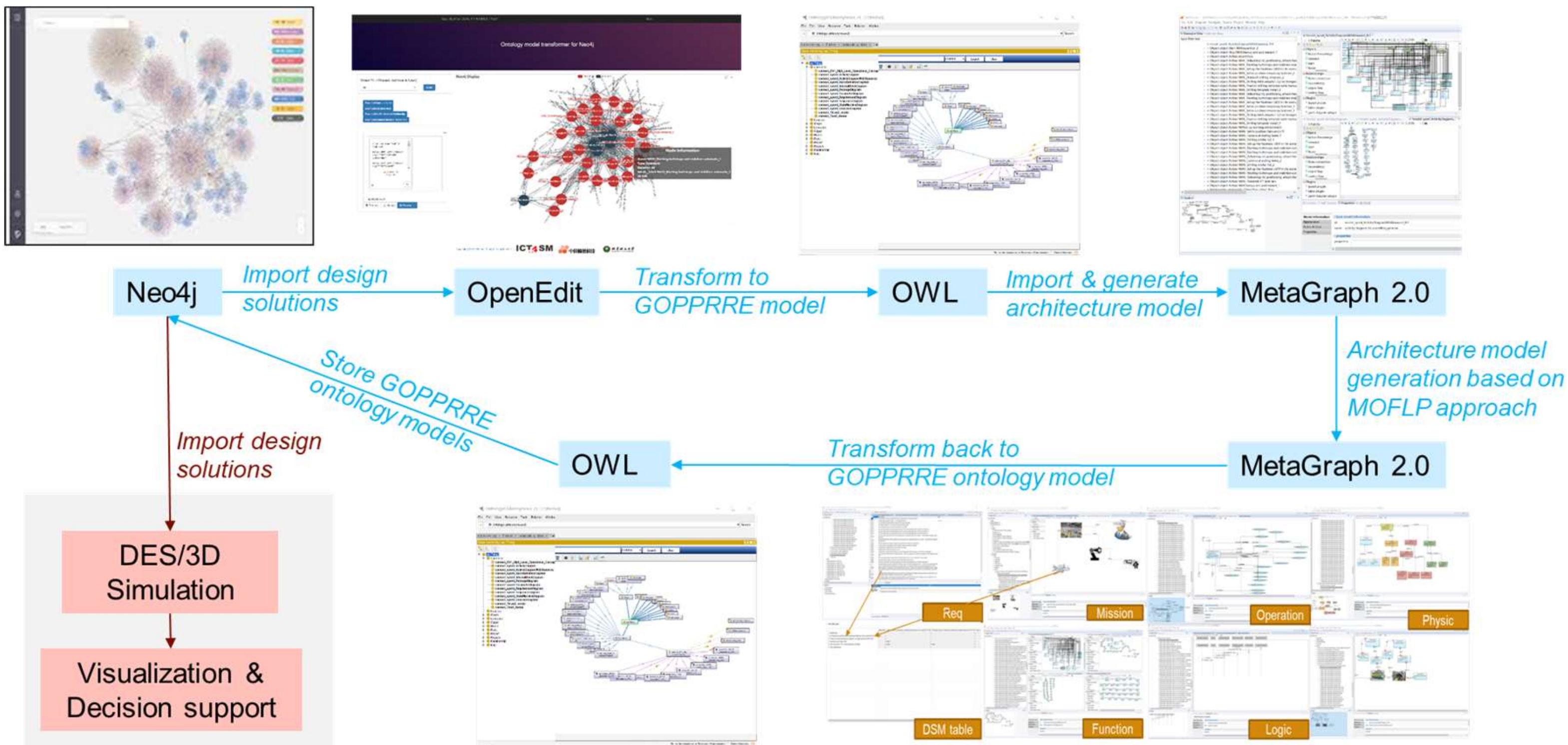
- Application ontology imported to graph database **neo4j** to create knowledge graph.
  - neo4j + Azure Cloud service
- Knowledge graph serves as the integrated knowledge hub to connect all function blocks.



automatically generate new solutions

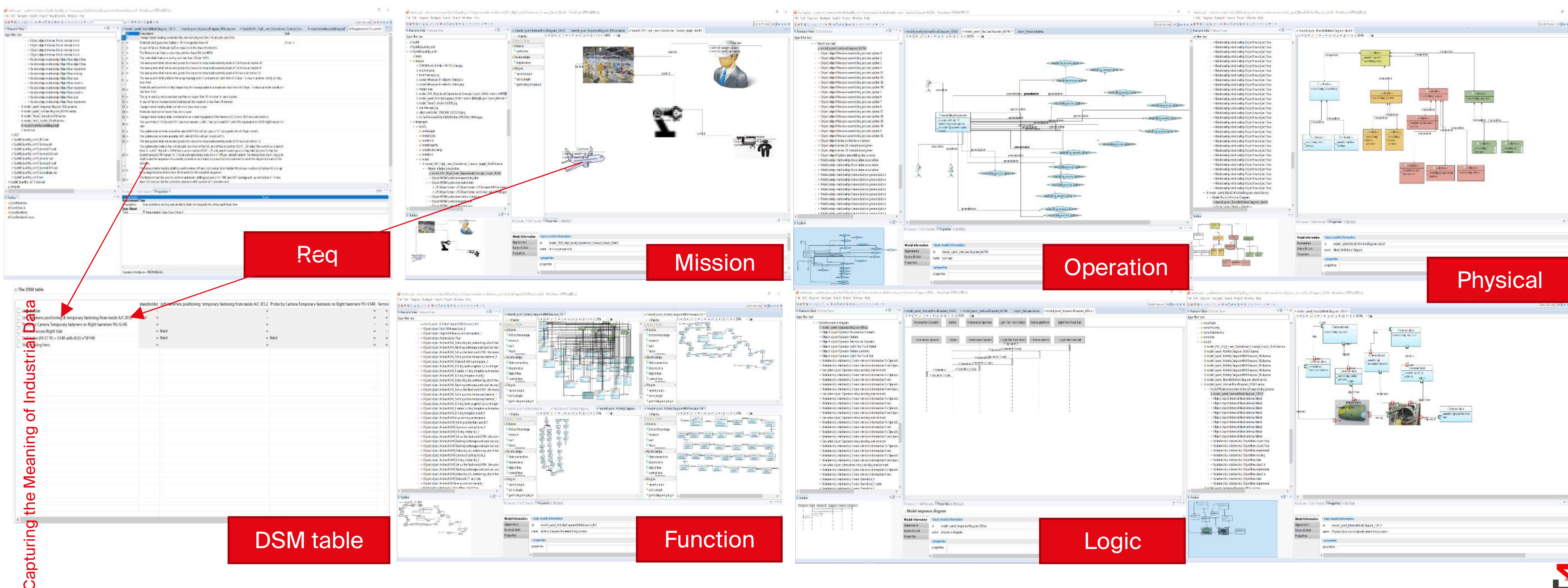


Transformation between modelling languages & methods



Ontology-based architecture design

- Architecture modeling with **MetaGraph 2.0**
  - Develop Architecture models based on a MOFLP approach
    - **MOFLP**: Mission, Operation, Function, Logic, Physical structure



- DSM: Design Structure Matrix

UiO EPFL

The QU4LITY AIRBUS demonstrator

AIRBUS EPFL Fraunhofer VISUAL COMPONENTS

https://youtu.be/kl_Kg-8DOSA

QU4LITY ICT4SM

Trends and Challenges

- **Knowledge Management**
  - Knowledge representation
  - Knowledge acquisition
  - Knowledge update
- **Integration of DT models**
  - Interoperability issues: cross-domain, cross-lifecycle-phases, multiple stakeholders etc.
  - Use of semantic and MBSE technologies as solutions
- **Standardization**
  - Lack of a universal standard
  - Existing options:
    - Platform Industrie 4.0 - Asset Administration Shell (AAS)
    - ETSI Industry Specification Group (ISG) - Next Generation Service Interfaces-Linked Data (NGSI-LD) APIs
    - W3C WoT working group - WoT Thing Description (WoT TD)
    - IMF
    - IDO
    - IOF ontologies
- **Implementations and Applications**
  - Align IMF & CDT in different industrial sectors
  - Verify, evaluate, validate and accelerate IMF & CDT developments

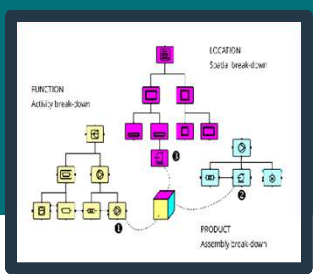
Agenda

- Role of Data in Circular Economy Context
- Semantic Modelling and MBSE
- Cognitive Digital Twin concept
- Application case of Airbus
- **IMF & CDT in new EU projects**

IMF - the Asset Information Modelling Framework

equinor

Aspect based language for modelling of engineering solutions



Modelling methodology:

- Model of model incremental approach
- Preservation of context, then integration
- Systems thinking: breakdown and topology
- Describing systems using aspects
- Reusable patterns using types
- Exploiting resource libraries
- Exploiting ontologies and semantic technology
- Enabling AI powered reasoning

Type language for reusable patterns

Language for mapping to engineering registers

Definition by mapping to ontology

ID management and management of change

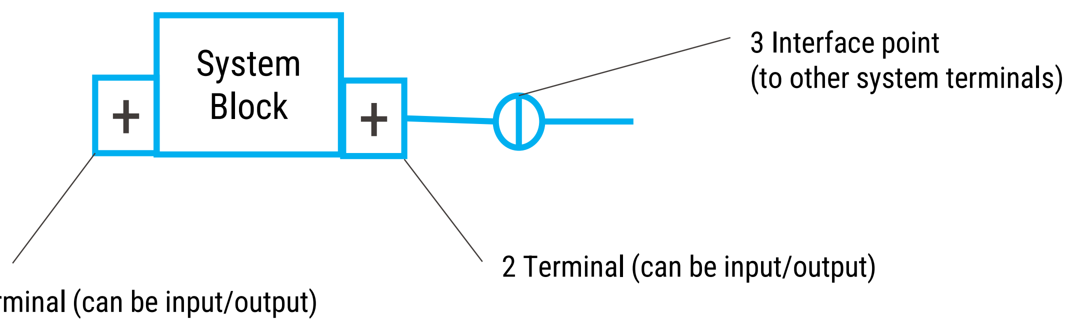
READI — IMF Concept paper	AkerBP, AkerSolutions, UiO, aibel, equinor — IMF Version 2.1	DNV — IMF DNV RP	ISO IEC — IMF ISO/IEC standard
Q1 2021	Q2 2023	Q1 2024	...
Background	As-is	Interim step	Long term objective

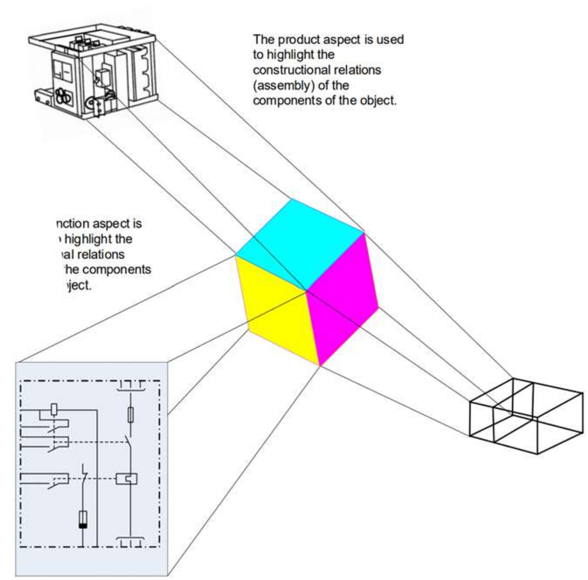
IMF - principles

Aspects: principles of system breakdown

Perspective:

- **Function**: breakdown of activities of a system
- **Product**: breakdown of artifacts of a system
- **Location**: breakdown of spatial extension of a system

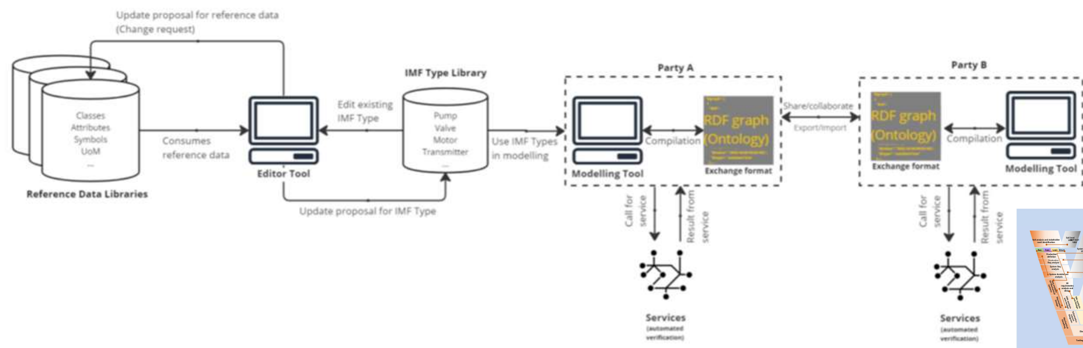




Function Block	Product Block	Location Block

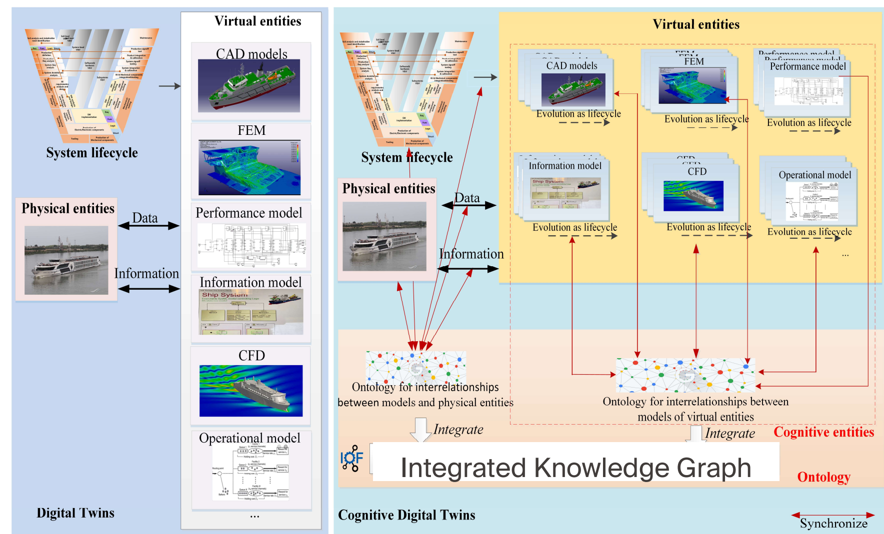
ISO/IEC 81346

Aligning IMF & CDT developments



IMF Eco-System

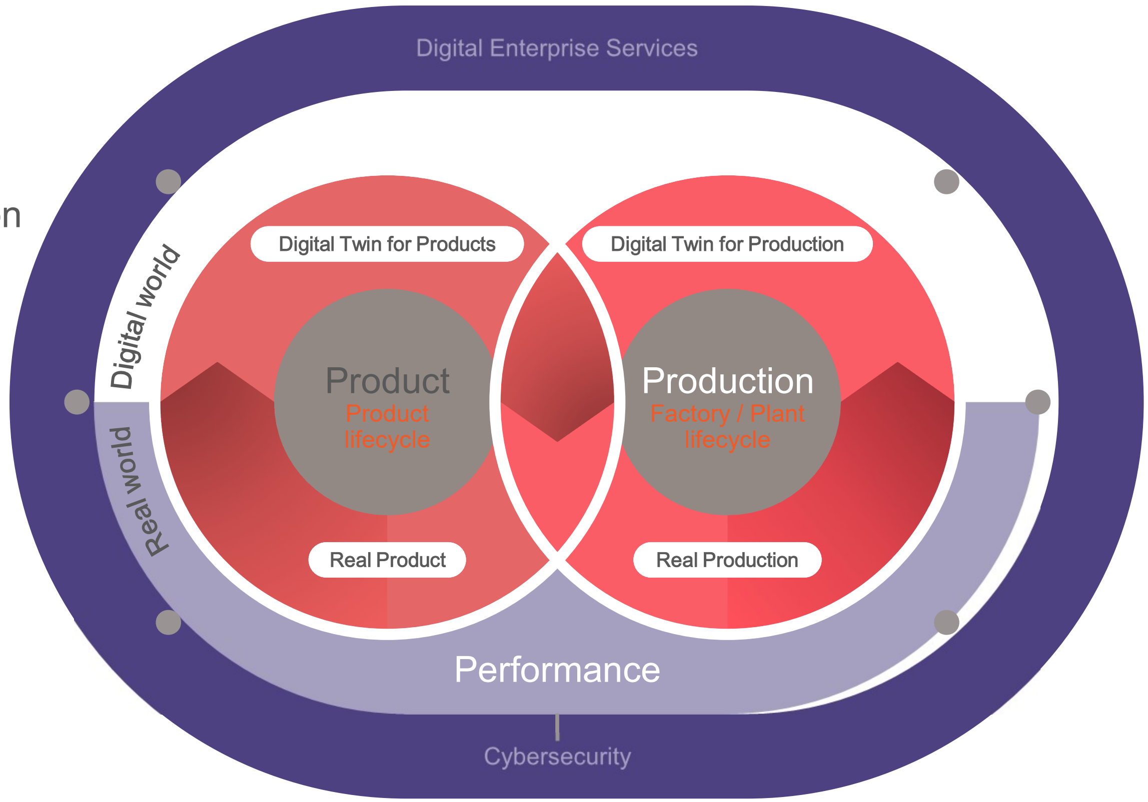
CDT



The RE4DY project

https://re4dy.eu/

The comprehensive Digital Twin approach allows the realistic simulation and validation of products, machines, lines and complete plants



They're the foundation for flexible and efficient manufacturing

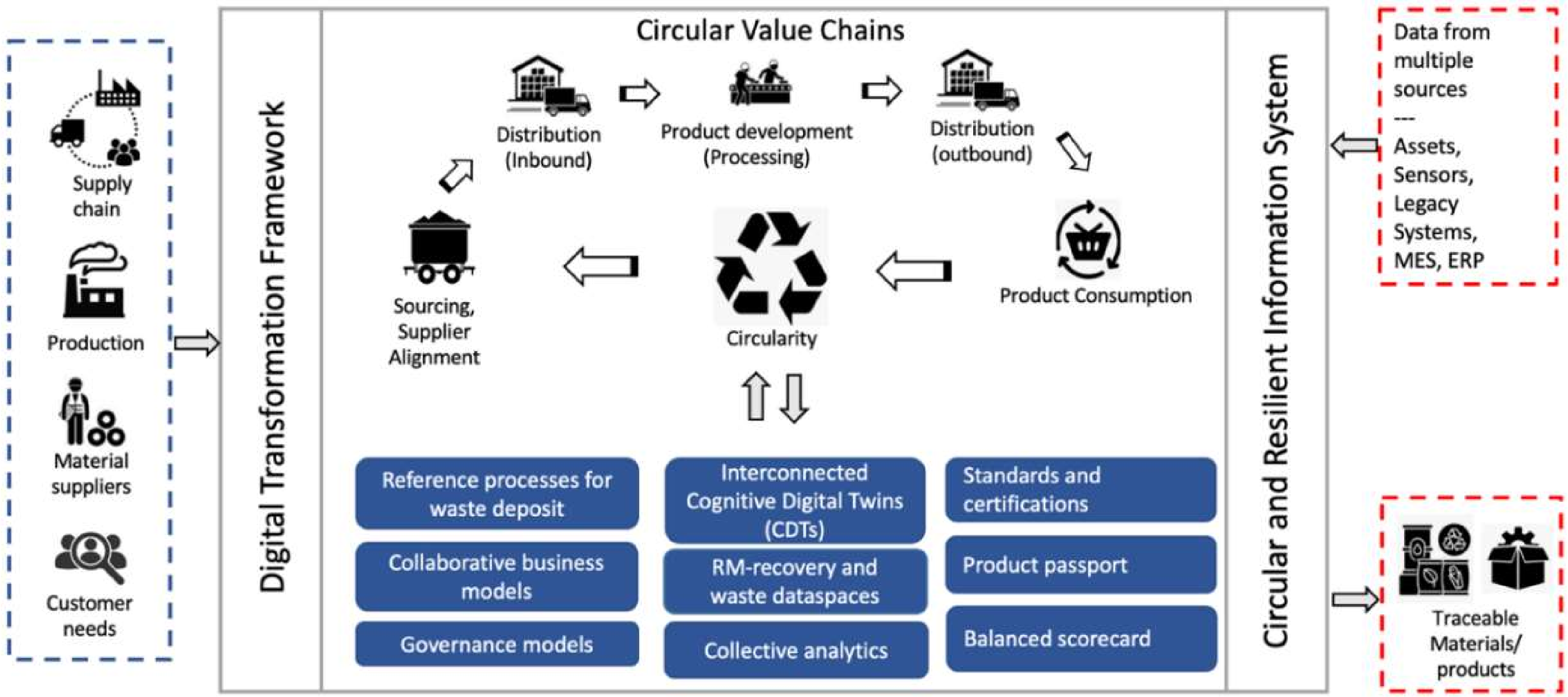
Slide produced by SIEMENS-CH

The Plooto project

Product Passport through Twinning of Circular Value Chains

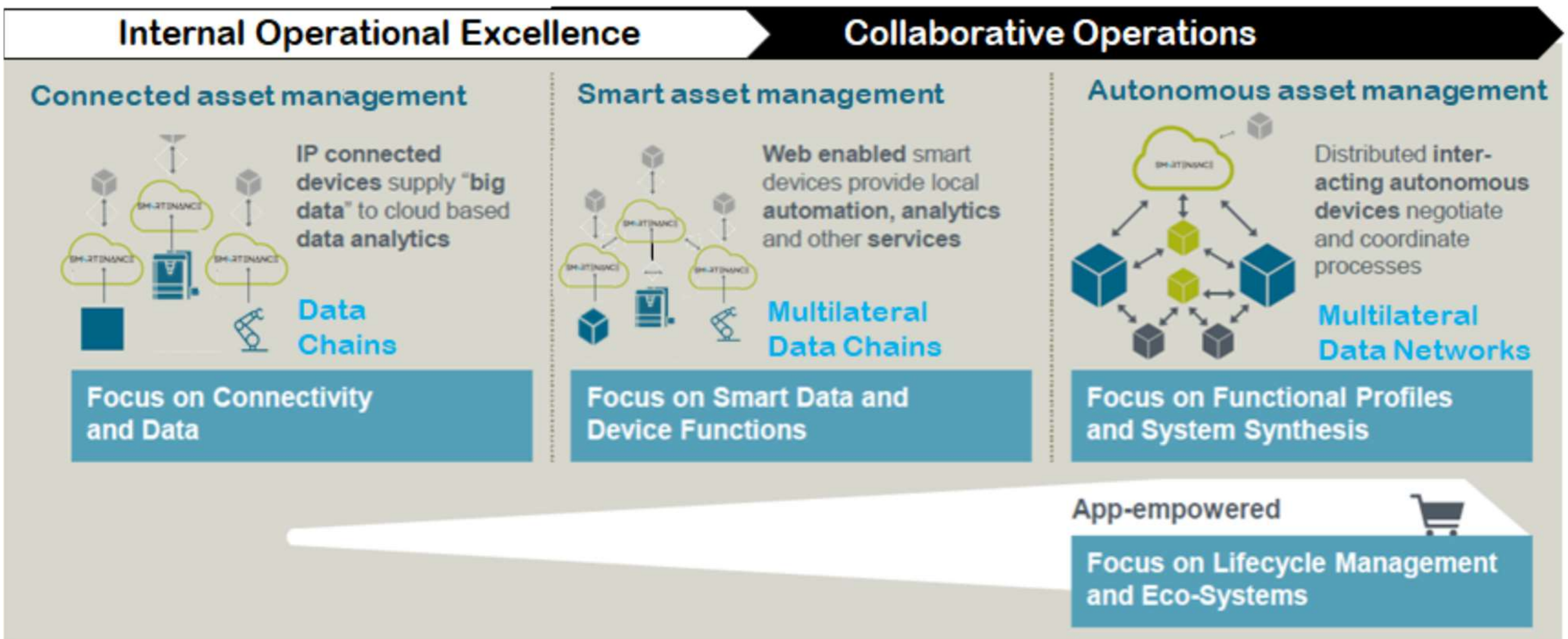
Product Passport through Twinning of Circular Value Chains

https://www.plooto-project.eu/



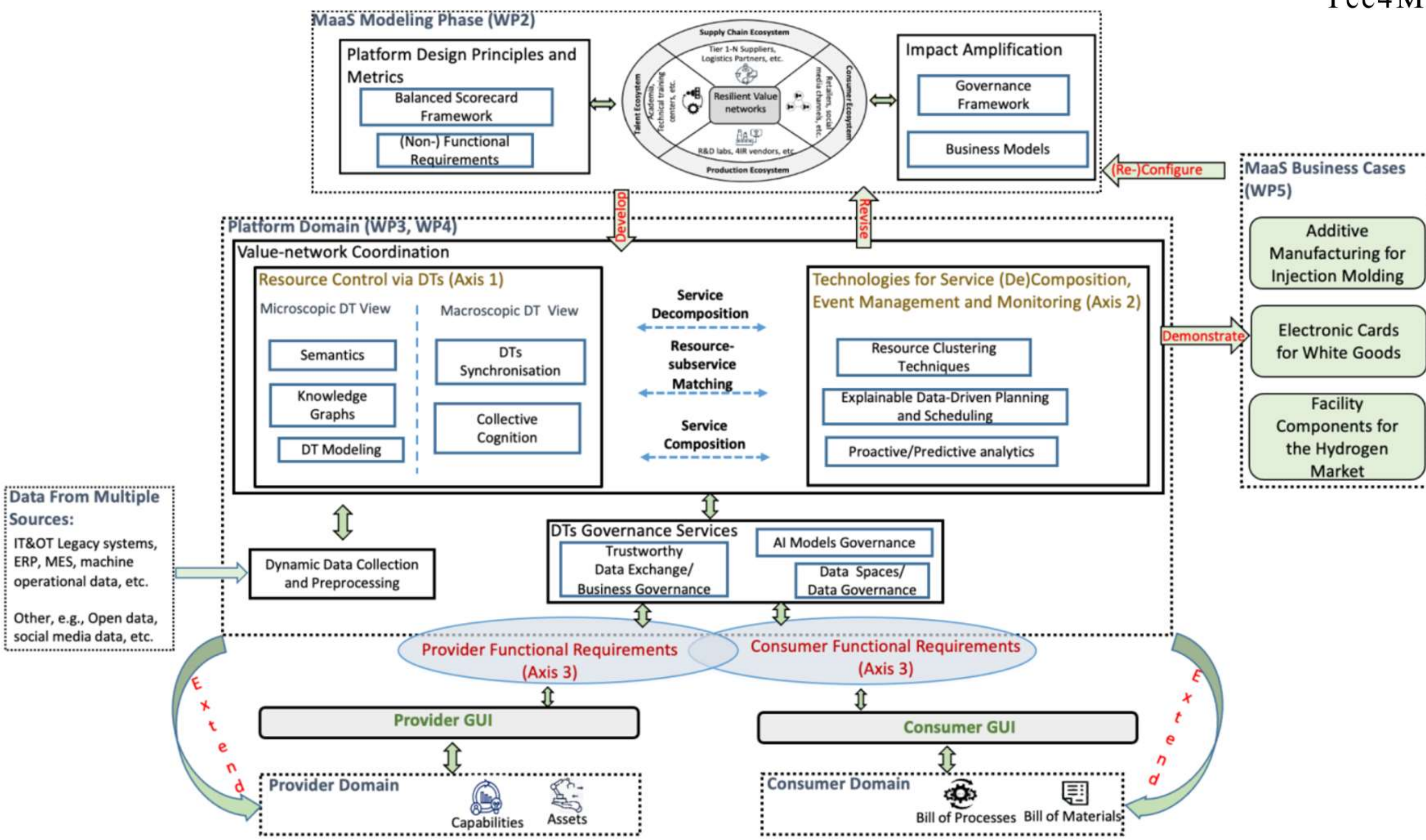
The SM4RTENANCE project

European Deployment of Smart Manufacturing Asset 4.0 MultilateRal DaTa Sharing SpacEs for an AutoNomous Operation of CollAborative MainteNance and Circular SErvices



The Tec4MaaSEs project

Technologies for Manufacturing as a Service Ecosystems



Capturing the Meaning of Industrial Data

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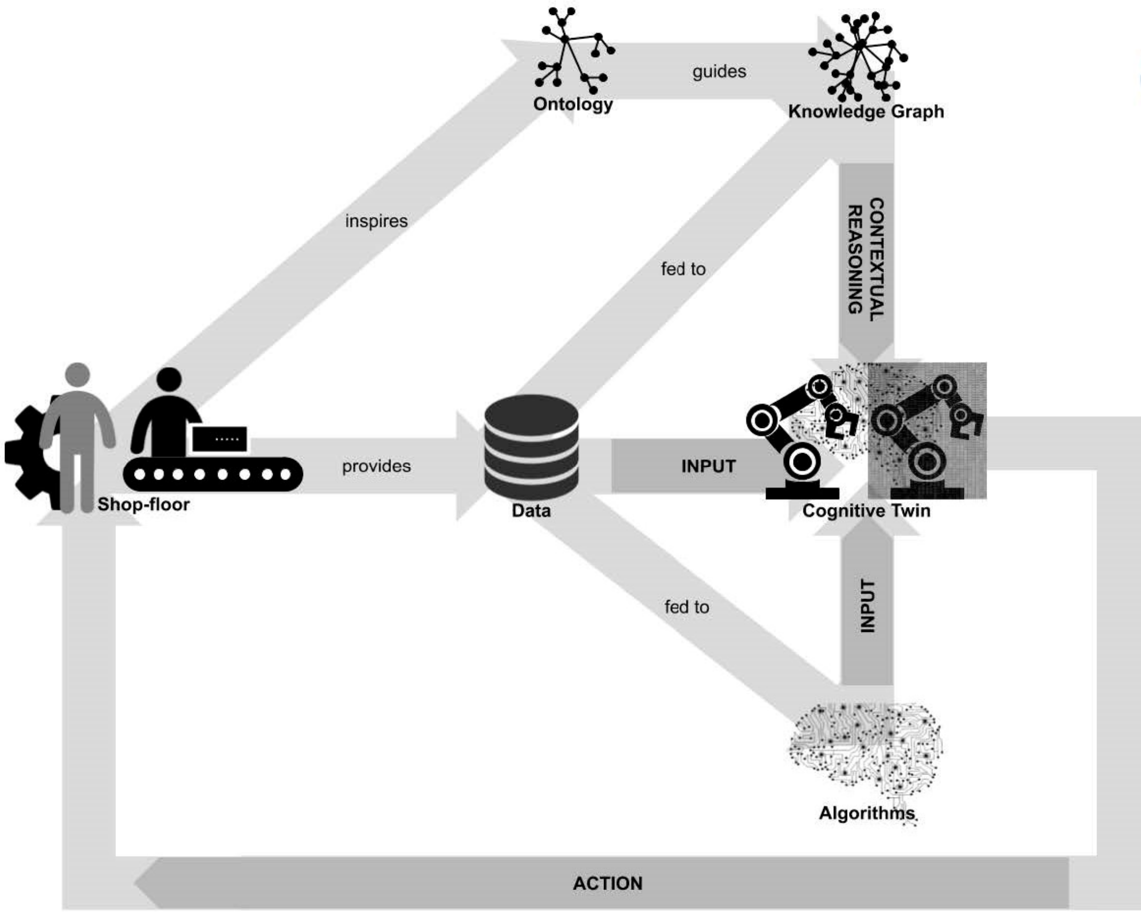
Actionnable Cognitive Digital Twin



FACTLOG

https://www.factlog.eu/

https://www.tandfonline.com/doi/full/10.1080/00207543.2021.2002967

Thank you for your attention!
Merci pour votre attention!

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