Cognitive Digital Twins

ict4sm.epfl.ch/

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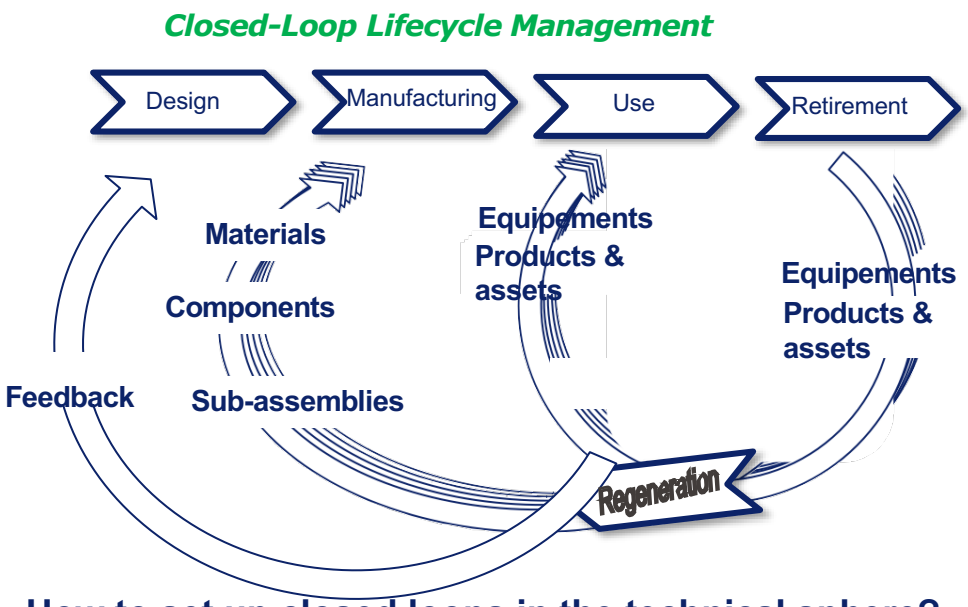
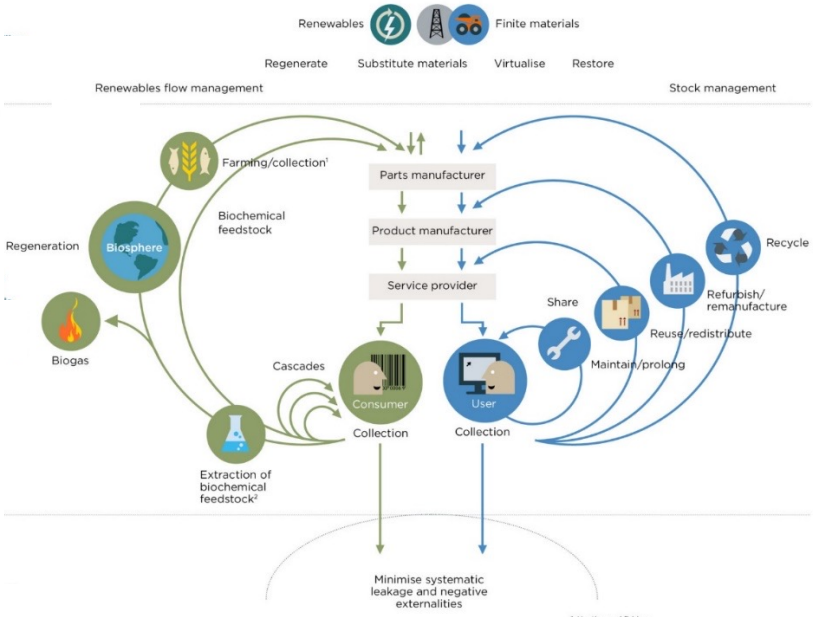
polytechnique
fédérale
de Lausanne

The new context: Circular Economy





How to set up closed loops in the technical sphere?

- Take into account several cycles of use
  - **Loops** (exploitation - regeneration - exploitation / manufacture)
  - **Types of products** (equipment, subassemblies, components, materials)

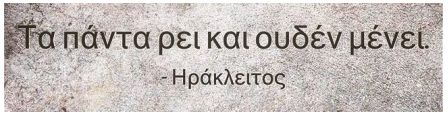
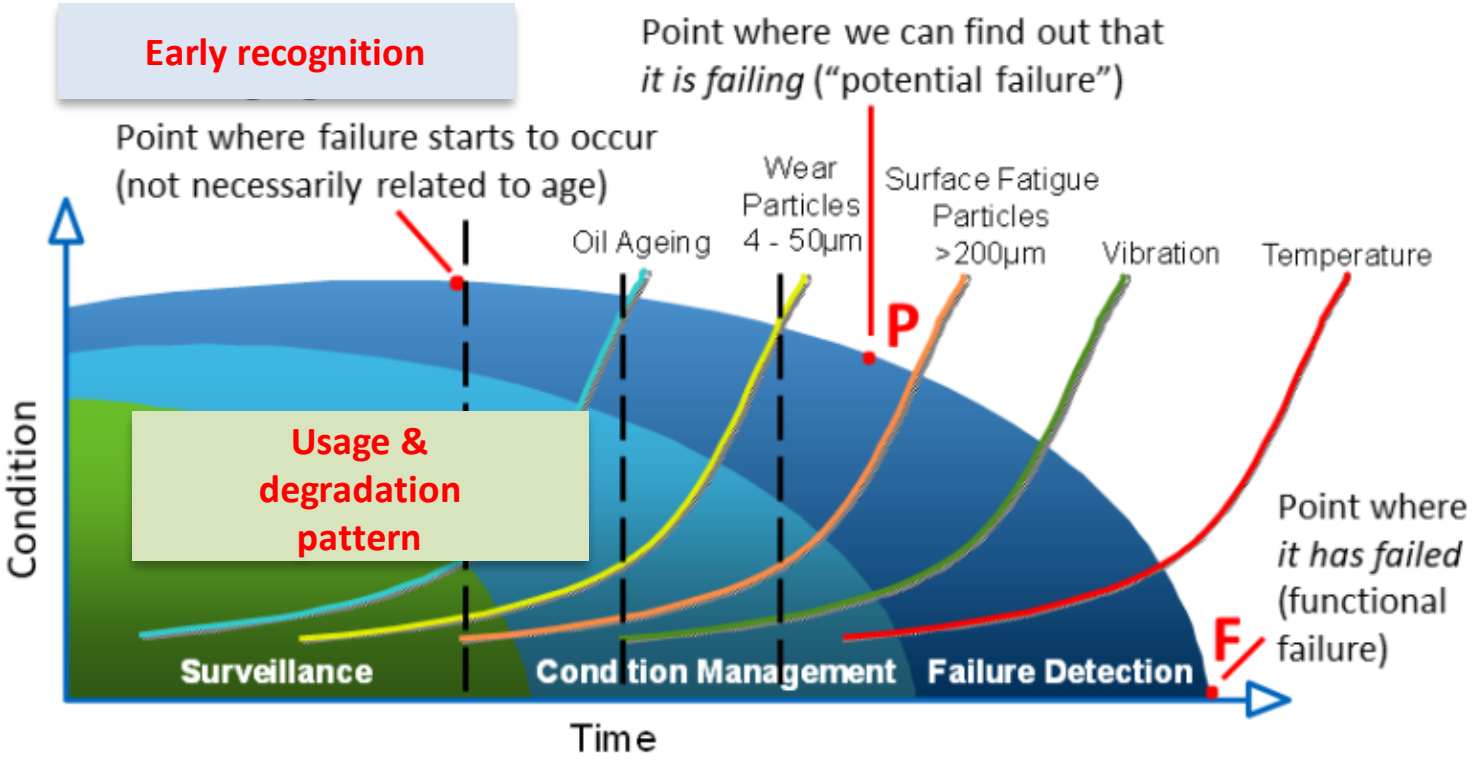


Figure adapted from PhD Thesis Laëtitia Diez, University of Lorraine

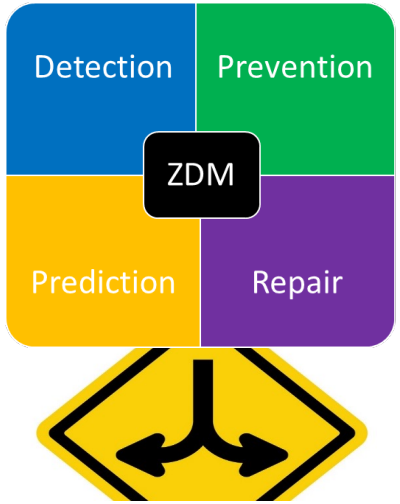
The problem: Degradation and Failure



Refer to: Moubray, J., 1997. Reliability Centred Maintenance. Butterworth Heinemann, Oxford, UK.

Zero Defect Manufacturing - ZDM

The objective is to eliminate as much as possible the number of defects either on parts or on manufacturing equipment by applying on one or more of the ZDM elements

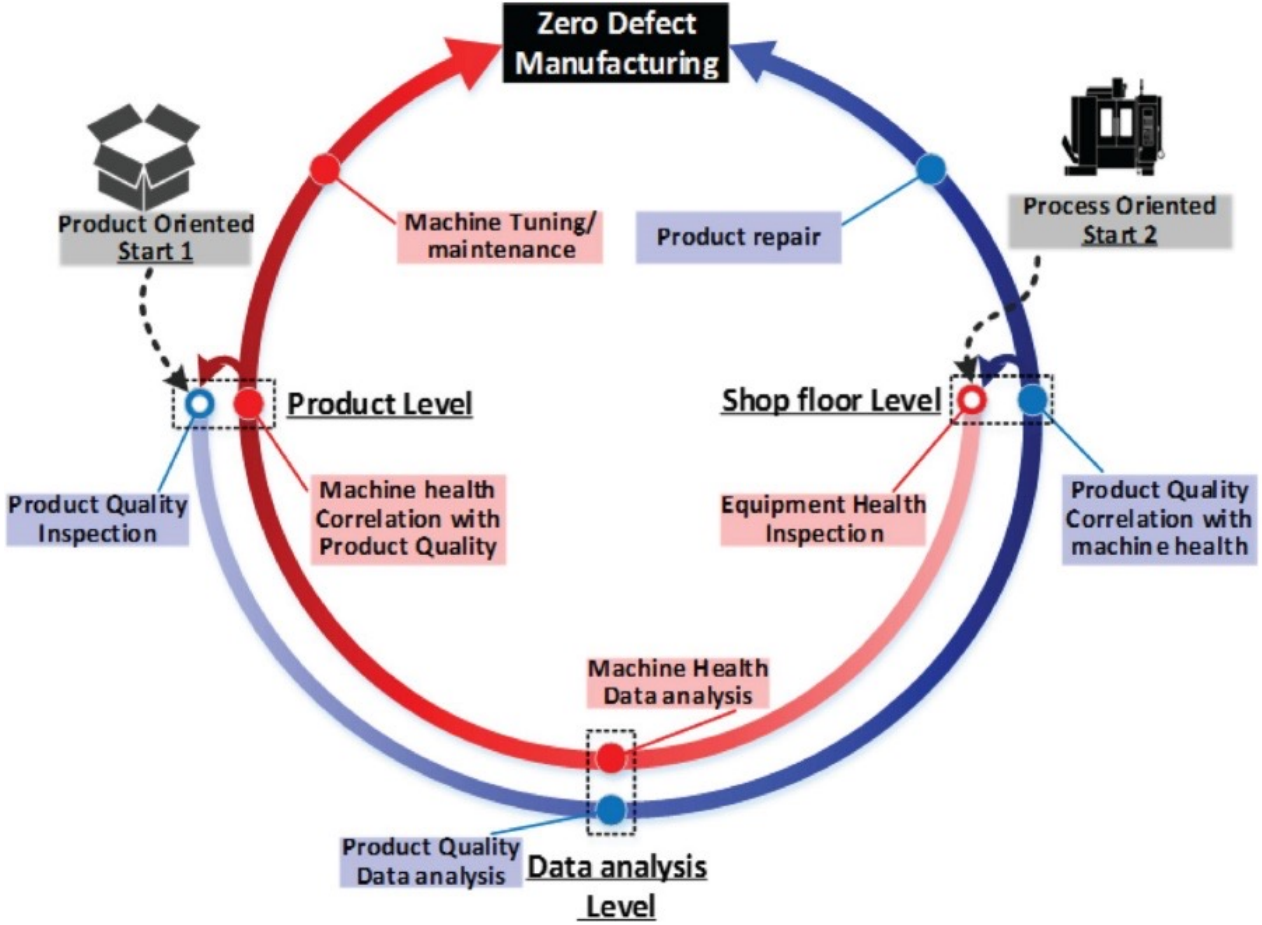


Product oriented ZDM

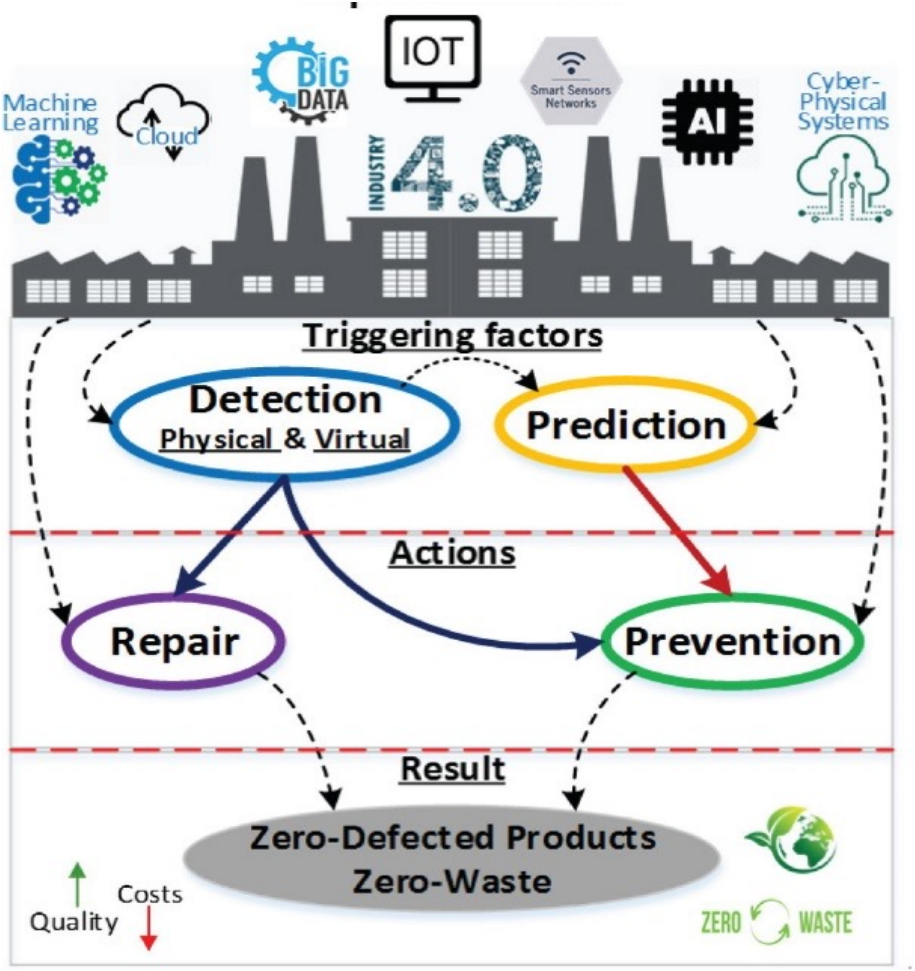
Energy Conservation

Machine oriented ZDM

The solution: Zero Defect Manufacturing - ZDM



Zero Defect Manufacturing - Implementation



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.

Data Sharing for Manufacturing

WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

White Paper

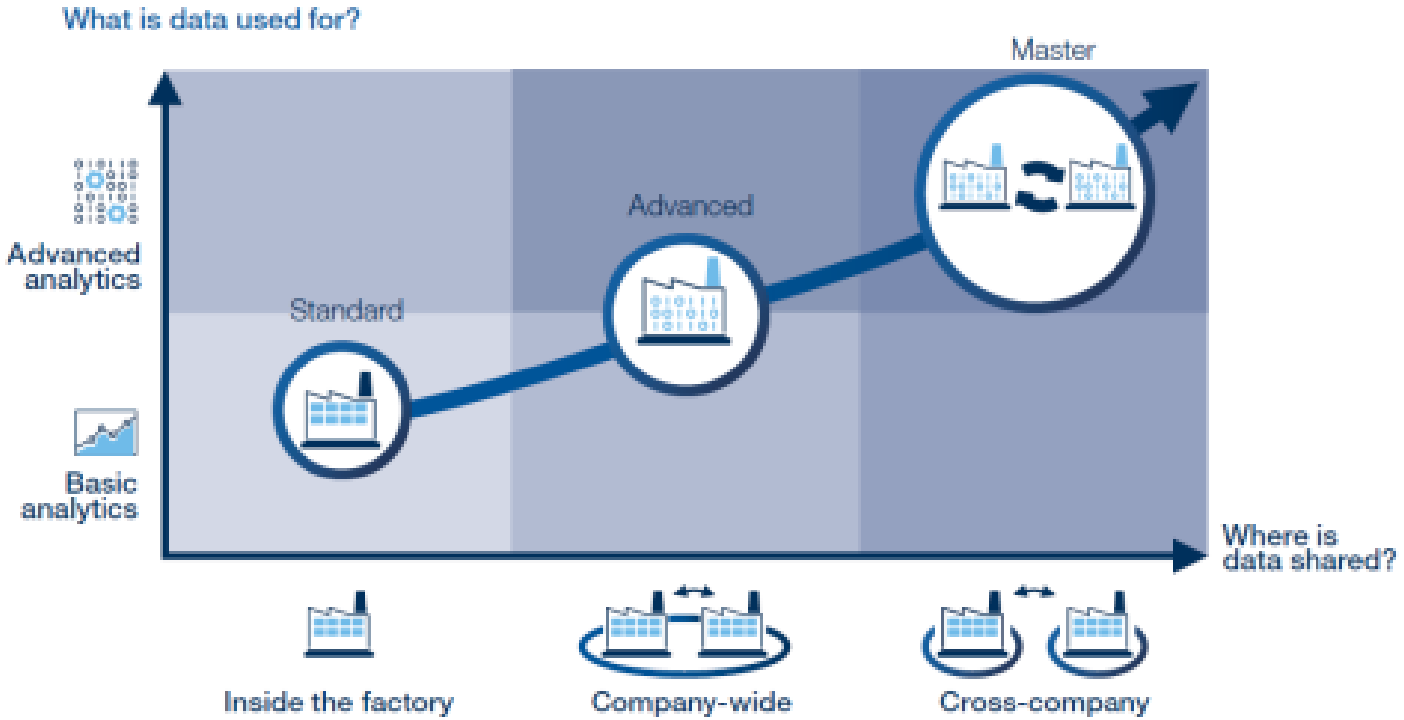
Share to Gain:
Unlocking Data Value in Manufacturing

In collaboration with Boston Consulting Group

January 2020

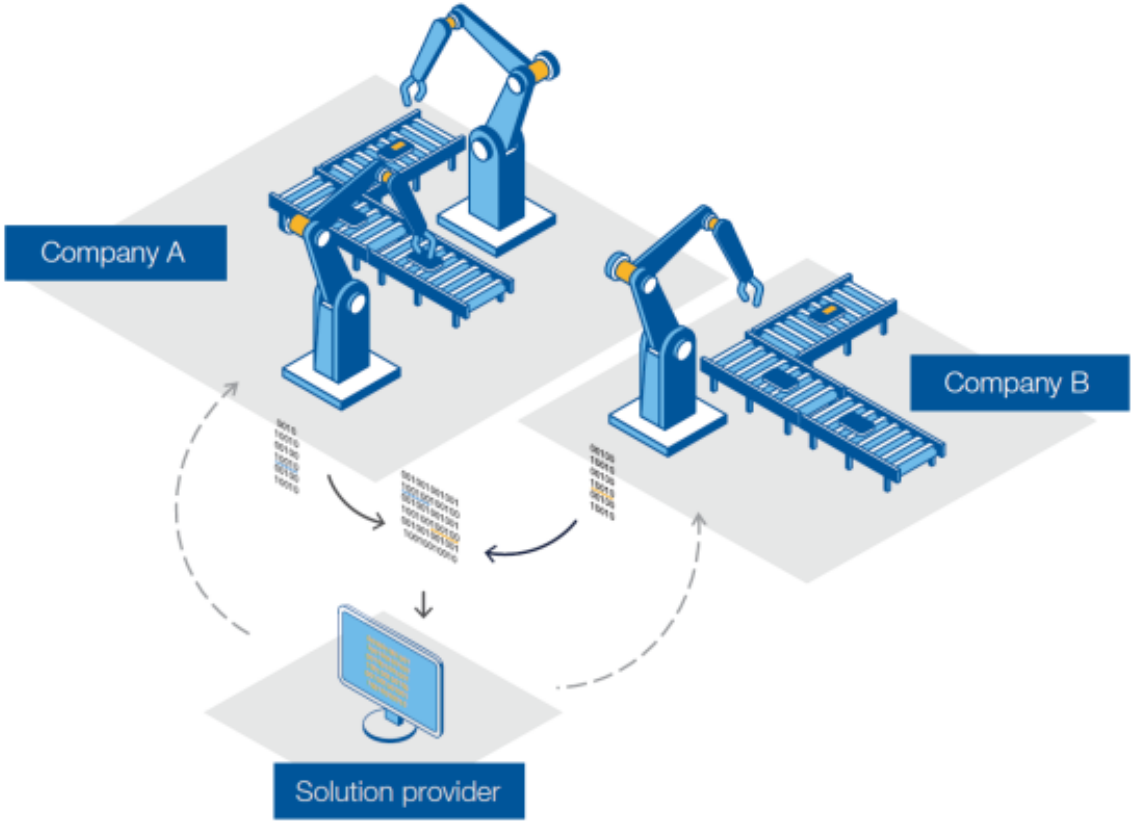
http://www3.weforum.org/docs/WEF_Share_to_Gain_Report.pdf

Data Sharing for Manufacturing



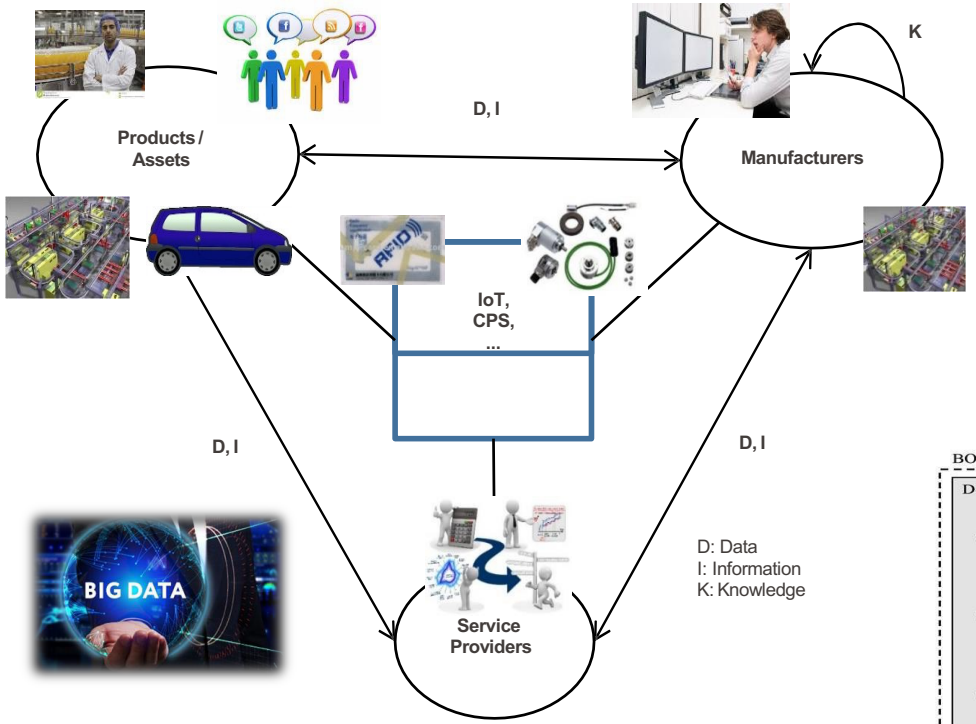
http://www3.weforum.org/docs/WEF_Share_to_Gain_Report.pdf

Enhance Asset Optimization

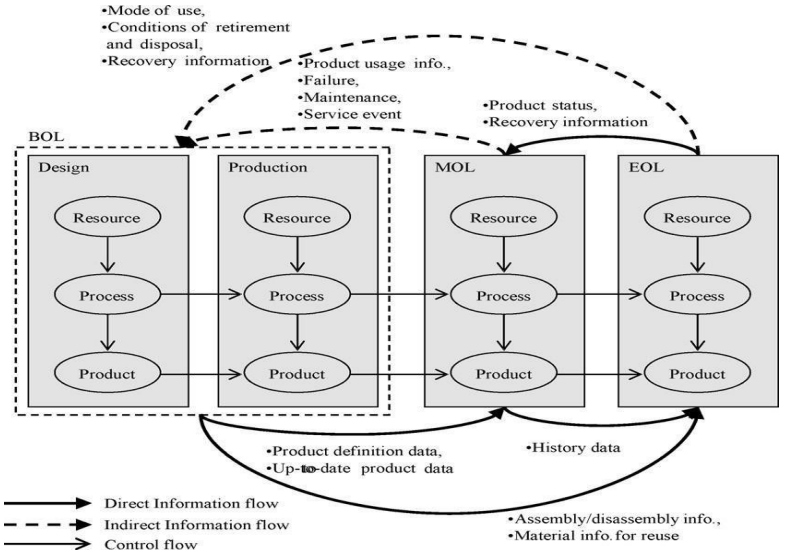


http://www3.weforum.org/docs/WEF_Share_to_Gain_Report.pdf

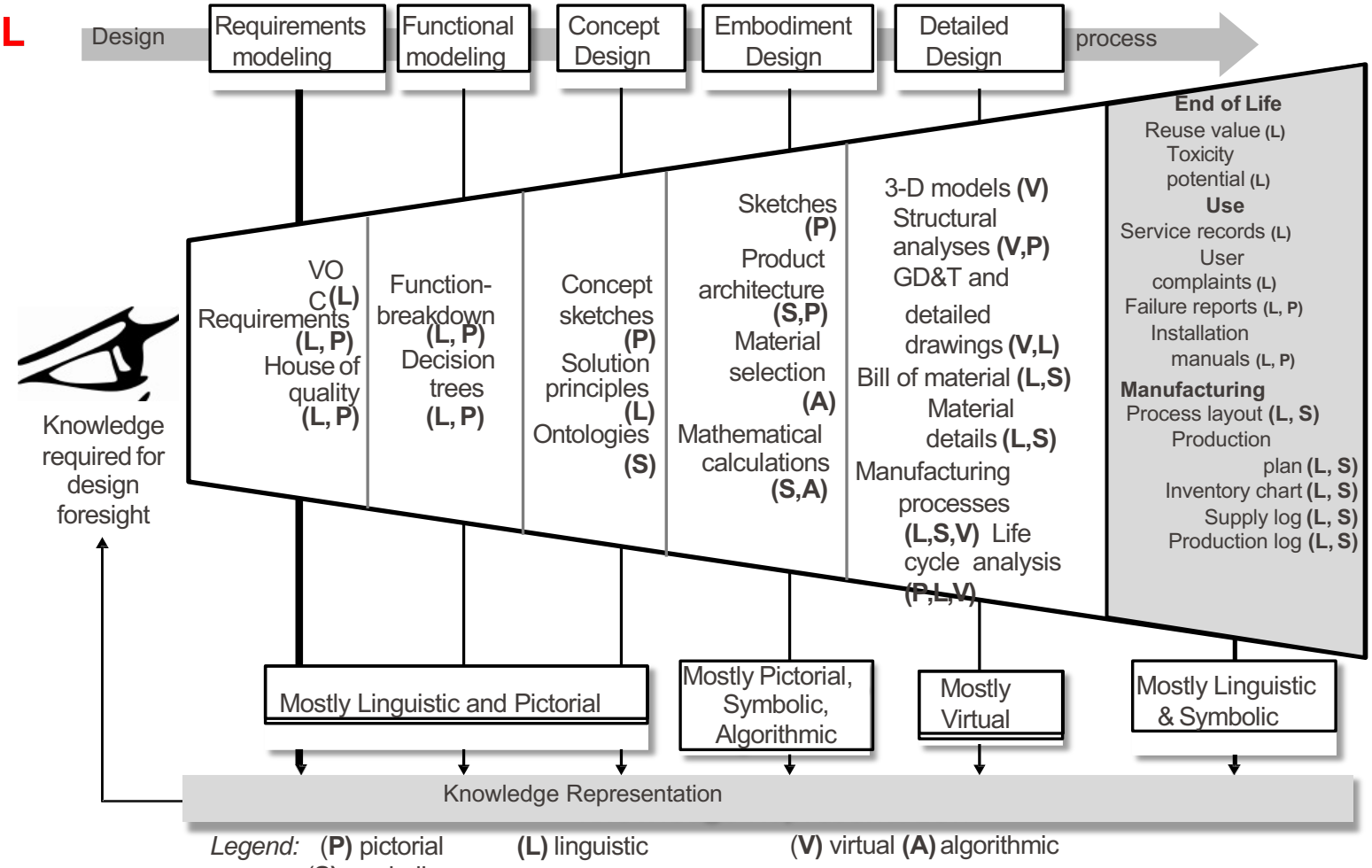
It is all about Big Life Cycle Data Transformations



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



LinkedDesign ZFactOr ZBre4k Boost 4.0 BIG DATA FOR FACTORIES QUALITY



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.

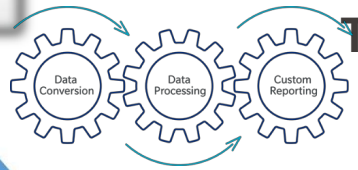
Characteristics of Data

Data Source

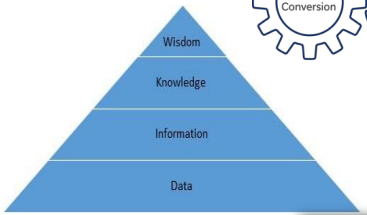
Value

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

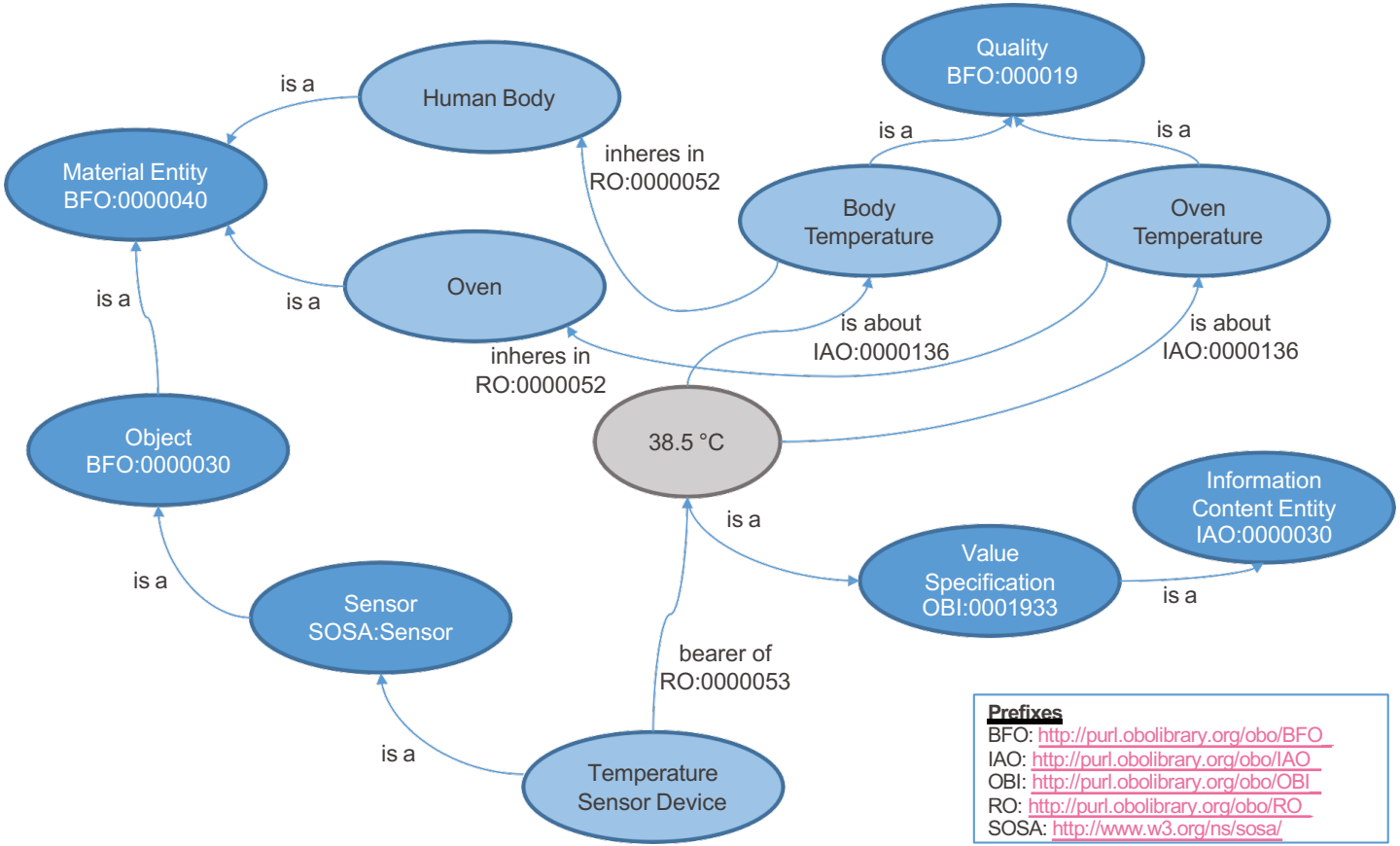
Reasoning

Domain disambiguation

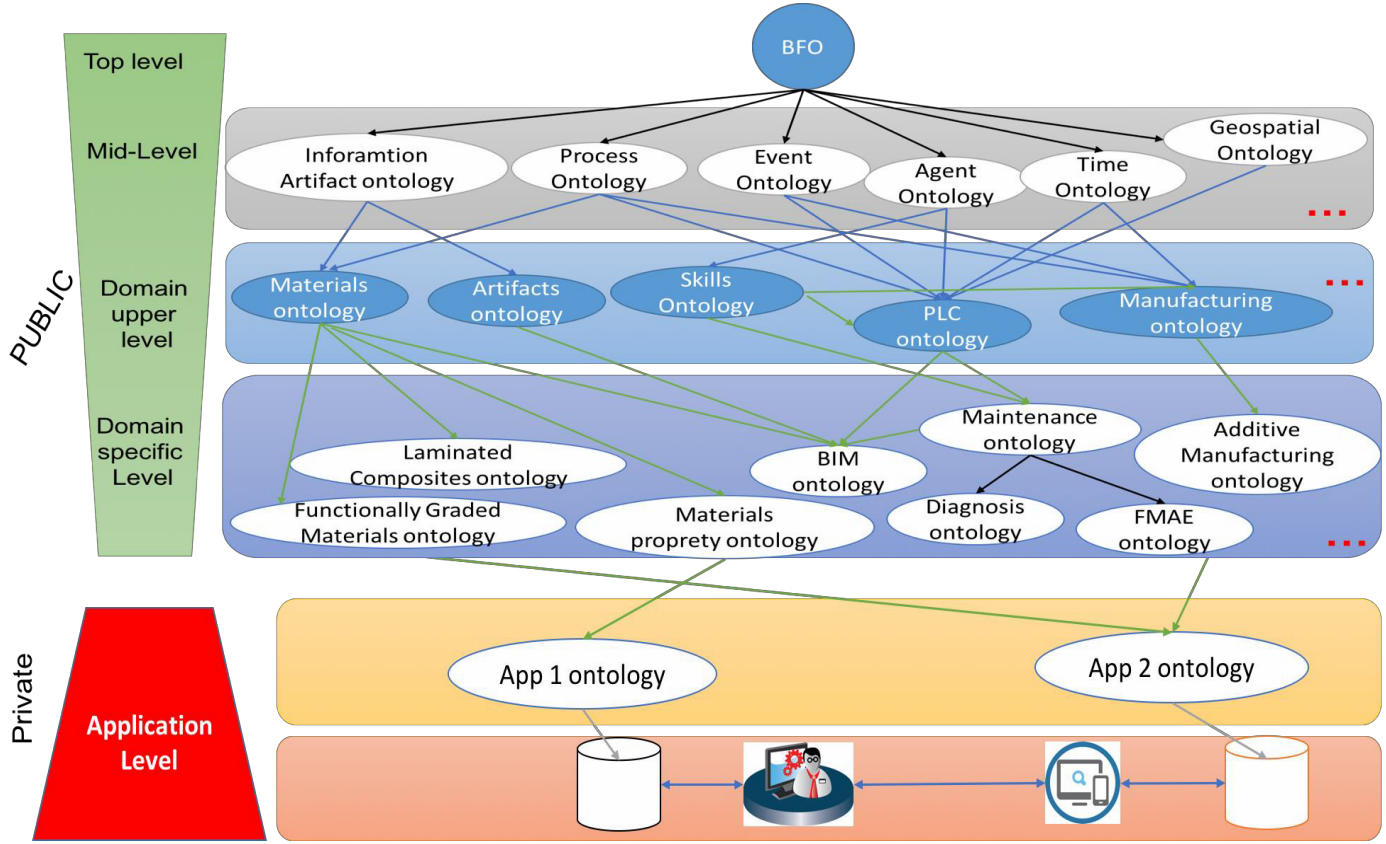
Data Silos

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

Capturing the Meaning of Data



IOF – Ontology Network



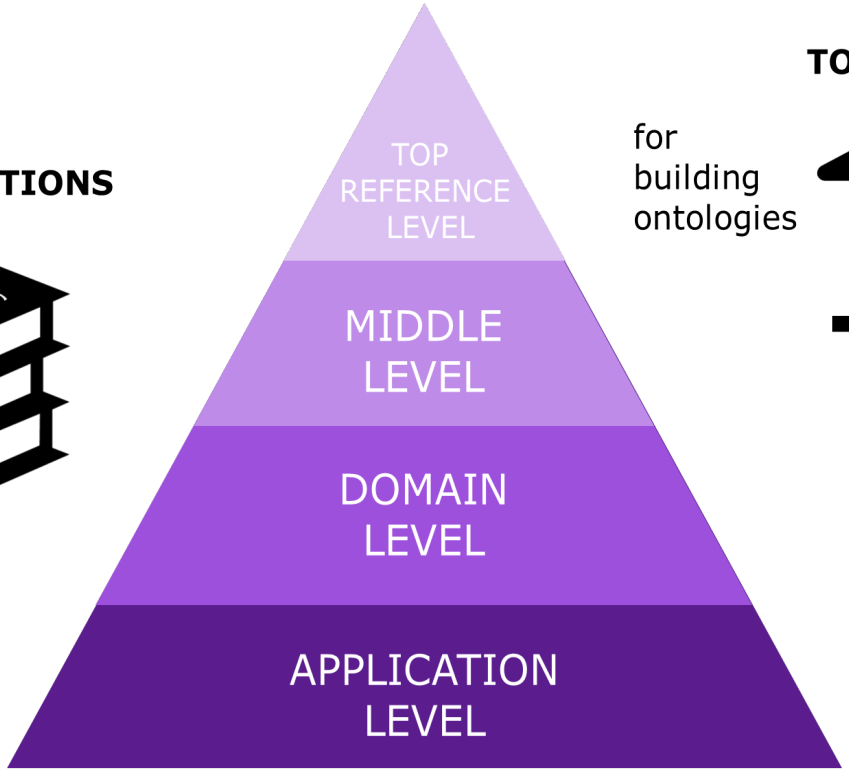
https://www.industrialontologies.org/

Drawn by Hedi Karray

Semantic modelling

- **Ontology –** OntoCommons EcoSystem (https://ontocommons.eu/)

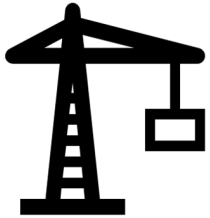
SPECIFICATIONS



ONTOLOGIES

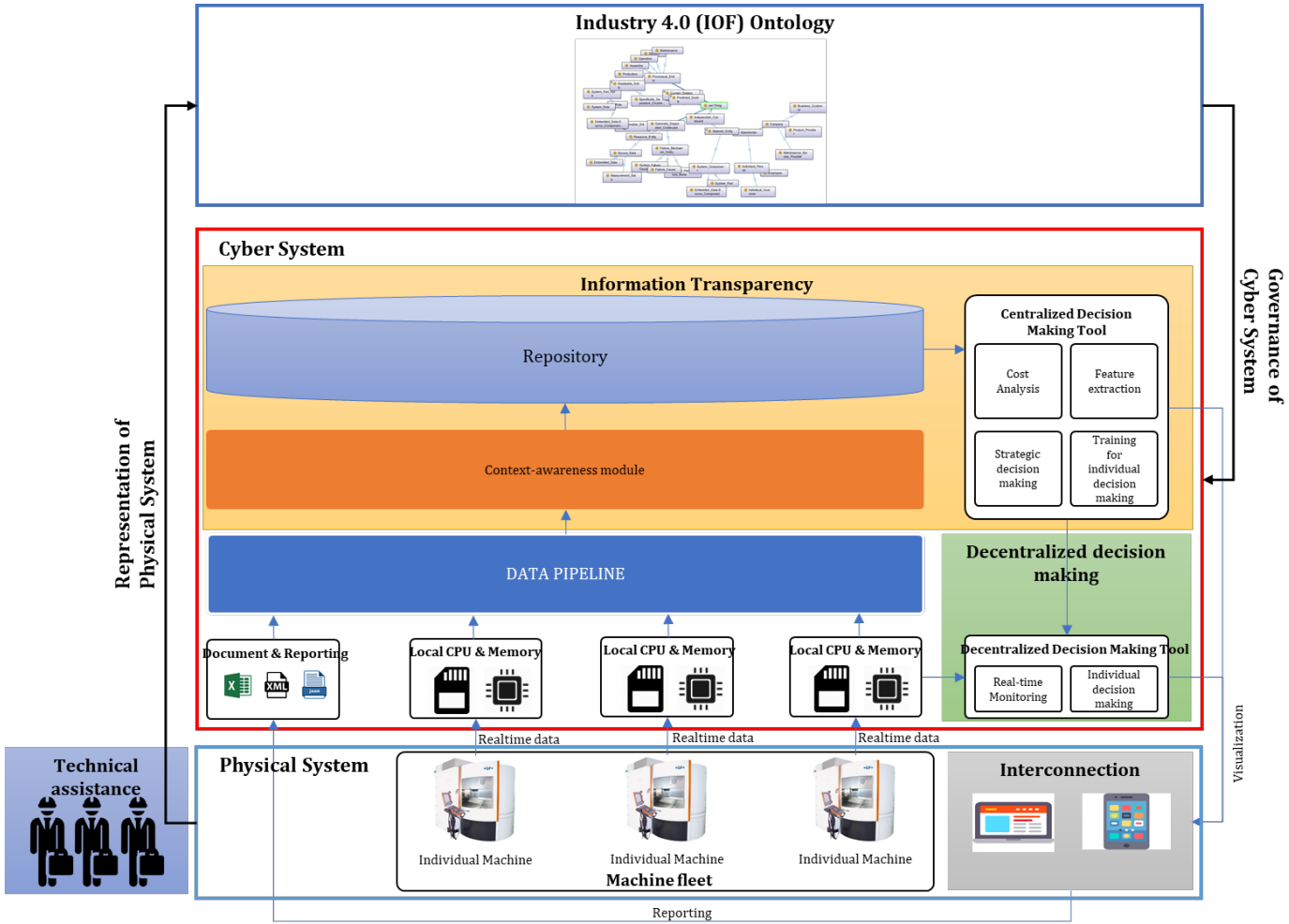
TOOLS

for
building
ontologies



for data
documentation

Semantics-Driven Architecture

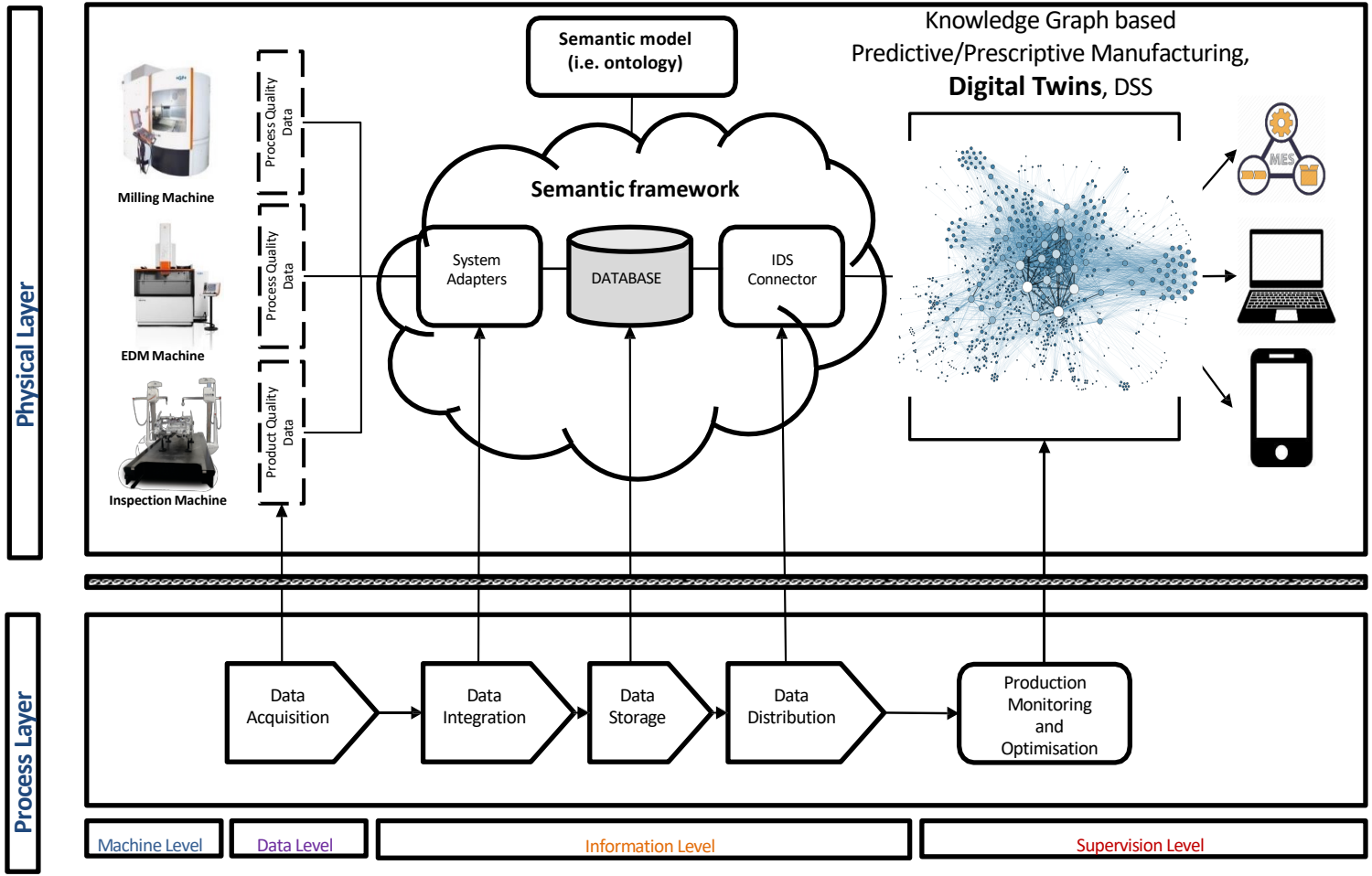


Cognitive Digital Twins

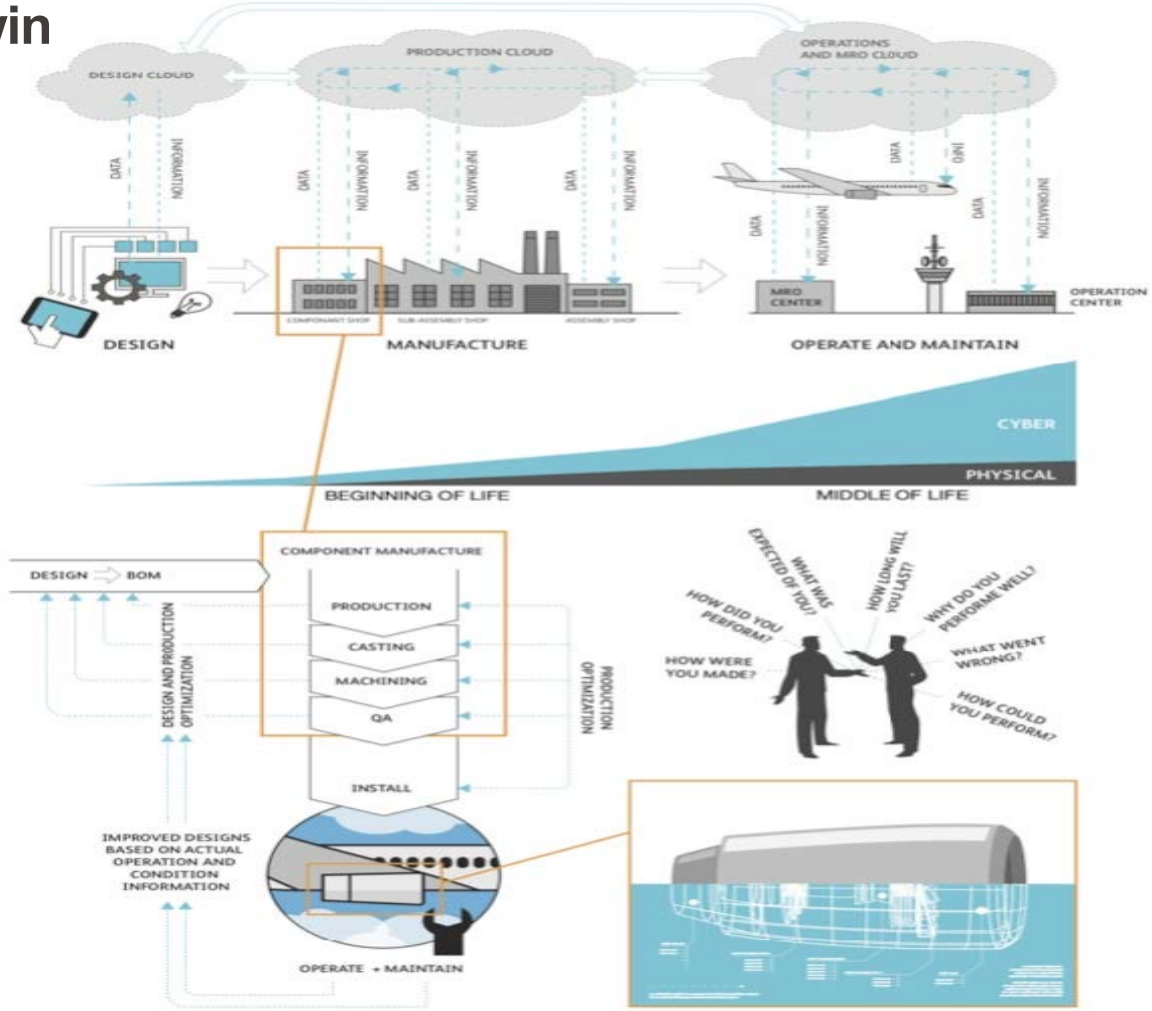
QUALITY Boost 4.0 BIG DATA FOR FACTORIES

ICT4SM

Predictive Manufacturing Framework - PMF



Digital Twin

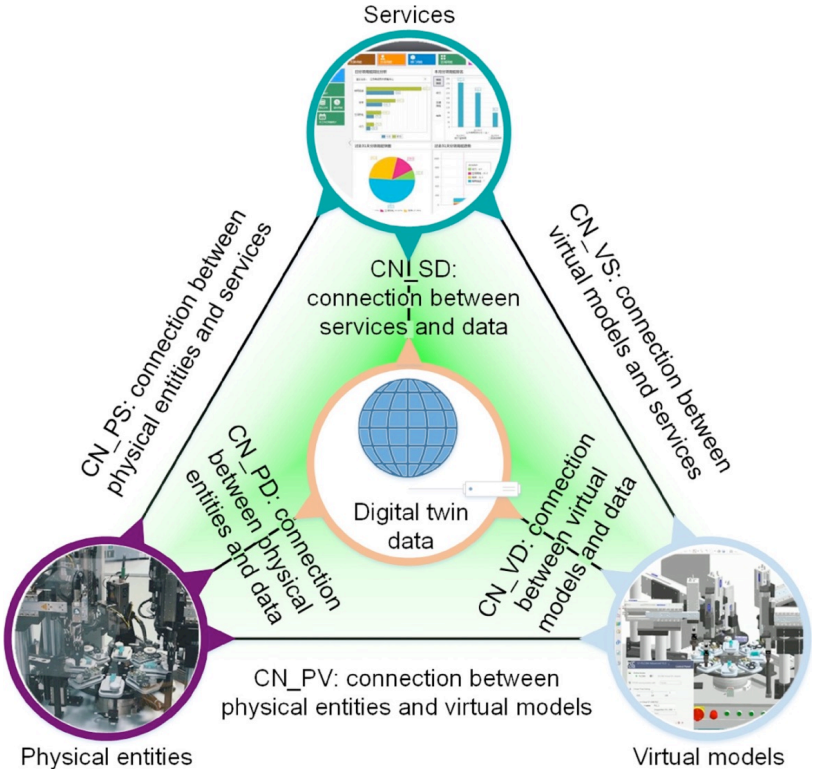


Source: DigitalTwin InnoSWISS project

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

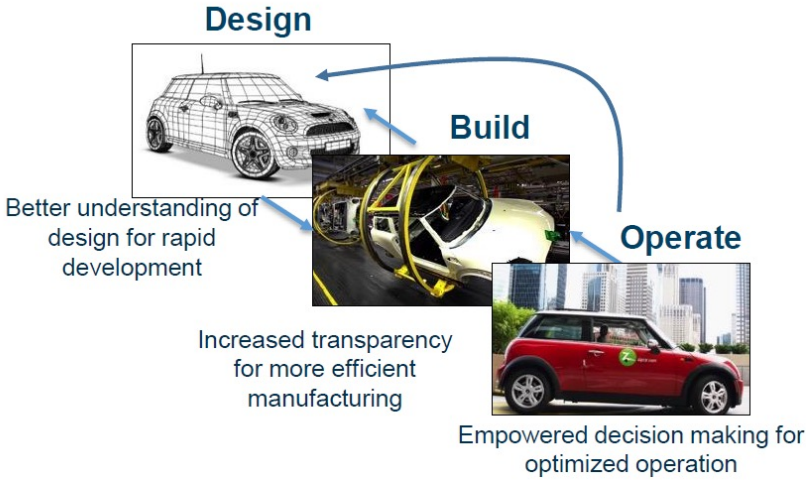


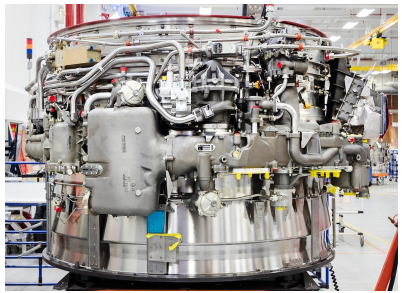
Five-dimension digital twin model [*b]

[*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*

DT 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

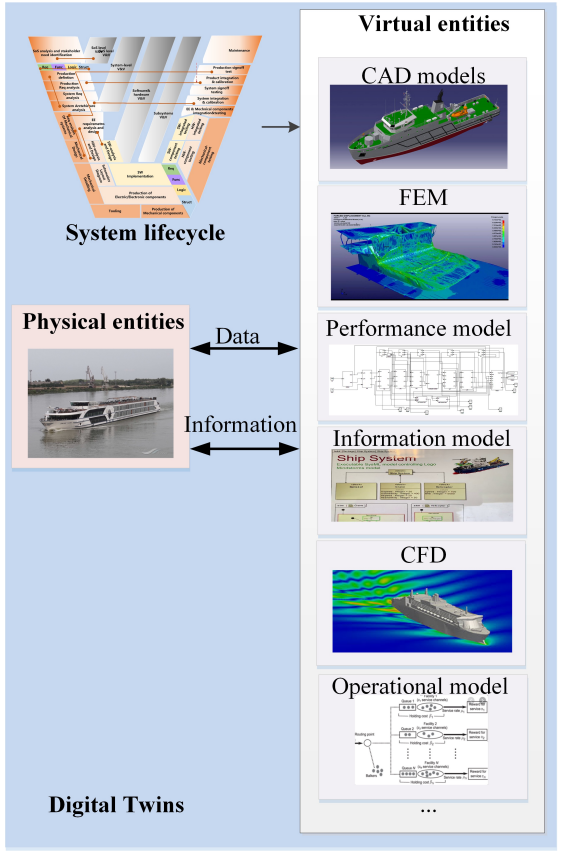


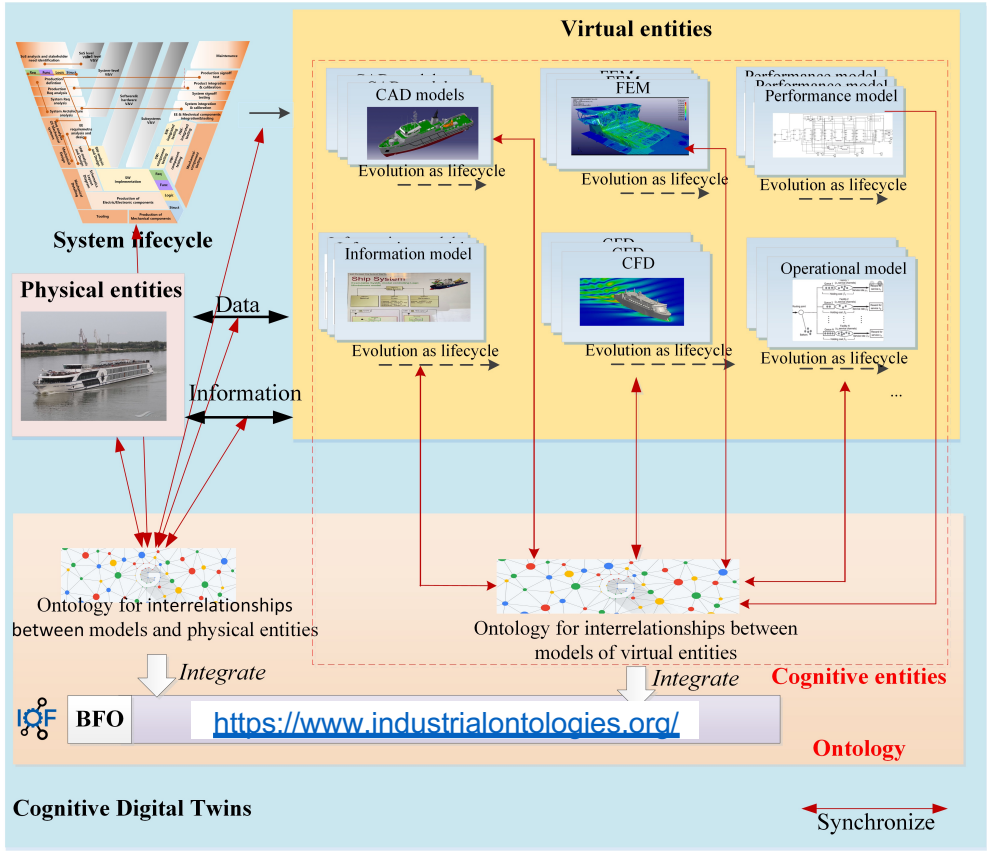


- *Fariz Saracevic, IBM, Cognitive Digital Twin, Bosnia Agile Day 2017*
- *https://www.nytimes.com/2017/05/03/magazine/a-look-inside-airbuss-epic-assembly-line.html*

Cognitive Digital Twin

- DT vs CDT



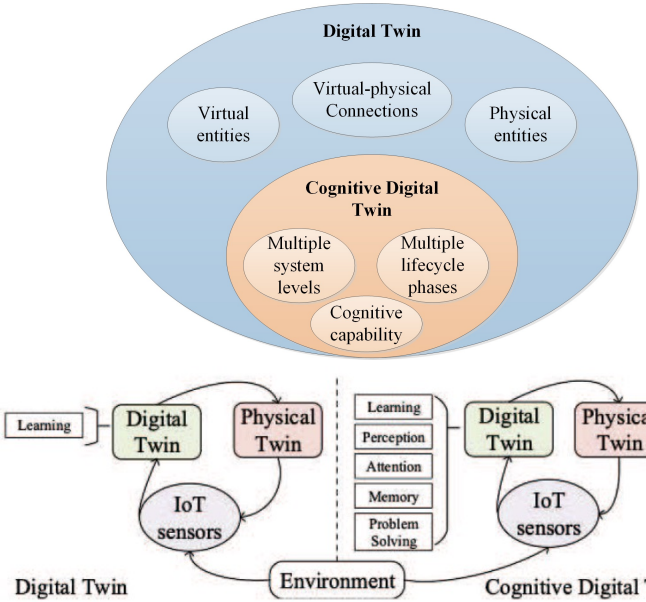


https://www.tandfonline.com/doi/full/10.1080/00207543.2021.2014591

Cognitive Digital Twin

- *Cognitive Digital Twin (CDT) is a **digital representation** of a physical system that is augmented with certain **cognitive capabilities**; comprises a set of **semantically interlinked digital models** related to different **lifecycle phases** of the physical system including its subsystems and components; **evolves continuously** with the physical system across the entire lifecycle; and support to execute **autonomous lifecycle activities**.*

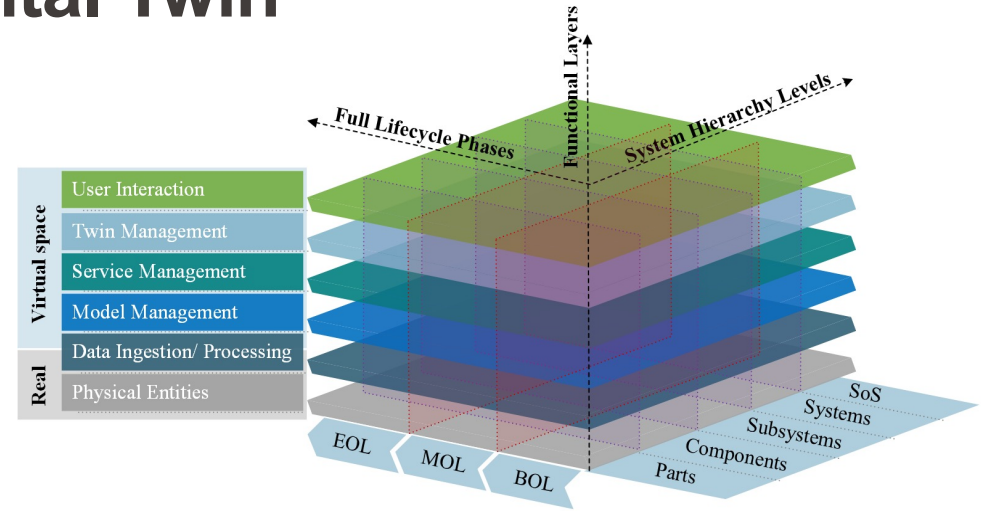
- **Characteristics** :
  - Based on Digital Twin
    - CDT is a subset of DT
  - Cognitive capabilities
    - attention, perception, comprehension, memory, reasoning, prediction, decision-making etc.
  - Autonomy capability
    - conduct autonomous activities without human assistance or minimum level of human intervention
  - Cross lifecycle phases & cross system levels
  - Continuous evolving
    - Multi-levels and multi-lifecycle phases interaction

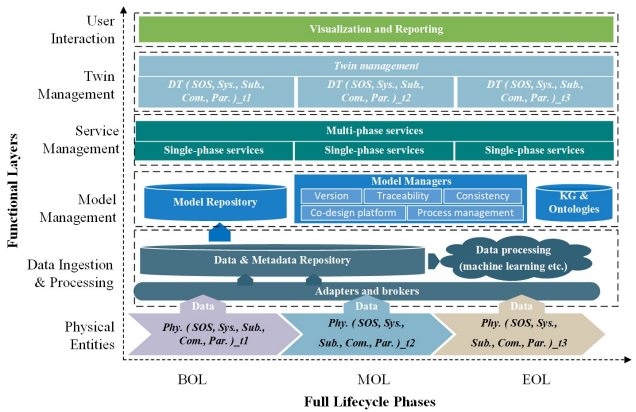


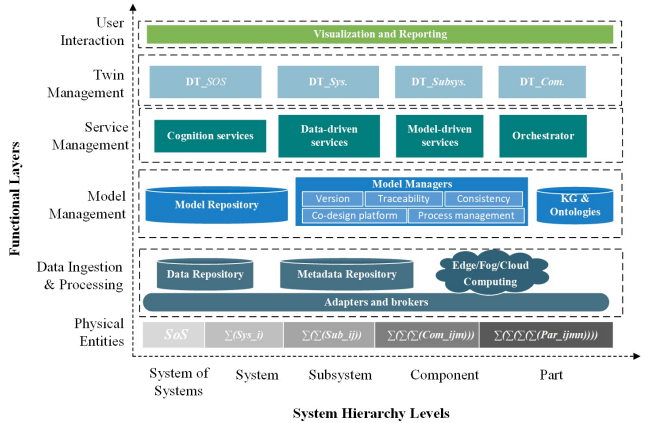
*a Al Faruque et.al. 2021. Cognitive Digital Twin for Manufacturing System

Cognitive Digital Twin

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

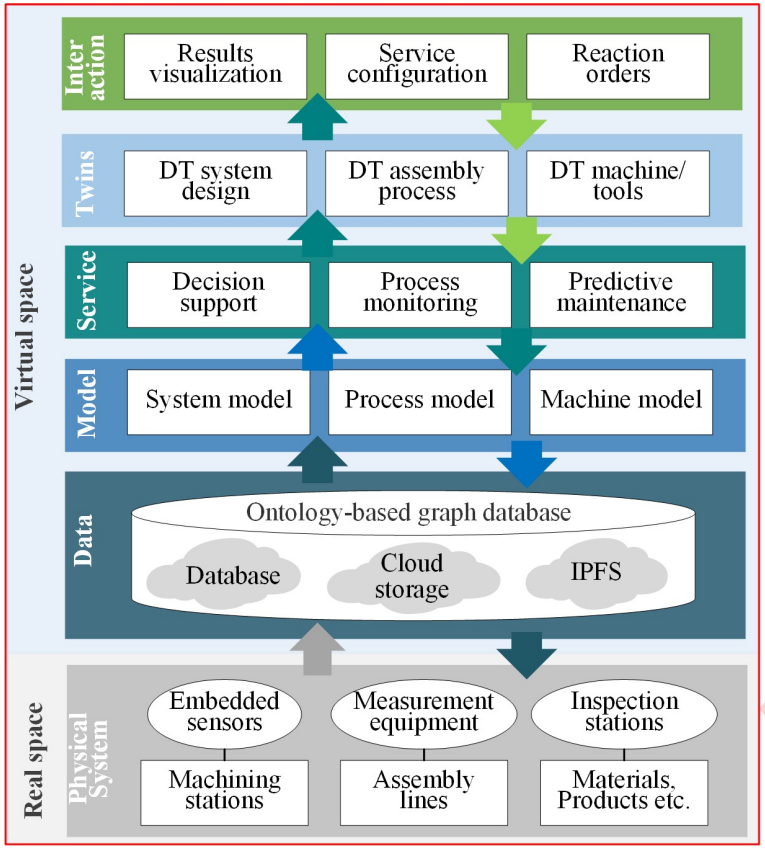


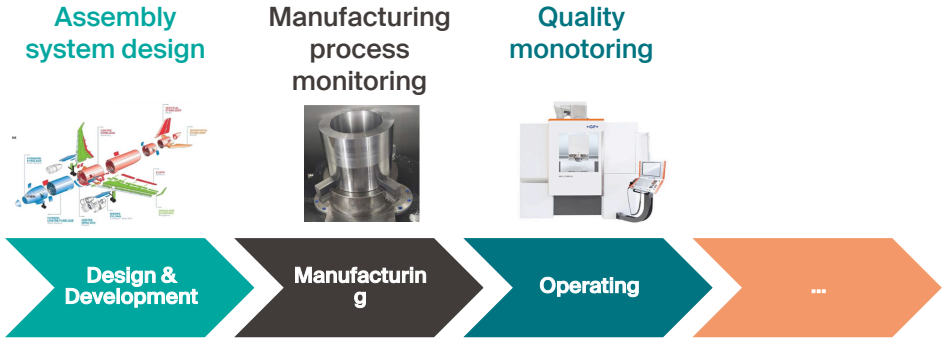


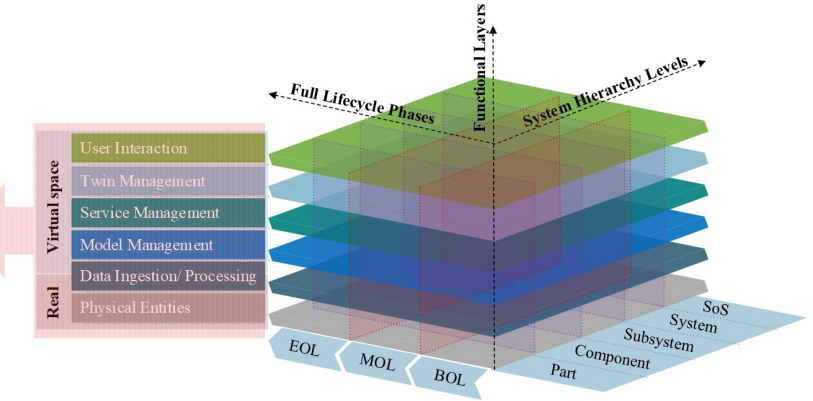


Application cases

- Multiple lifecycle phases:

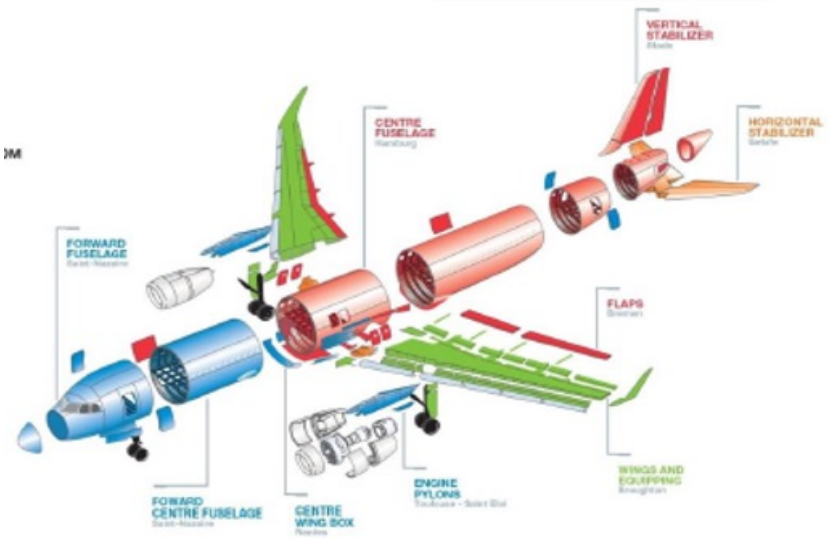






Application case

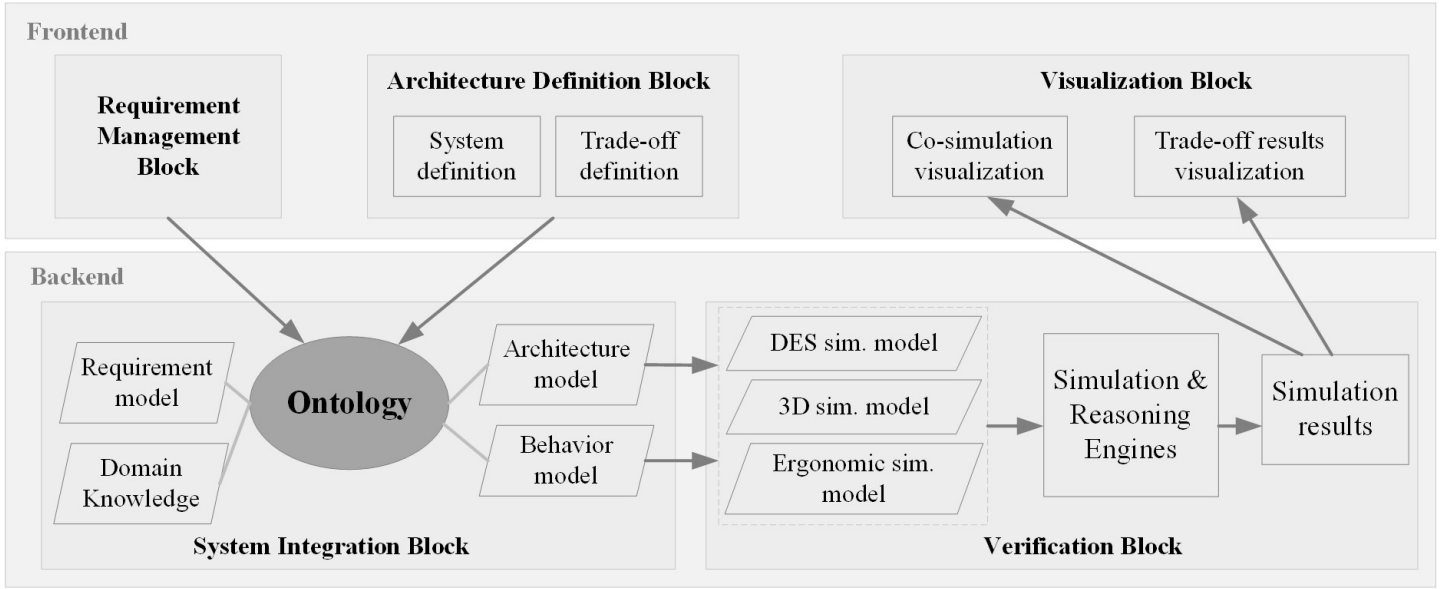
- **CDT supports aircraft industrial system design**
  - Focuses on the R&D phase of the assembly line for a new model of aircraft
    - Fuselage orbital junction process for a given assembly station of a Final Assembly Line (FAL) for the new aircraft model



https://atcnews.org/2016/05/31/rwandairs-ubumwe-now-on-the-airbus-assembly-line/

Application case

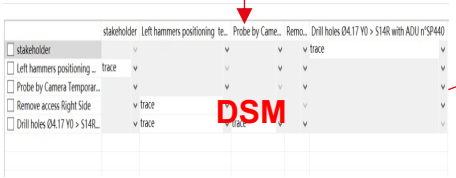
- **CDT supports aircraft industrial system design**
  - Supports automatic trade-off among different performance parameters under different industrial scenarios
  - Key functional block of the trade space framework for system integration, e.g. requirement model, architecture models and behavioral models etc.



Application case

Requirement

ReqIF



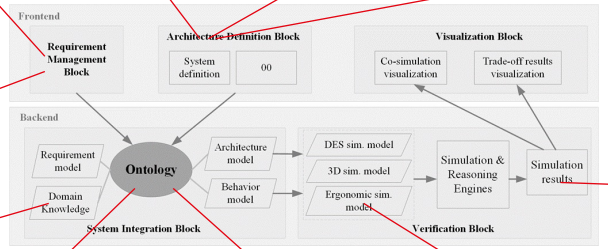
DSM

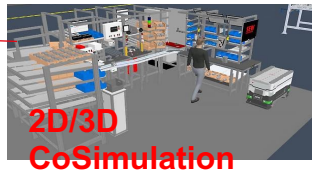
Mission model

Operation model

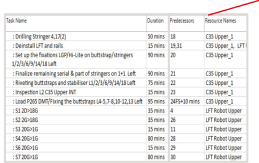
Function model

MOFLP at MetaGraph 2.0

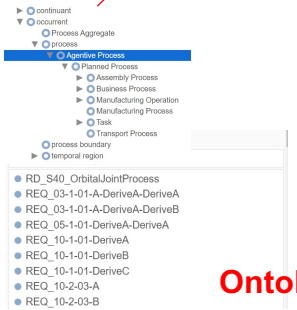


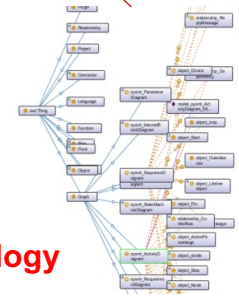


2D/3D CoSimulation

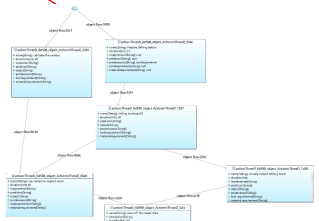


Domain Knowledge





Ontology



Graphical rep. of 2D/3D models in MetaGraph 2.0

Application case

Formalisms for defining transformation rules

Transformation rules

Knowledge management & Decision-making

KG for MBSE models

KG for real worlds

Ontology

GOPPRRE ontology

Requirement ontology

BFO-ontology/BFO

Architecture models

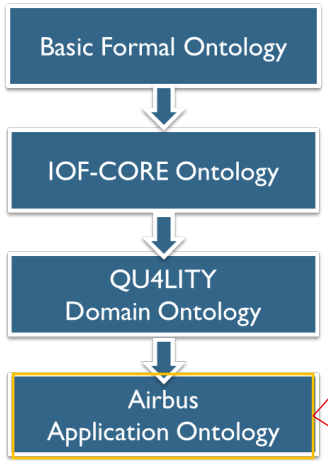
Real system manufacturing processes

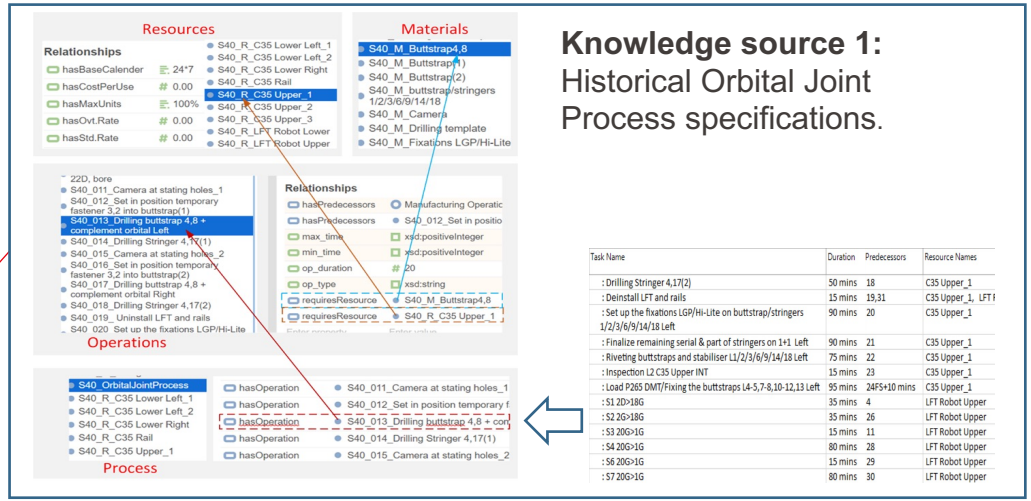
DTs

Aircraft Assembly

Application case

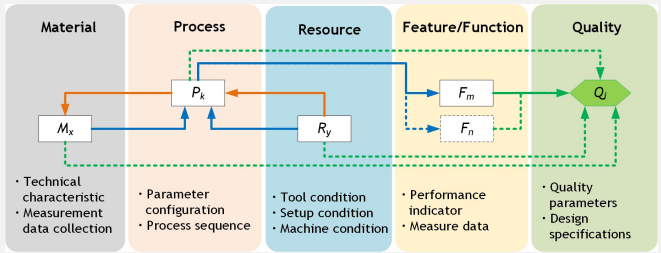
- **Ontology development**

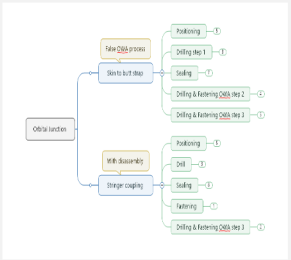




Knowledge source 1:
Historical Orbital Joint Process specifications.

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

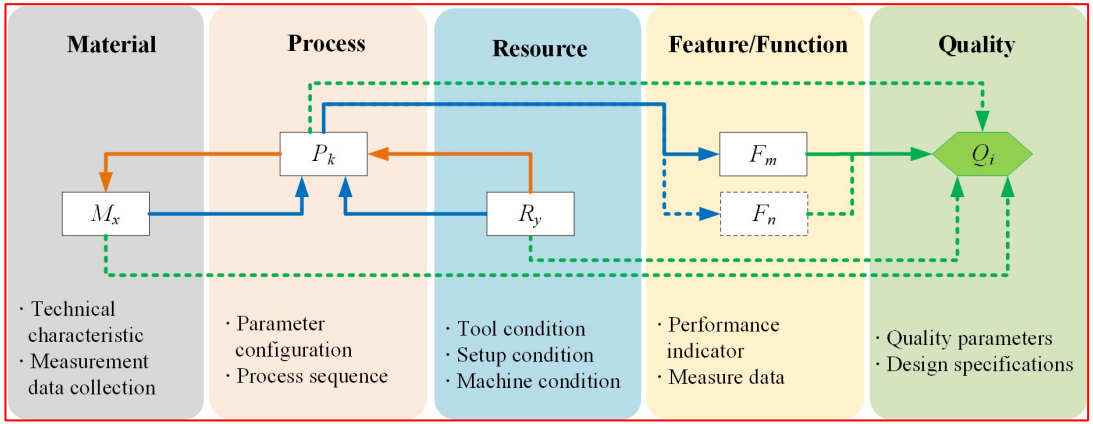




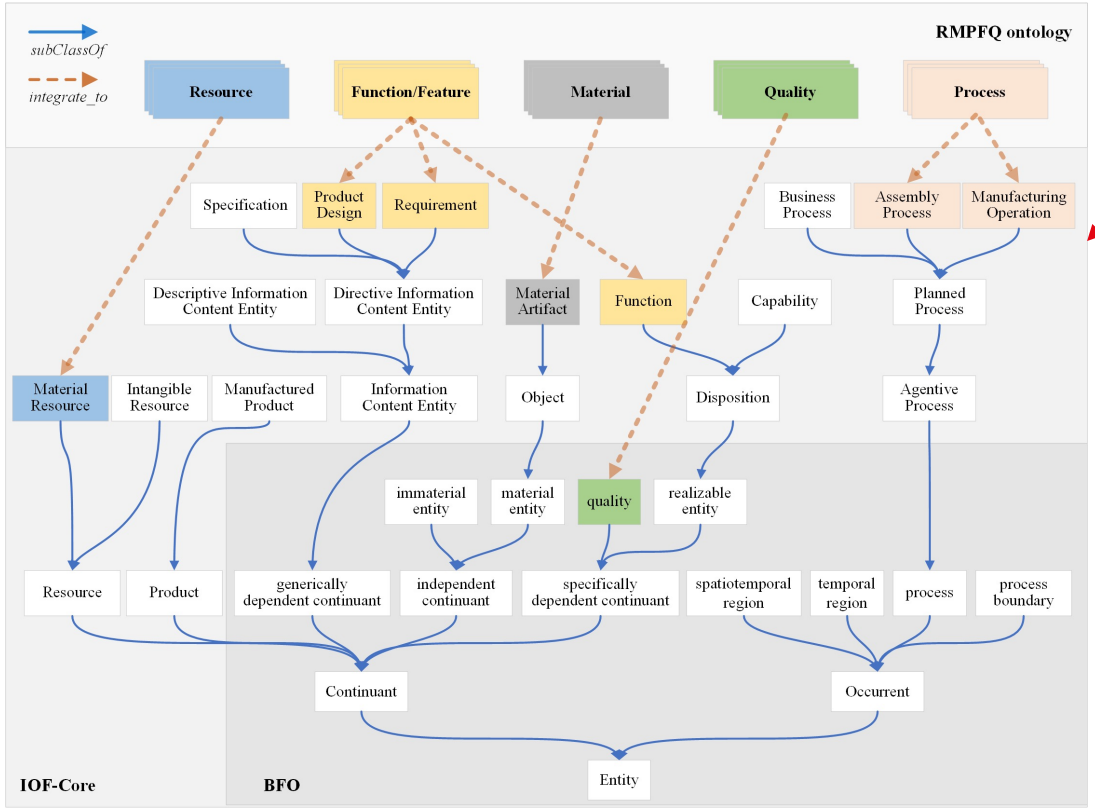
Knowledge source 2:
Domain experts' knowledge.

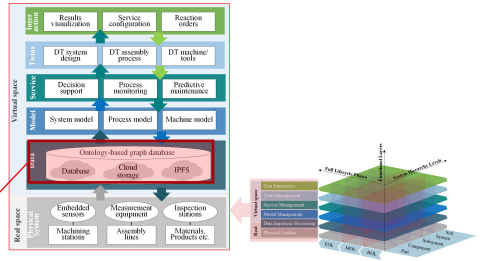
RMPFQ model

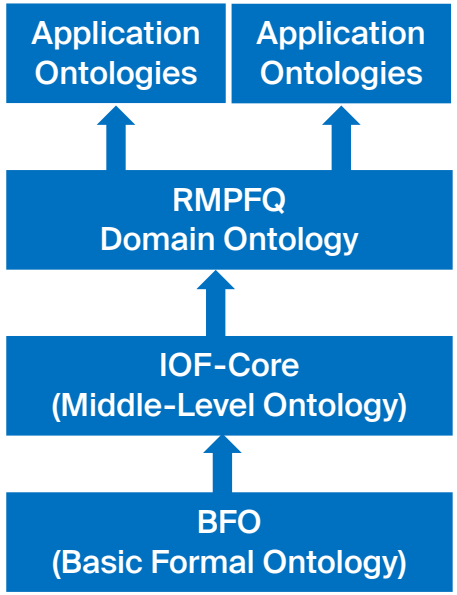
- **RMPFQ-model:**
  - **Resource**: devices, tools and means to produce goods and services, except raw material and product components [ISO 15531].
  - **Material**: raw materials, product components and assemblies etc., that is needed to produce a certain product.
  - **Processes**: processing and transforming materials into the final goods by using machines, tools and human labour.
  - **Functions/Features**: distinguished characteristics of a product, e.g. functionalities like specific tasks, actions or processes that the product is able to perform; and/or other features like performance
  - **Quality**: the degree of conformance of final product functions and features to designed requirements [ISO 9000].



From BFO to RMPFQ to applications





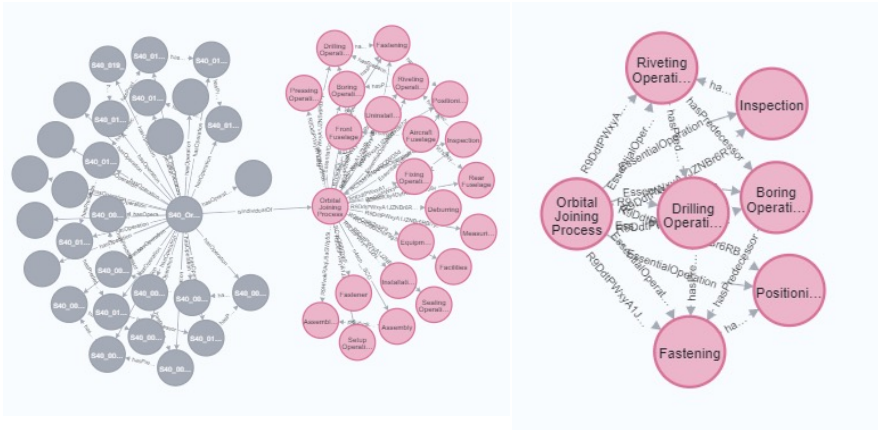


Cognitive Digital Twins

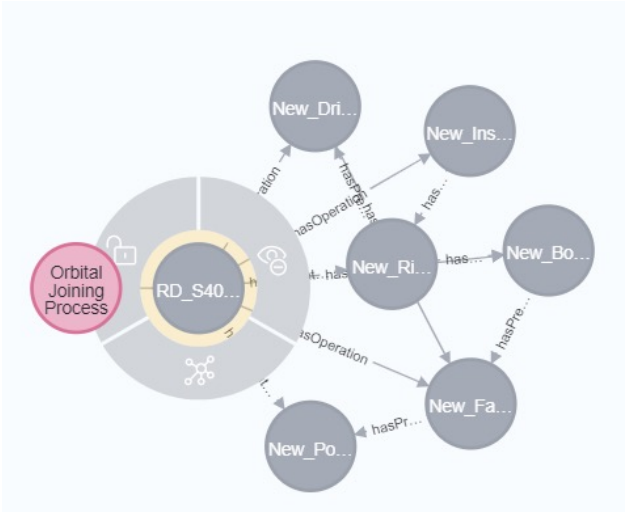
AIRBUS EPFL Fraunhofer VISUAL COMPONENTS ICT4SM

Ontology support new process design

- Knowledge captured from the existing orbital joining process is represented in the ontology by a generalized class which contains necessary operation classes and their relationships
- When designing a new Orbital Joint Process, the new instance (e.g. Individual RD_S40_OrbitalJointProcess) automatically inherit the predefined properties (operations).
- It provides starting point for Industrial System Engineer for new system design

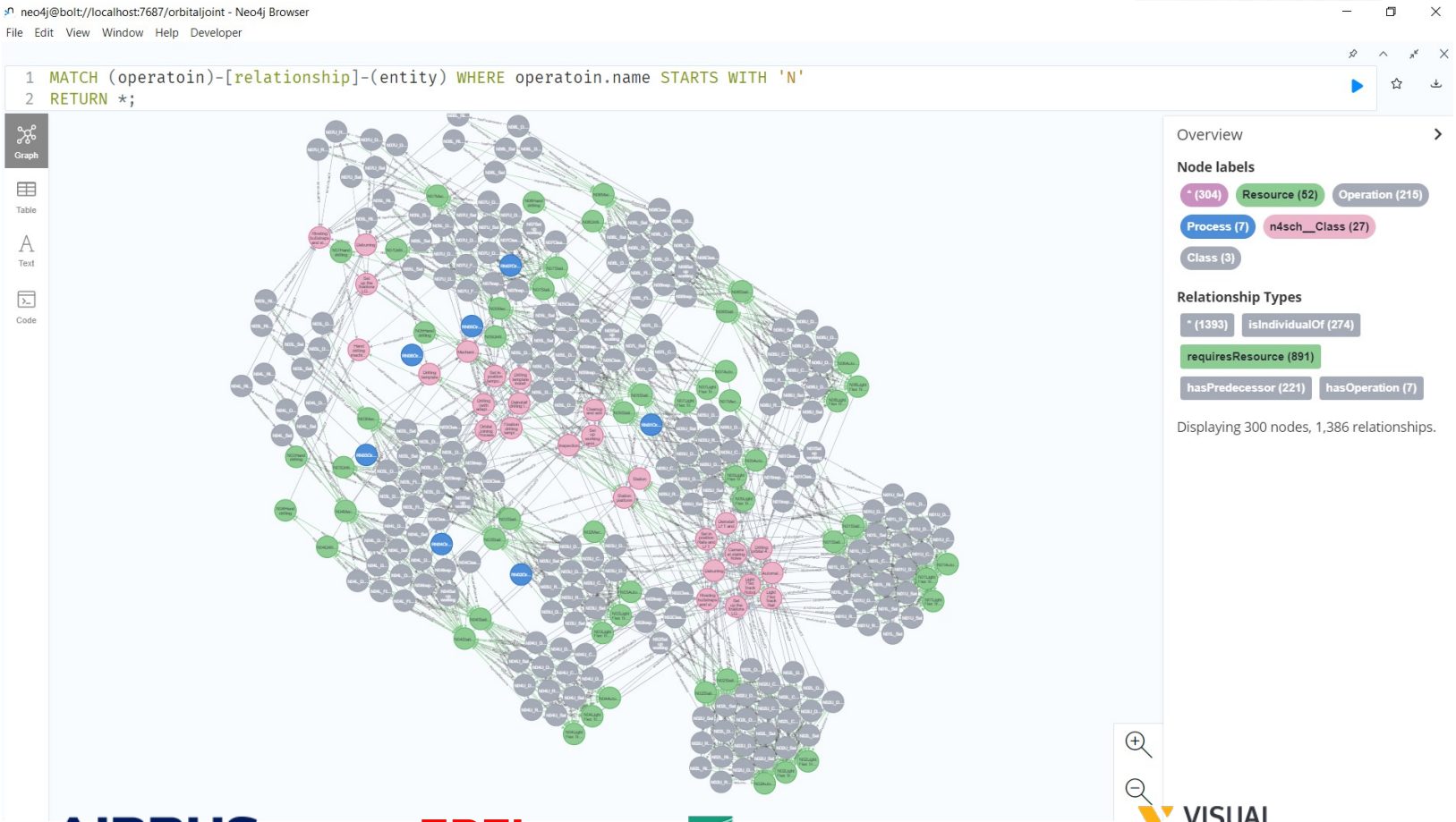


Captured Knowledge



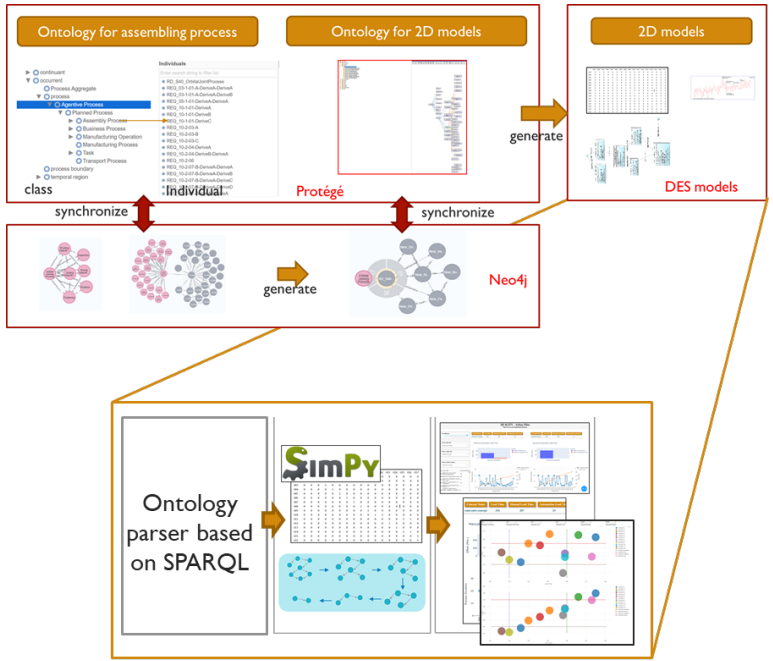
Knowledge instantiating

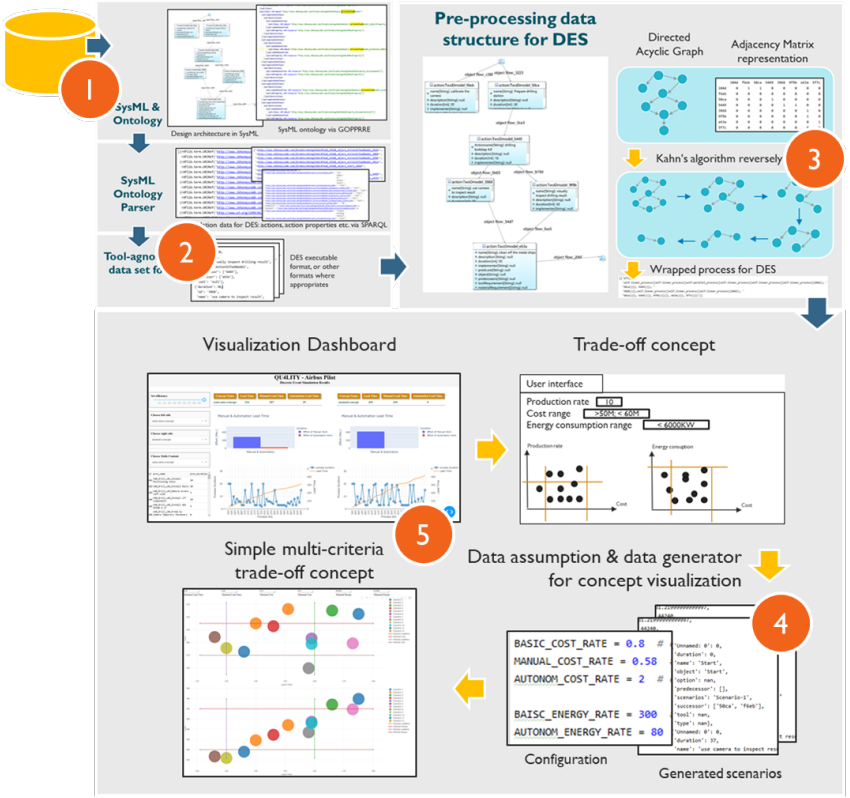
Ontology in Graph Database - Neo4j



2D Simulation

- Generate Discrete Event Simulation (DES) model from application ontology, which describes a design architecture
- Automatic generation covering different scenarios for assembly process designing
- Achieve decision supports with DES and data analysis during industrial system design

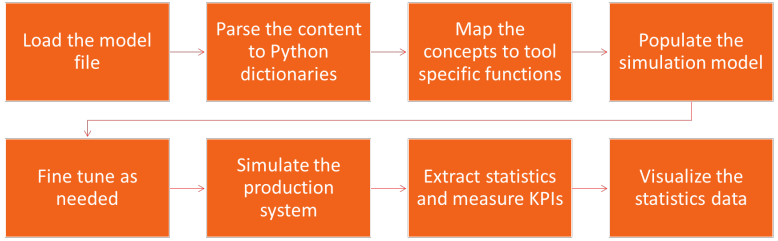


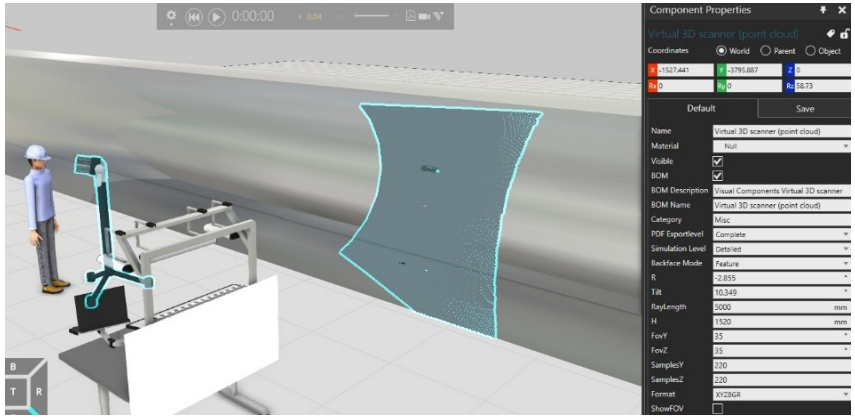


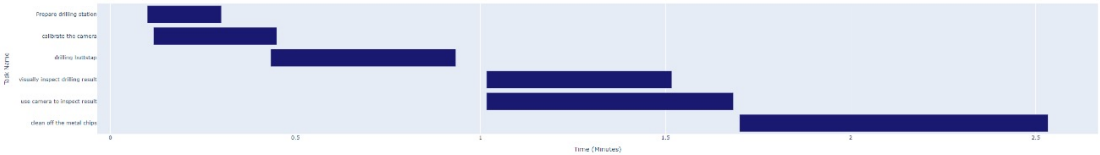
D. Kyritsis

3D Simulation

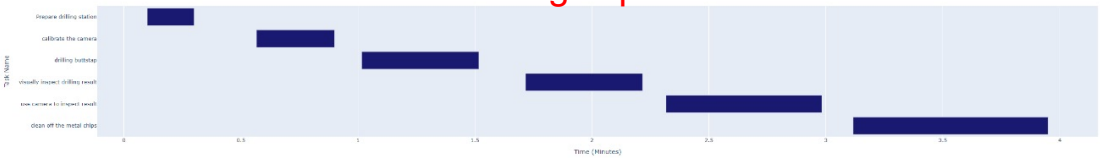
- Once created the virtual scenario faster validation, allows using 3D simulation from the initial design steps
- Easy validation of different cases (workers, resources,..), independent of the facility
- Mapping from Ontology to Simulation:



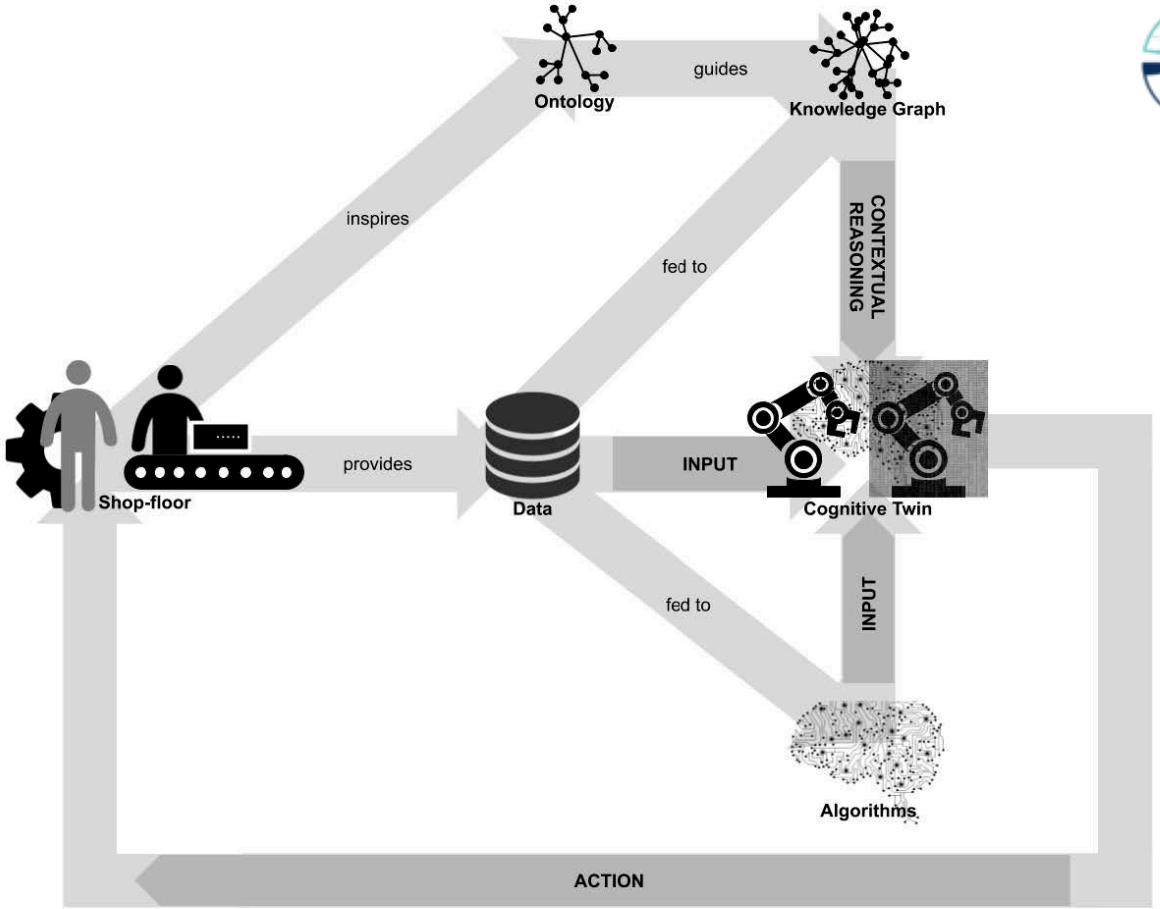




Design options



Actionnable Cognitive Digital Twin



https://www.factlog.eu/

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

Thank you for your attention!

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