

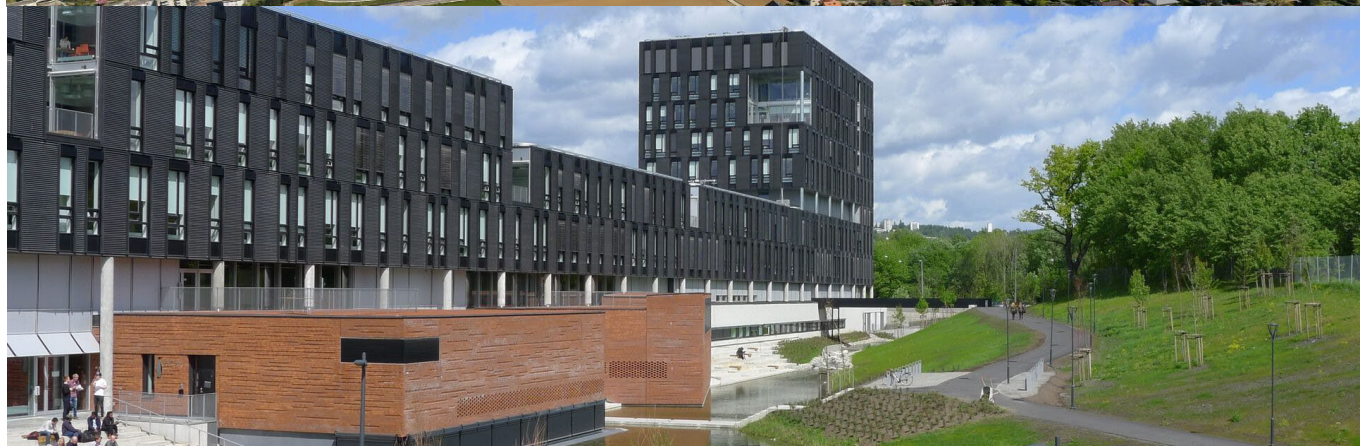
Information Modelling Framework for Addressing Information Fragmentation in Systems Engineering

Dimitris Kyritsis (Kiritsis)

- *Professor Emeritus of ICT for Sustainable Manufacturing, EPFL*
- *Senior Adviser, UiO*

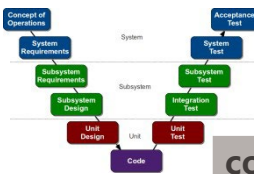
dimitris.kiritsis@epfl.ch

dimitrky@ifi.uio.no





Standards



Process



Business model



Electronic engineers



Software



Project managers



System Engineers



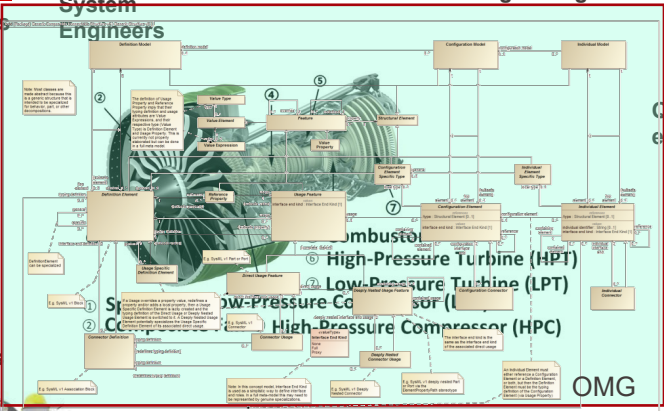
Mechanical Engineers



Testers



Training managers



OMG



Domain engineers...



IT managers



Information



Data...



Knowledge



Model...



Quality engineers



Safety engineers

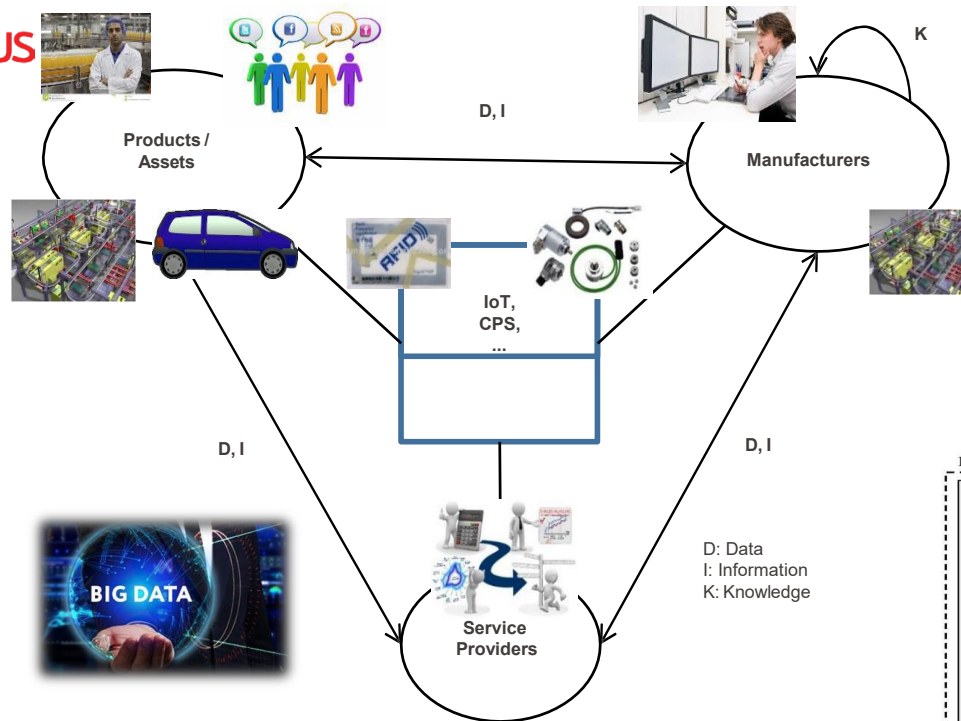


Stakeholders

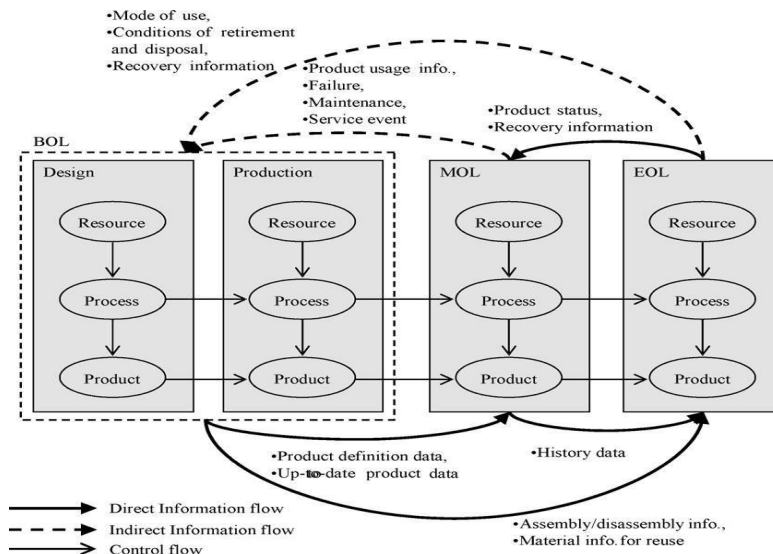


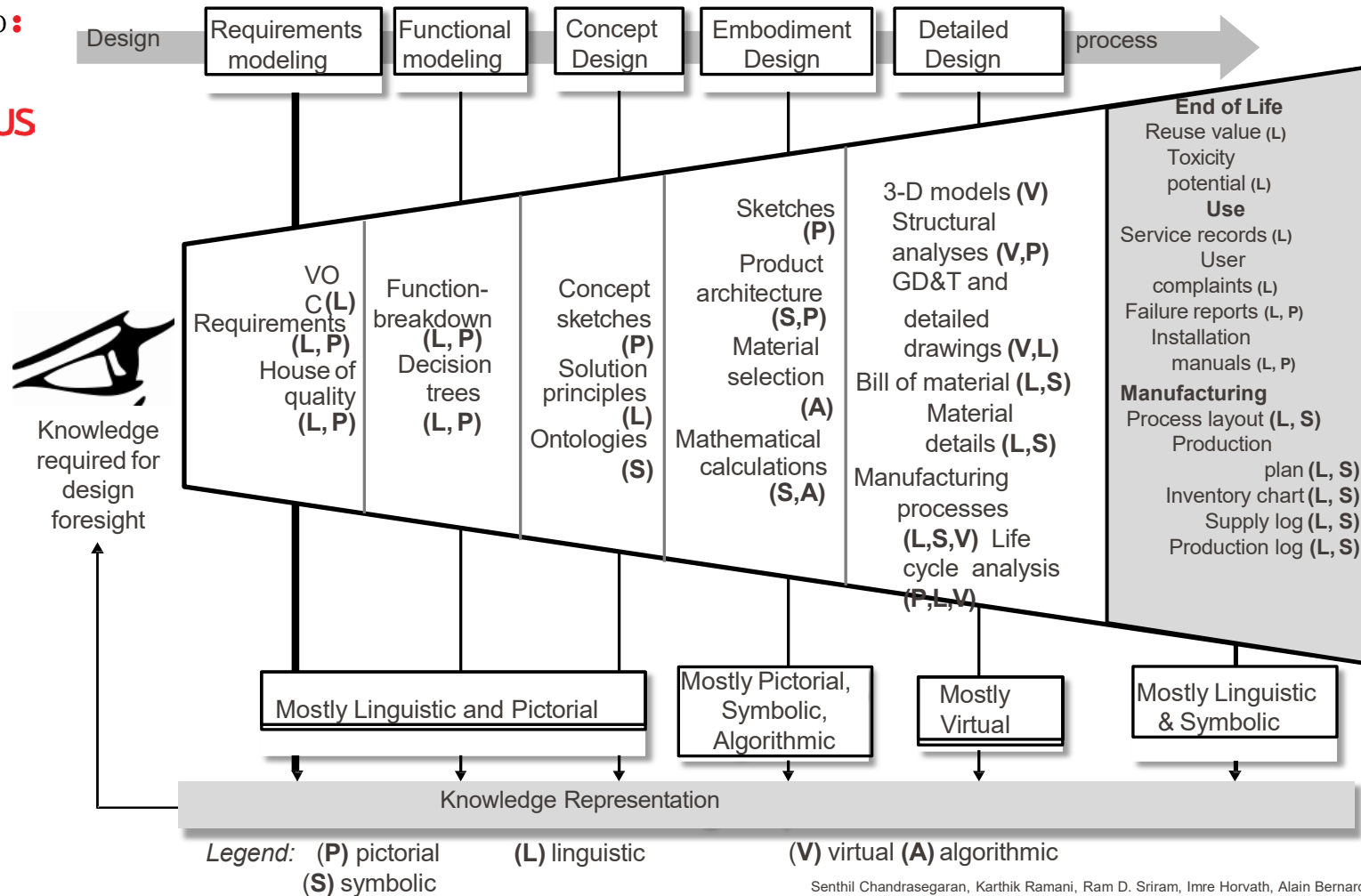
Efficiency

It is all about Big Life Cycle Data Transformations



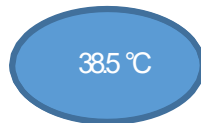
- Closed-Loop Life cycle Data-Information-Knowledge Transformations
- Semantic Model-Based Systems Engineering for Industrial Data Analytics





The Meaning of Data

Body
temperature



Oven
temperature



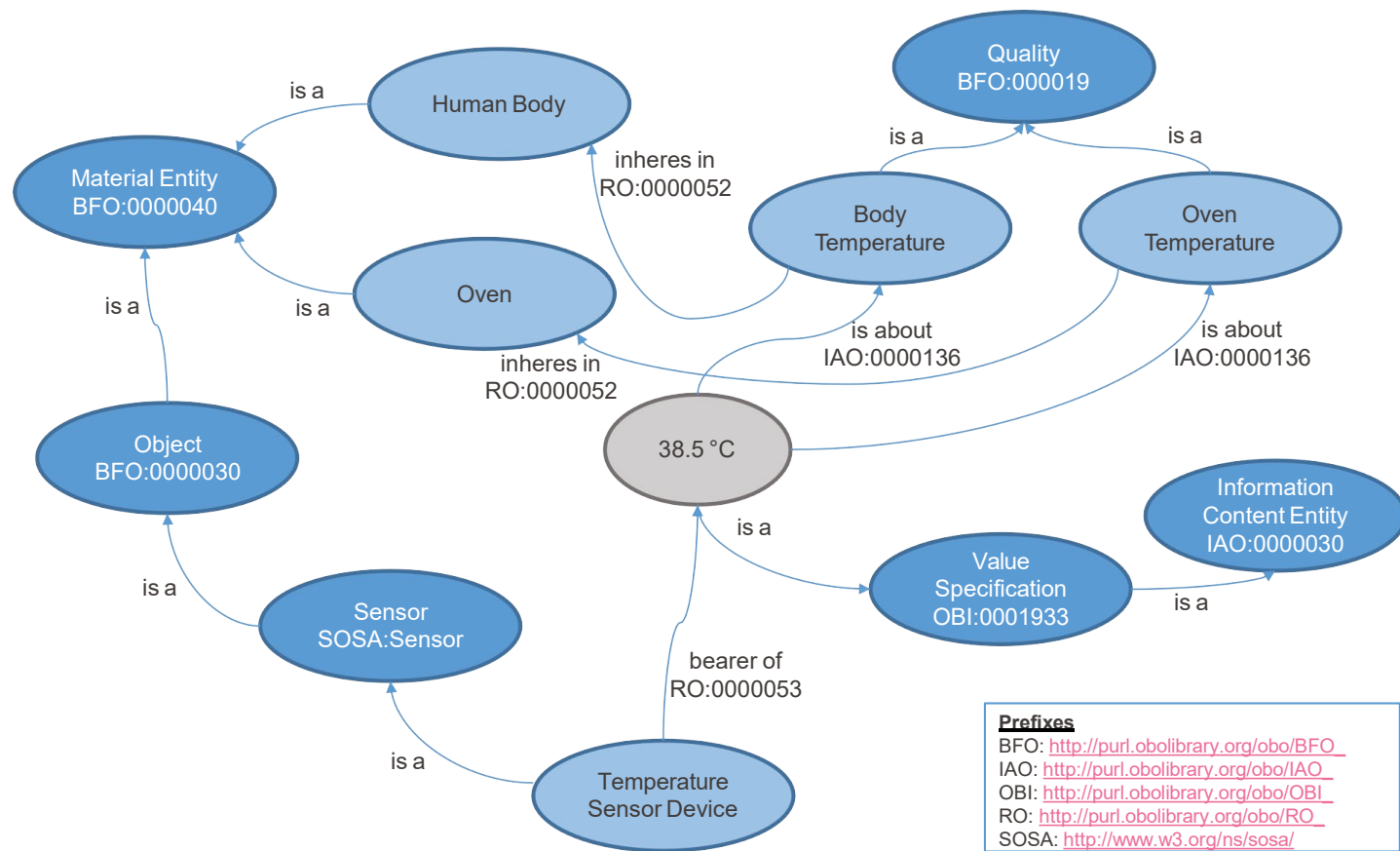
Ontologies allow the interpretation of the right meaning of data

Reasoning

Domain disambiguation

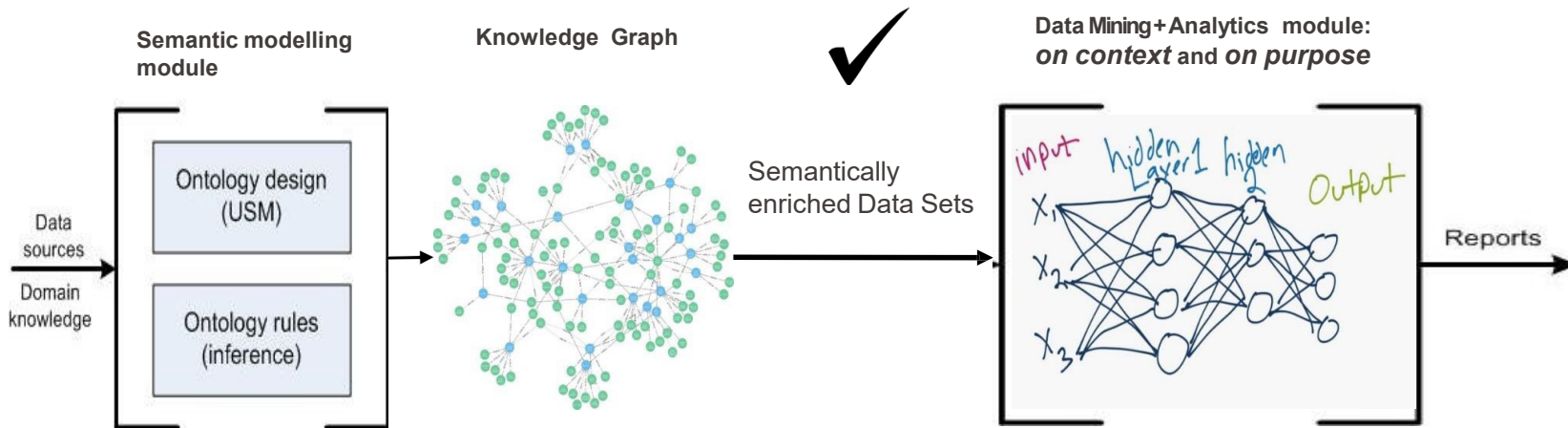
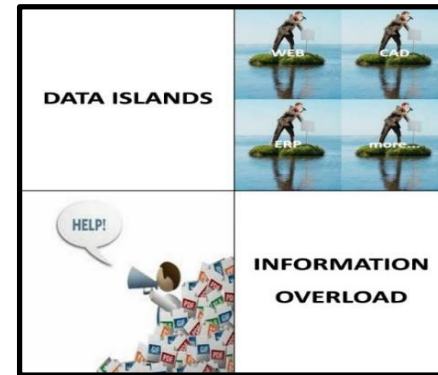
Data Silos

Capturing the Meaning of Data with Ontology



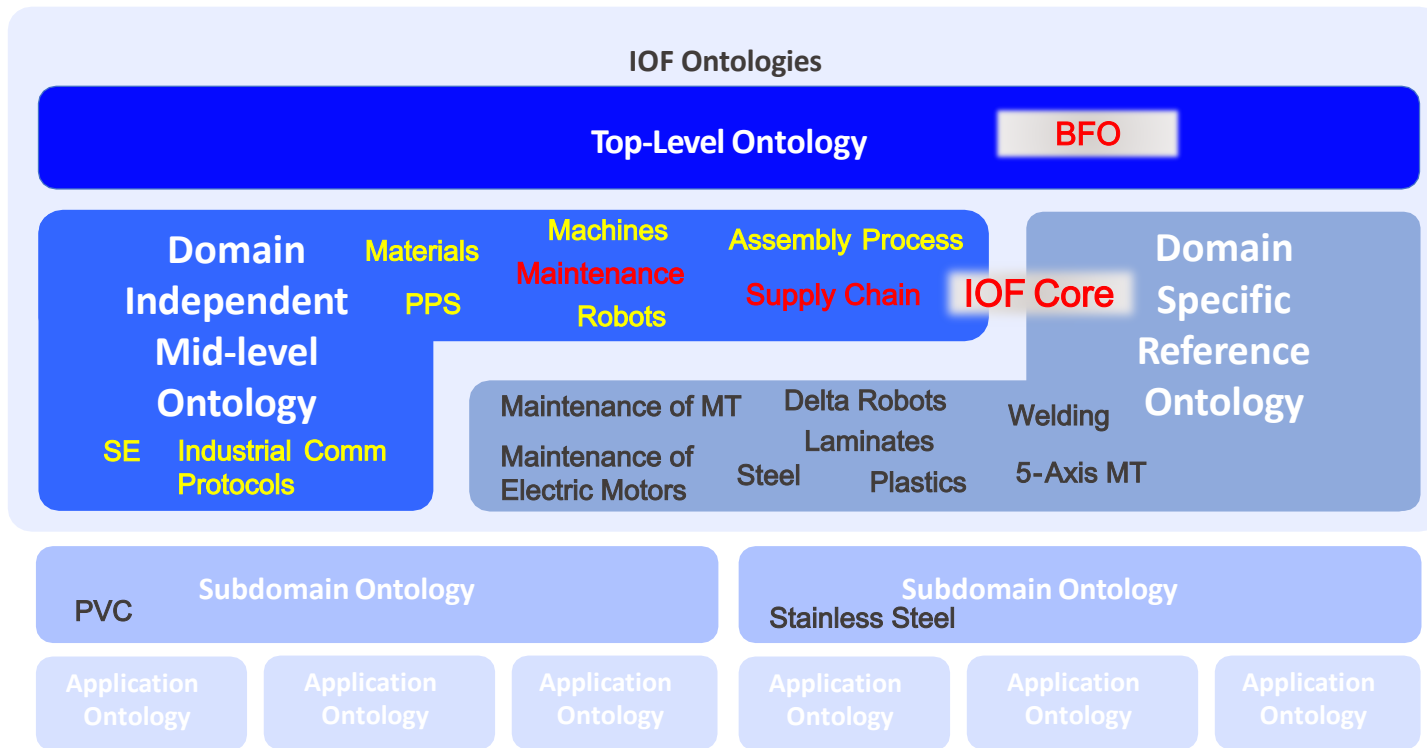
Ontologies & Big Data

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





- SIRIUS 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/>

SPECIFICATIONS

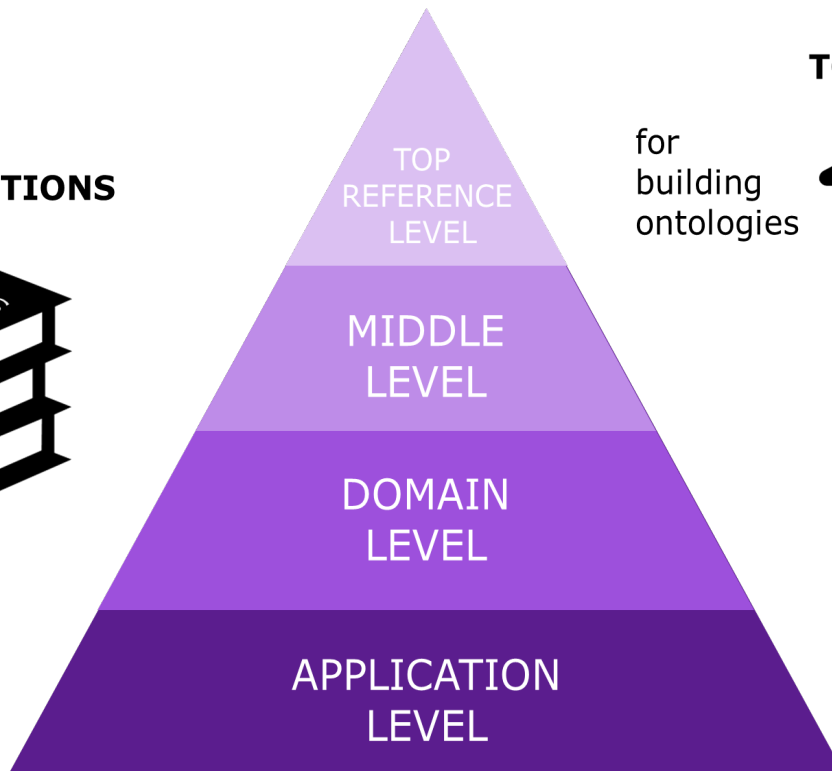


TOOLS

for
building
ontologies



for data
documentation



ONTOLOGIES



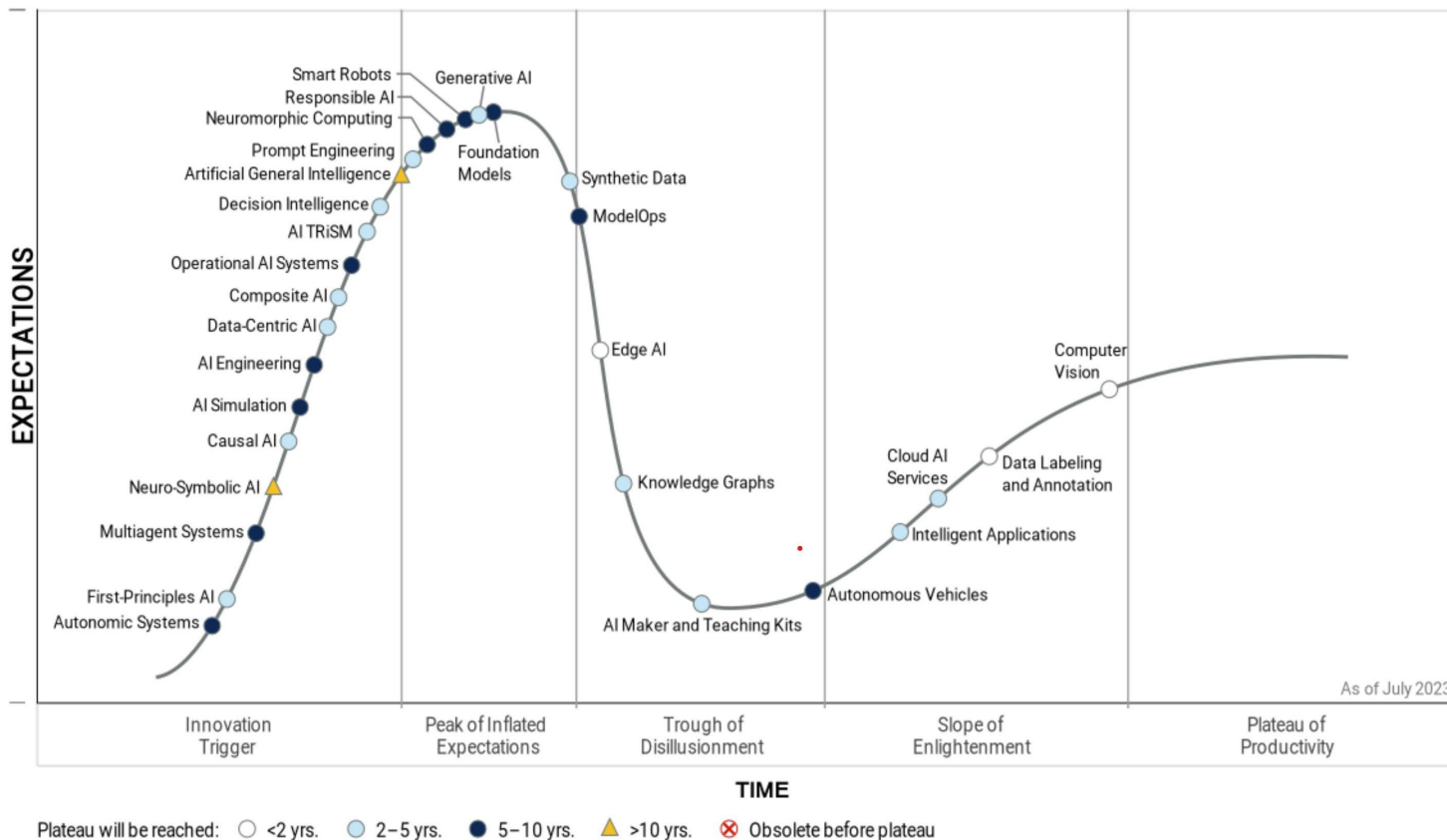
KNOWLEDGE GRAPH ALLIANCE

Data to Wisdom:

KGA is pioneering the future of Knowledge-Driven Innovation

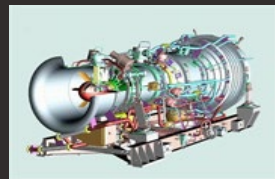
80% of data will be stored in KGs by 2025

Hype Cycle for Artificial Intelligence, 2023





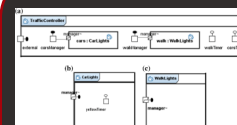
interface



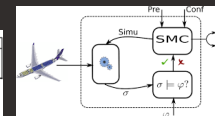
CAD



FEM models

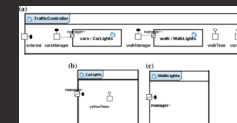


Model checking models

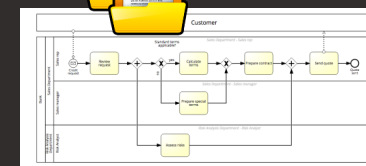


Realtime model...

Testing models

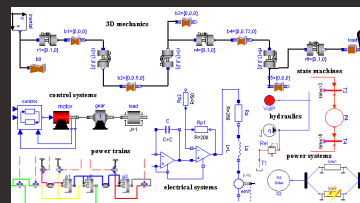


Property models

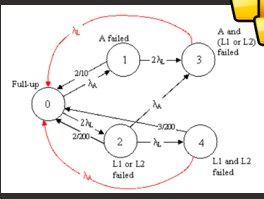


BPMN...

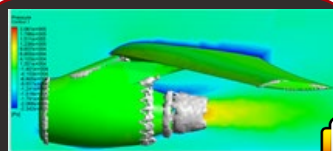
Process models...



Performance models



Analysis Models



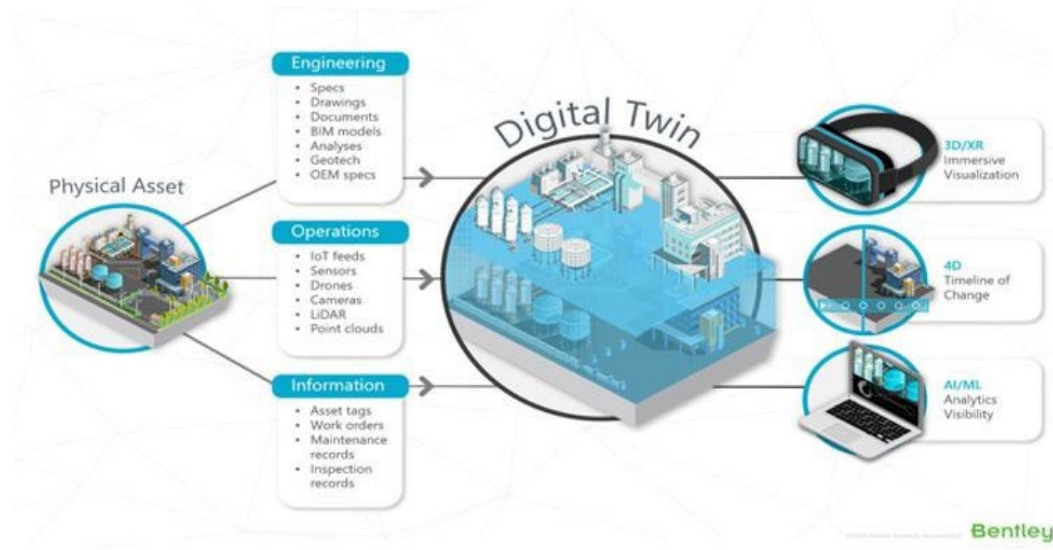
CFD models



What is a Digital Twin?

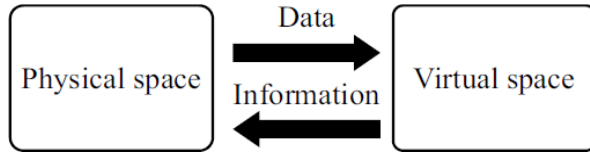
- A digital twin is a **digital representation of a physical object, process or service**.
 - ❑ A digital twin = **digital replica of an object in the physical world**, such as a jet engine, wind farms, or even larger items such as buildings or whole cities.
 - ❑ As well as physical assets, the **digital twin technology can be used to replicate processes in order to collect data to predict** how they will perform.

Example:



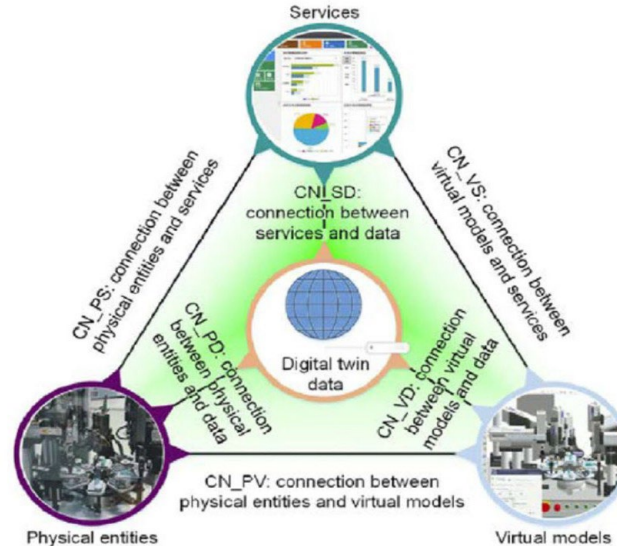
Source: Presentation by Anne-Marie Walters of Bentley Systems at
ARC India's Virtual Forum

- The 3-dimensional digital twin model proposed by Grieves (2014)



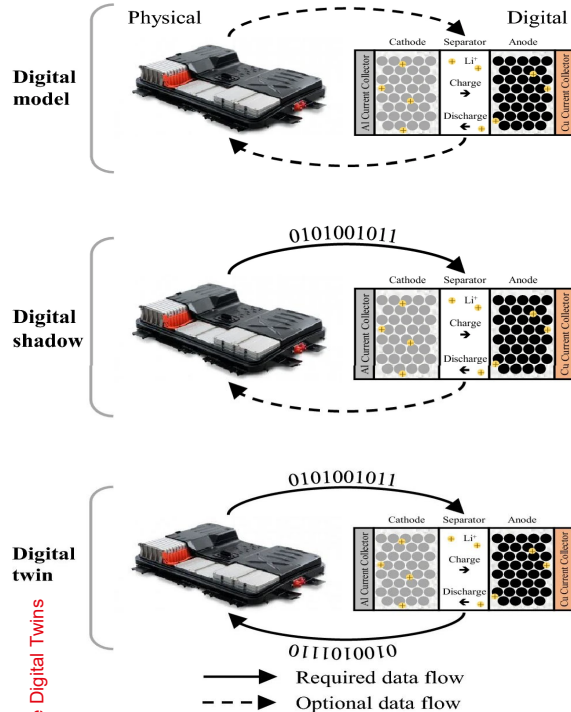
The 3-dimensional digital twin model consists of a physical space, a virtual space, and connections between them.

- The 5-dimensional digital twin model by Tao et al. (2018).



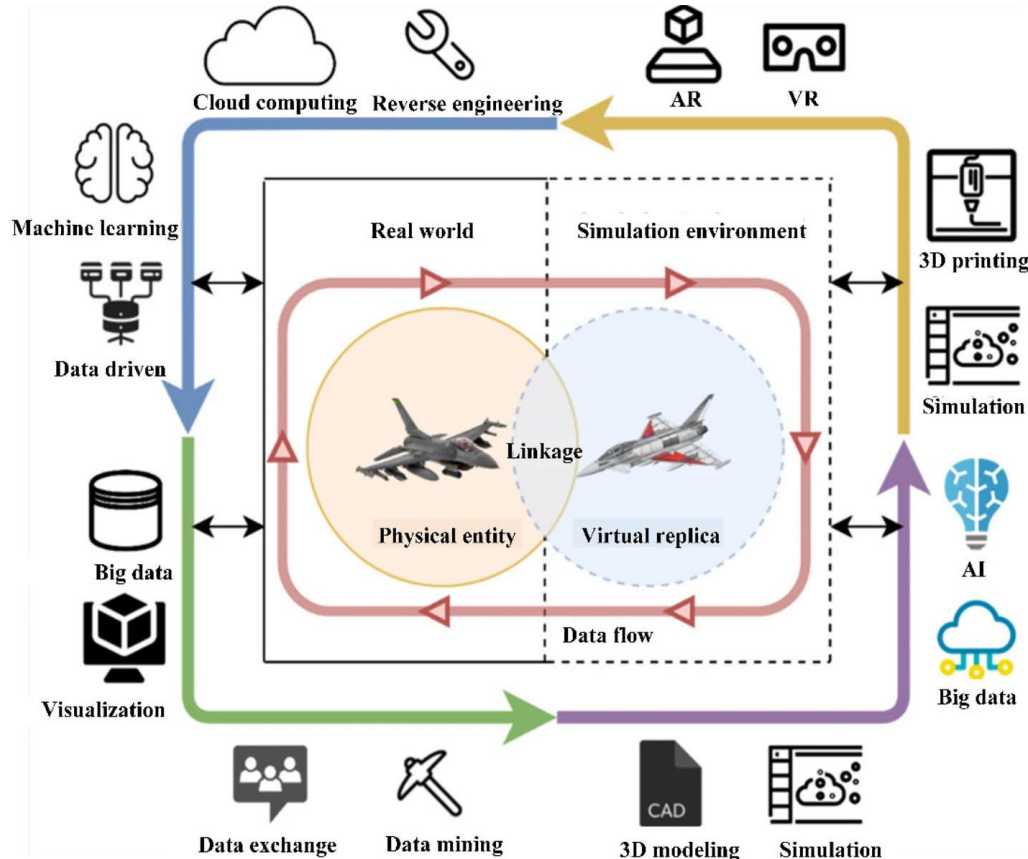
The 5-dimensional digital twin model consists of a *physical system (PS)*, a *digital system (DS)*, an *updating engine (P2V)*, a *prediction engine (V2P)*, and an *optimization dimension (OPT)* and $F(\cdot)$ integrates all five dimensions together.

concept for a lithium-ion battery cell



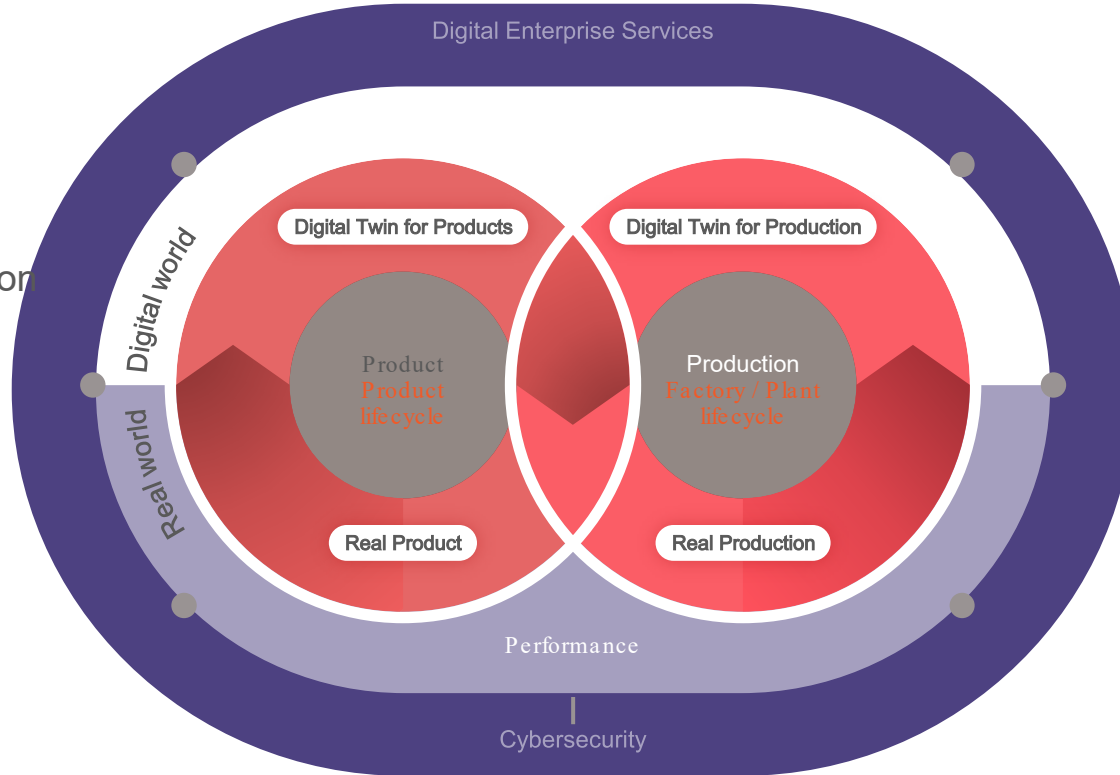
- **Digital model:**
- data flow between the physical space and virtual space is optional, or at the very most, achieved manually.
- **Digital shadow:**
- data flow is unidirectional from physical to digital.
- **Digital twin:**
- data flow is bidirectional. In control-related applications, the bidirectional data flow needs to be automatic, often enabled by monitoring and control software.

Digital Twins and related technologies

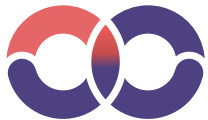


Digital Twins in *Manufacturing Data Networks*

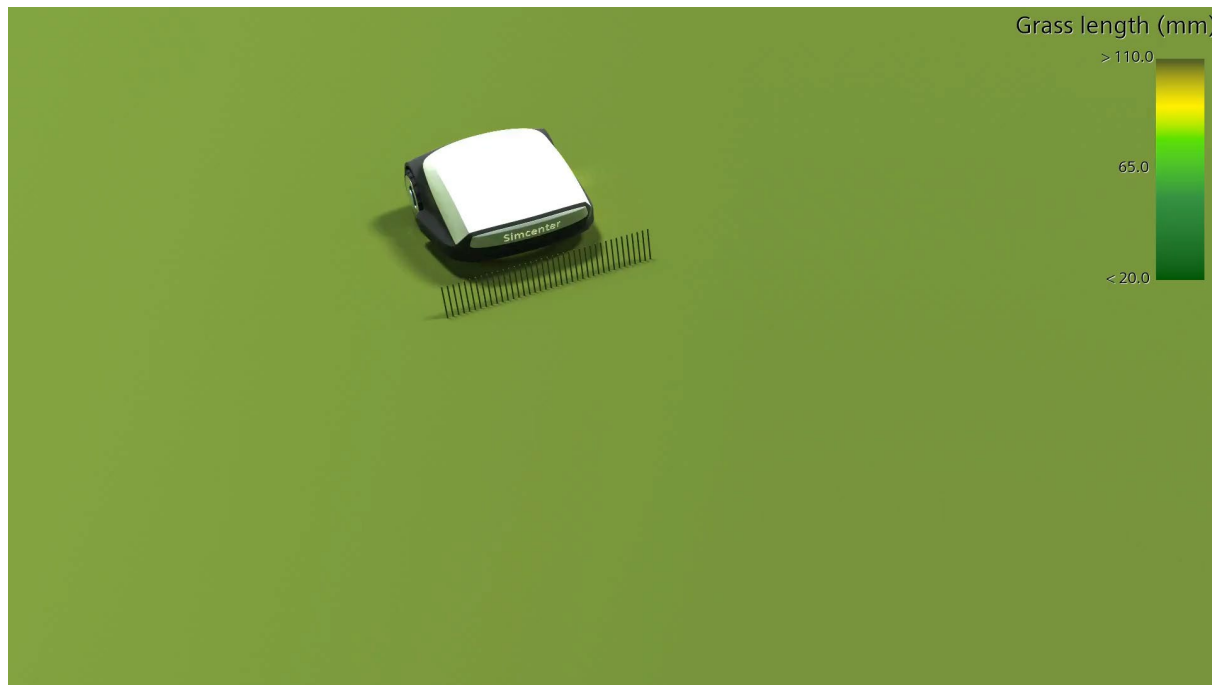
The comprehensive Digital Twin approach allows the realistic simulation and validation of products, machines, lines and complete plants

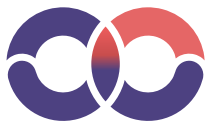


They're the foundation for flexible and efficient manufacturing

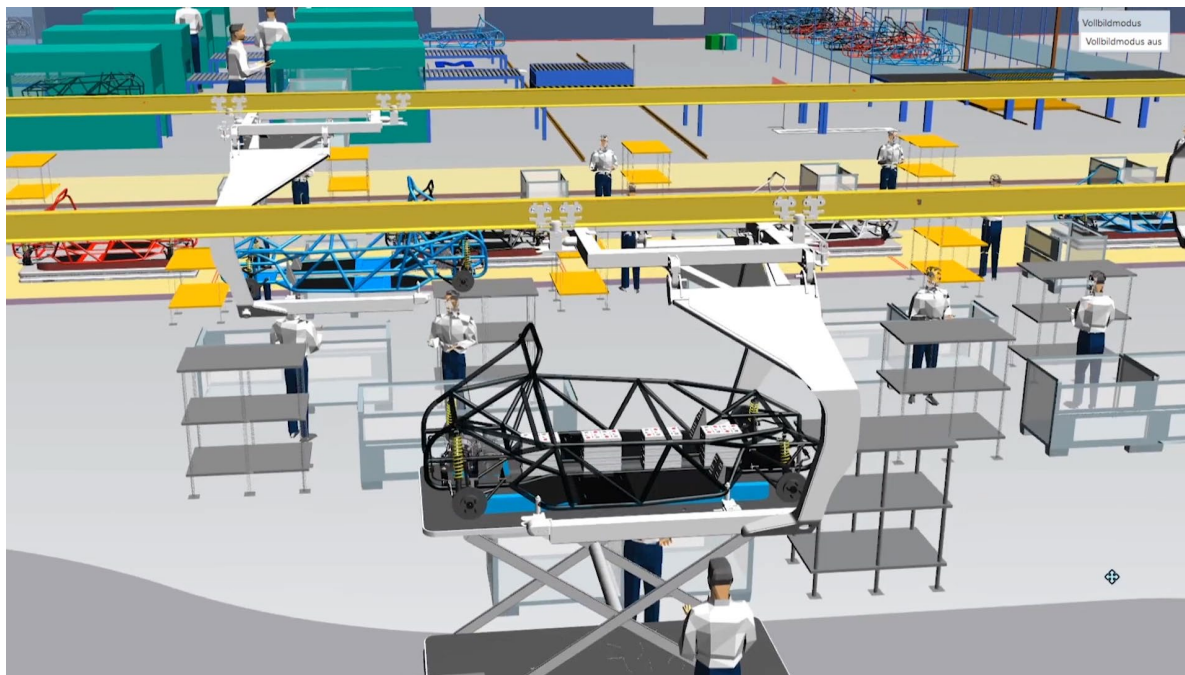


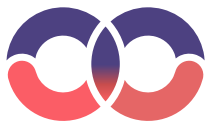
Design, simulate,
and verify products
digitally, including
mechanics and multi-
physics, electronics
and software
management





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





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



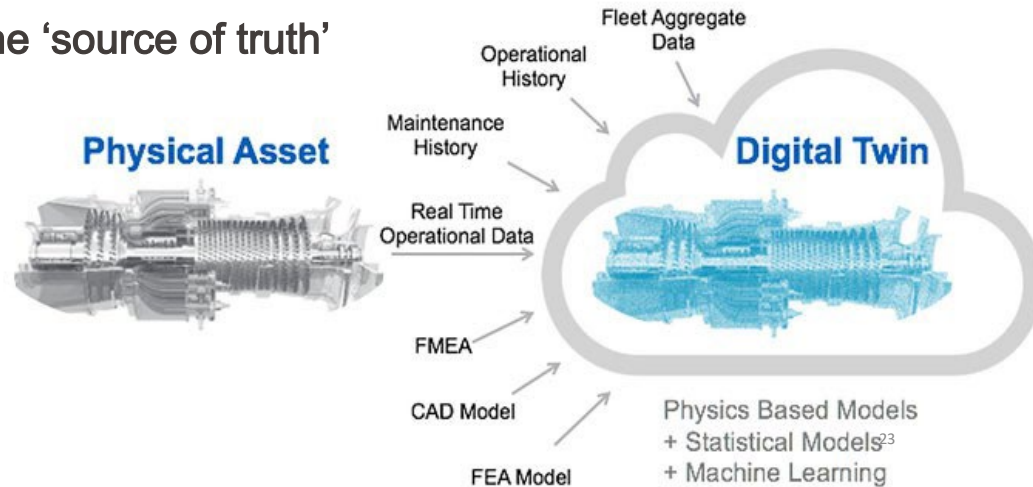
(Virtual) Metrology data can be integrated

Slide produced by SIEMENS-CH

Three main purposes to implement a DT:

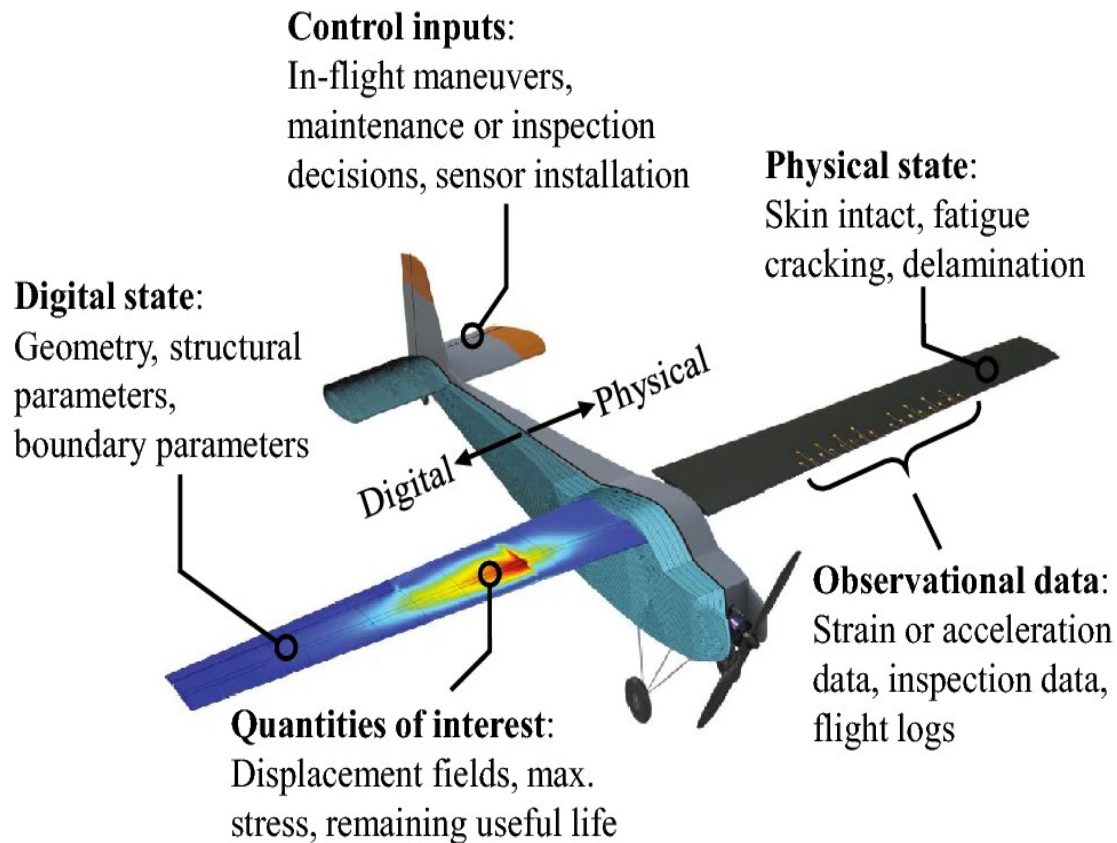
- A PRODUCT Digital Twin – to guarantee reliable design in product development and improvements.
- A PRODUCTION Digital Twin – to improve production planning and manufacturing.
- A PERFORMANCE Digital Twin – to capture, analyse and act on data while an asset is in operation.

One 'source of truth'



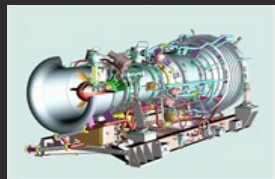
The Asset Owner gathers necessary data to feed modelling and simulation software solutions to support decision making at several operational levels, e.g. system operation or maintenance activities.

Example: the Digital Twin of an airplane

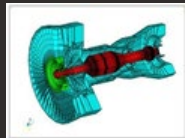




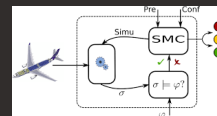
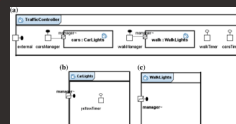
interface



CAD



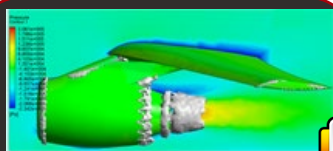
FEM models



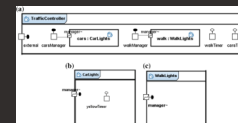
Realtime model...

Model checking models

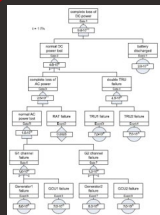
Testing models



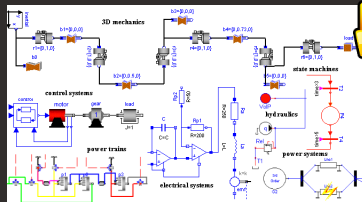
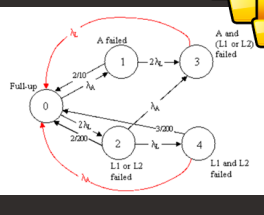
CFD models



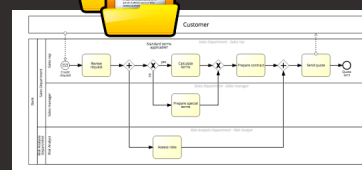
Property models



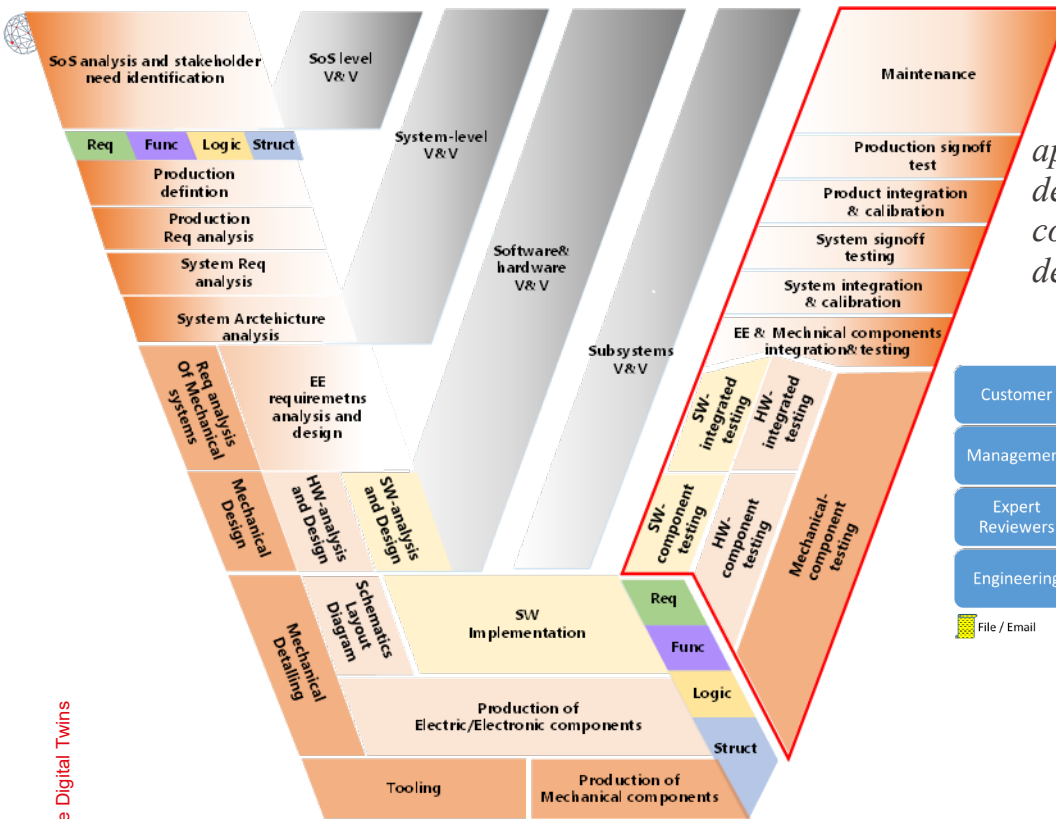
Analysis Models



Performance models

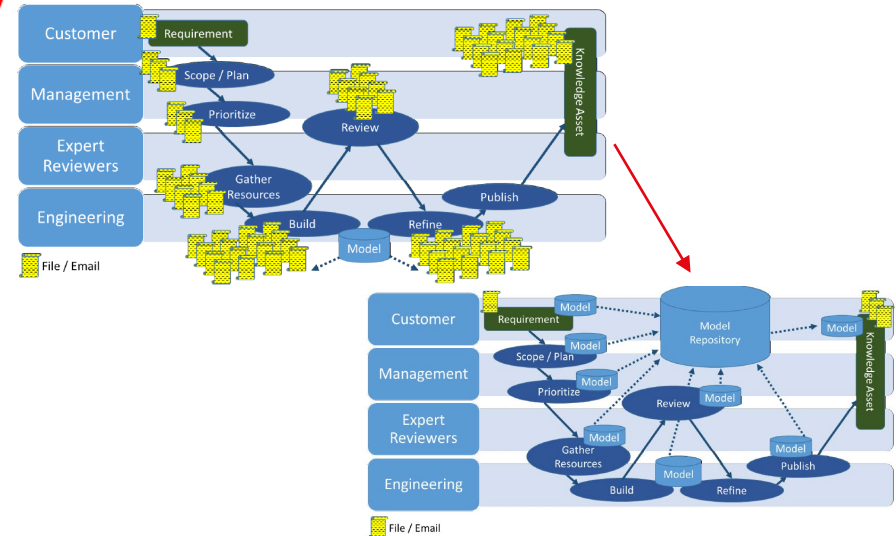


Process models...

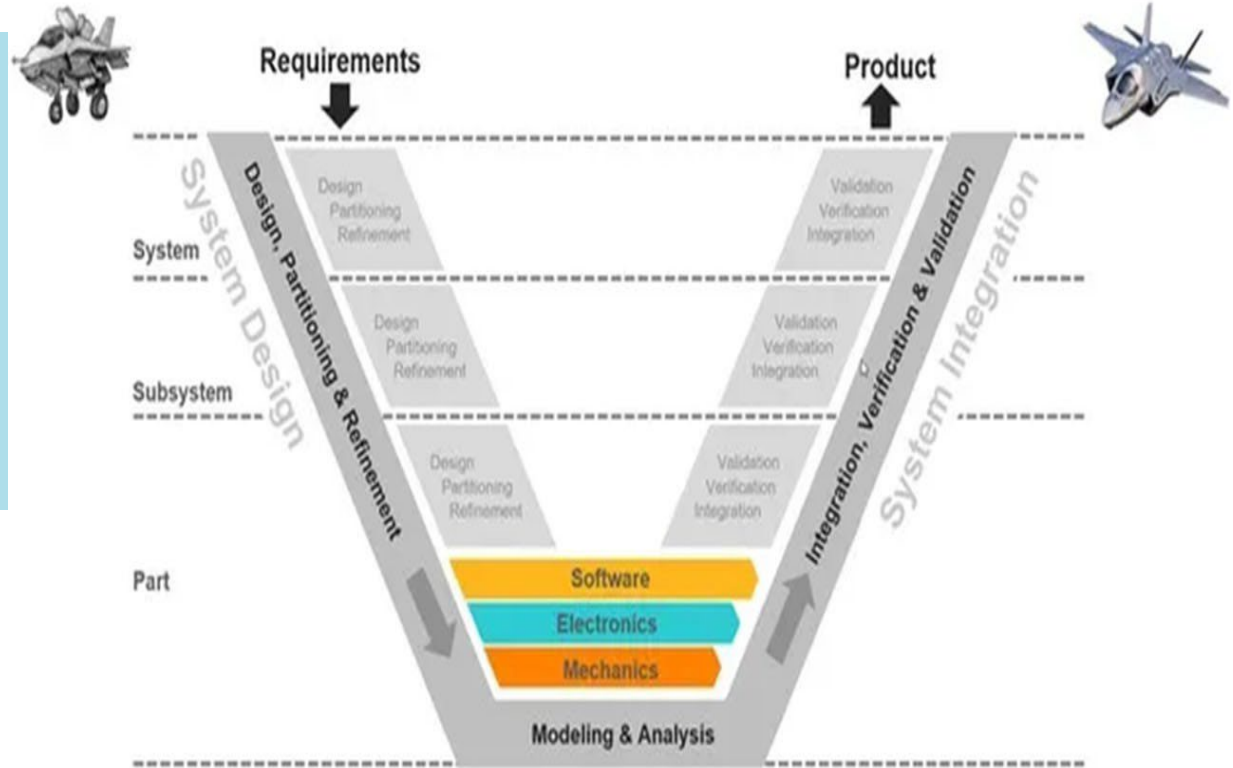


“Model-based systems engineering is the formalized application of modeling to support system requirements, design, analysis, and V&V activities beginning in the conceptual design phase and continuing throughout development and later lifecycle phases.”

INCOSE VISION 2020

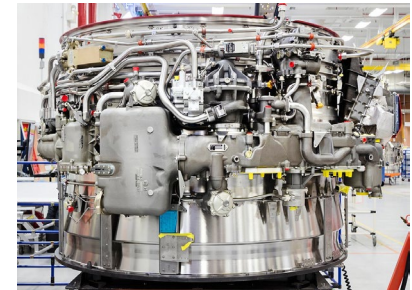
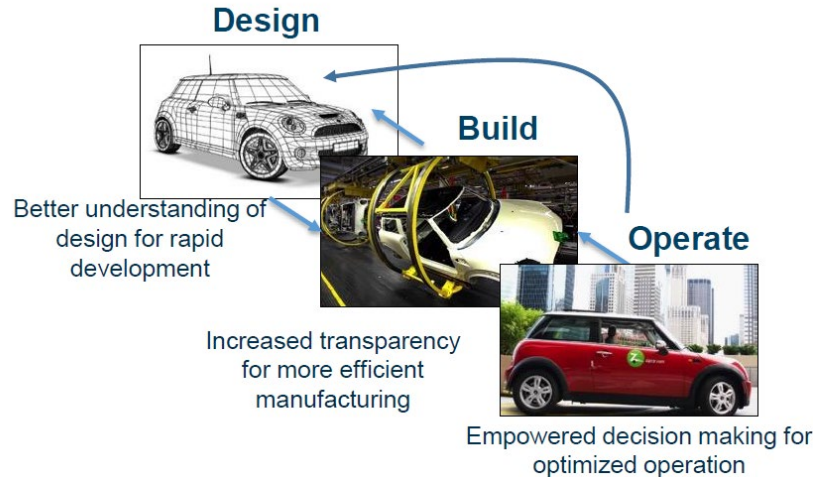


- 200,000 parts made by 1,600 suppliers
- houses 3,500 integrated circuits
- >20,000,000 lines of software code.
- designers face hugely intricate hardware/software interaction and interactions at the system level across multiple domains —mechanical, electronic, thermal, etc.



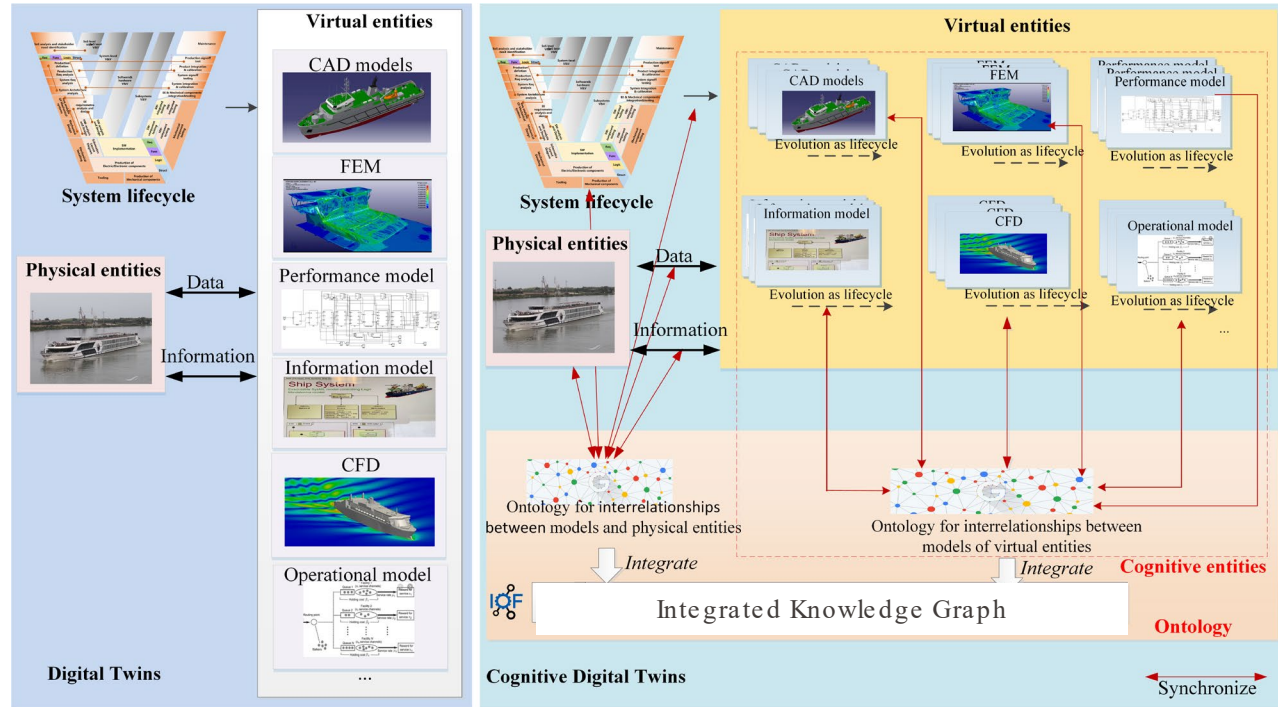
DT Challenges

- 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



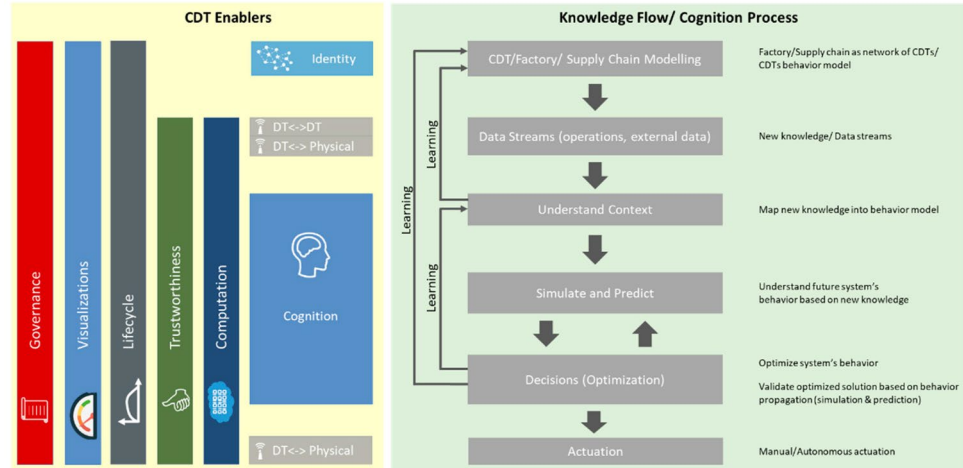
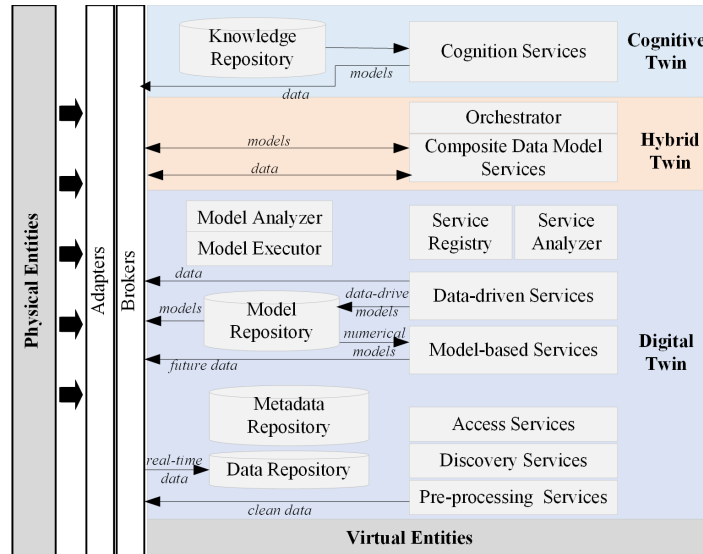
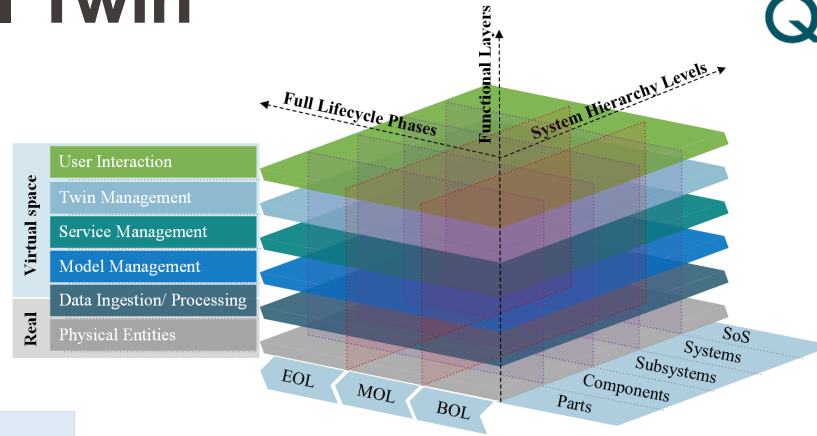
Cognitive Digital Twin

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.

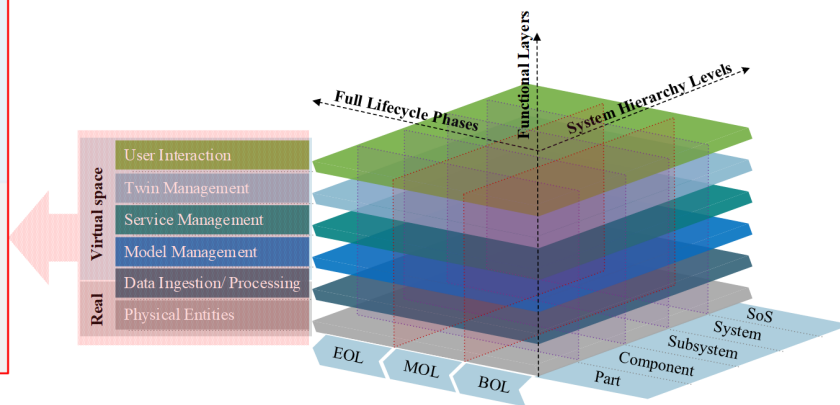
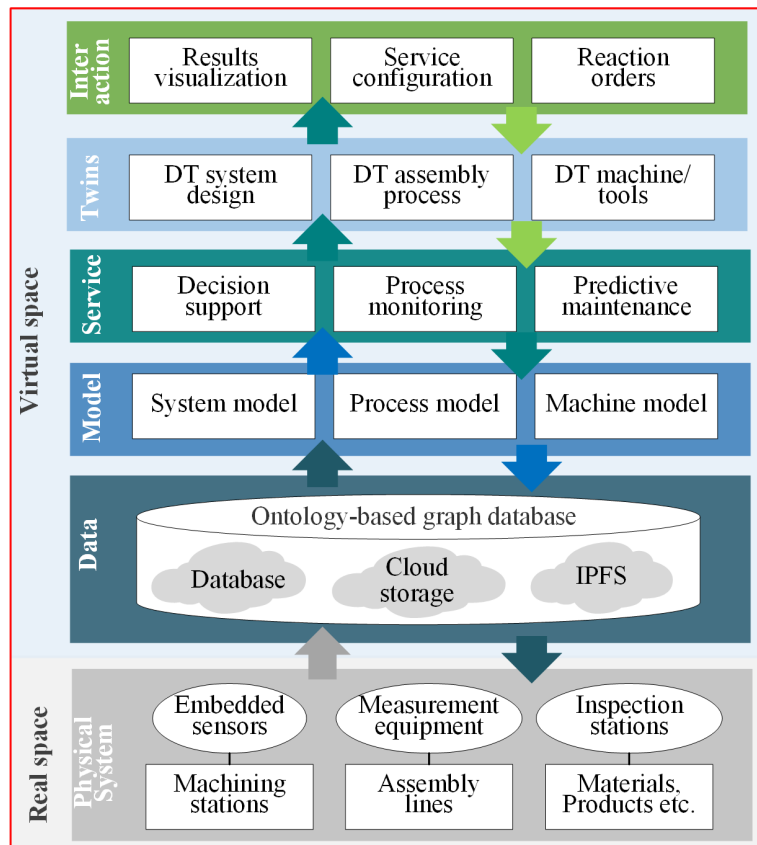


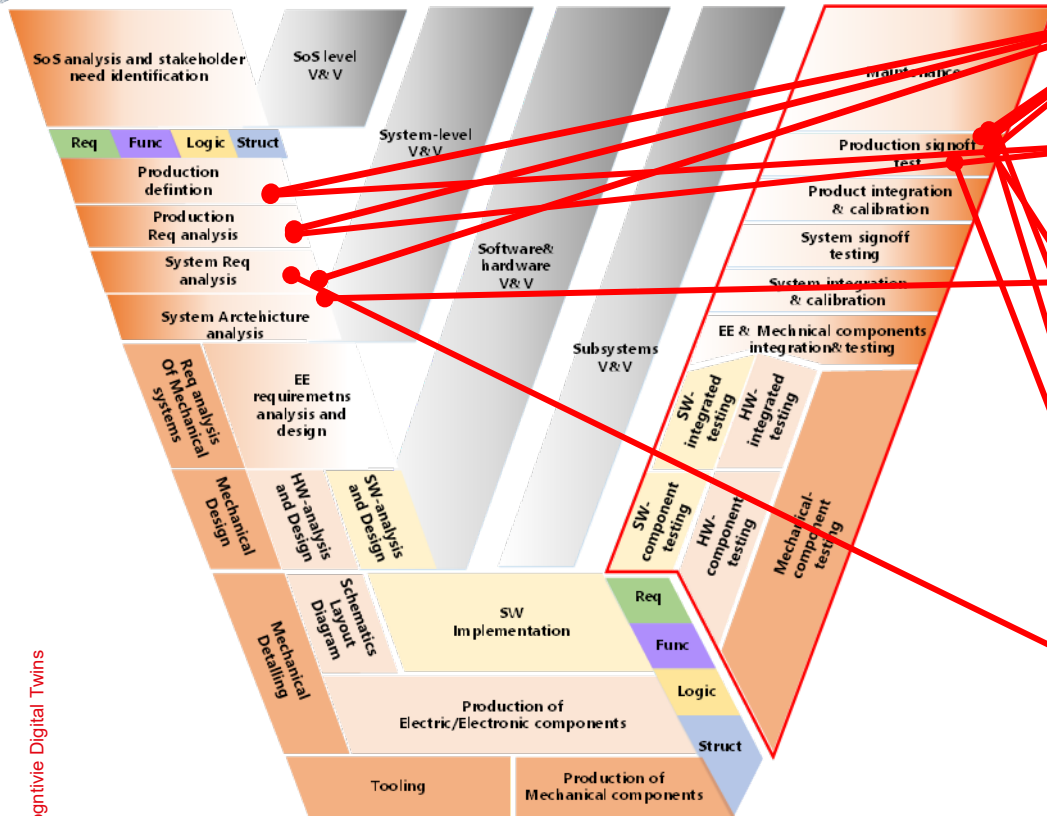
Reference Architecture

- Full lifecycle phases
- System Hierarchy levels
- Functional layers



- Multiple lifecycle phases:





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.

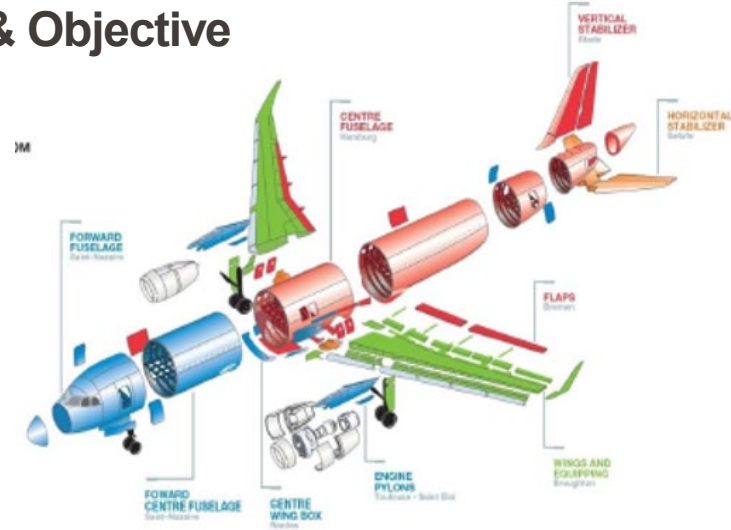
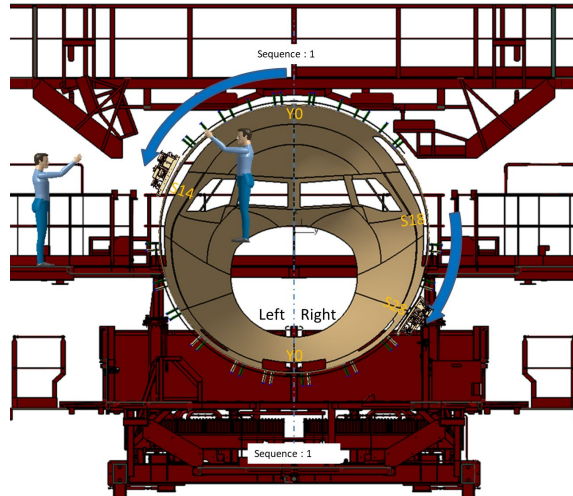
ARCHITECTURE
Semantic MBSE is used to implement MOFLP approach for assembly based on ontology.

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.

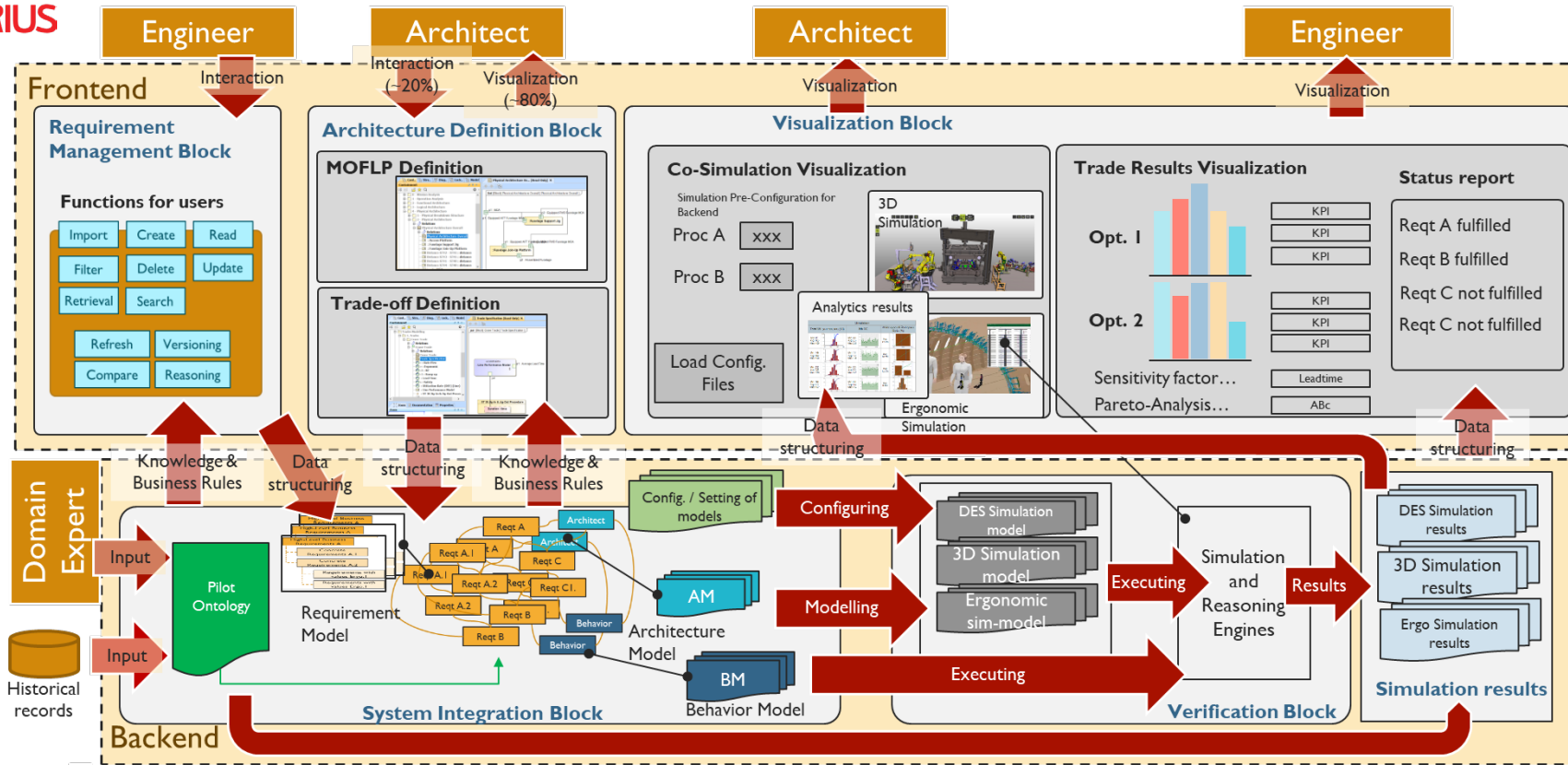
The goal of this pilot is to enable an **MBSE and collaborative design process** between the Aircraft and Industrial system domains, overcoming bottlenecks concerning knowledge management, interoperability and decision making in the design process.

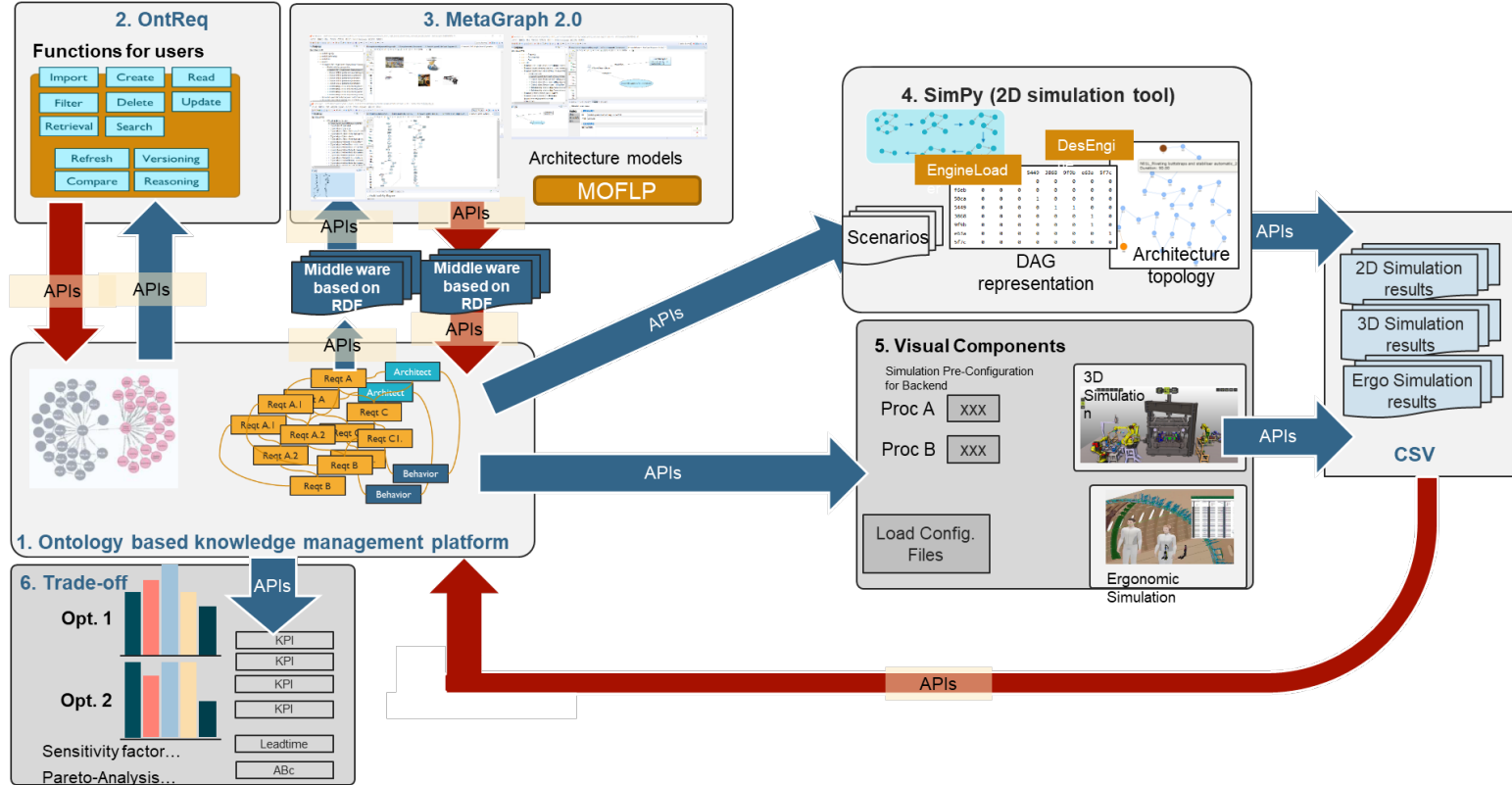


The **Use Case** is the design process of the Aircraft **fuselage orbital joint process**, in the Final Assembly Line (FAL) to be reconfigured / redesigned for new industrializations...

MVP5 final prototype enables Orbital Joint Process trade-off analysis, by generating and simulating all possible design alternatives based on defined requirement targets.

Prototype Functional Architecture





The QU4LITY AIRBUS demonstrator



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



UiO

EPFL



SIRIUS

The QU4LITY AIRBUS demonstrator

QU4LITY

35

■ Cognitive Digital Twins

AIRBUS

EPFL

Fraunhofer

VISUAL
COMPONENTS

ICT4SM

Challenges and future directions of Digital Twins (1)

- ✓ **The theoretical foundation of DTs must be strengthened**
 - ✓ the emerging research direction of “practice first, concept later,” which is often attached to information technology, big data, artificial intelligence, and IoT in the development process, lack a relevant theoretical basis in research.
- ✓ **The virtual modeling technology of DTs must be improved**
 - ✓ DT engineering remains a complex process in any type of industry. It involves not only the spatial modeling of the geometric structure and positional relationships of objects but also the logical modeling of mechanistic and regular models of these entities requiring interdisciplinary cooperation.
- ✓ **The evaluation criteria for DTs should be more rigorous**
 - ✓ systems that evaluate the degree of development of existing DTs and clarify the direction of DT construction to guide upgrading and optimization, are still lacking.
- ✓ **Standardization and adoption**



Challenges and future directions of Digital Twins (2)

✓ Integration of related technologies

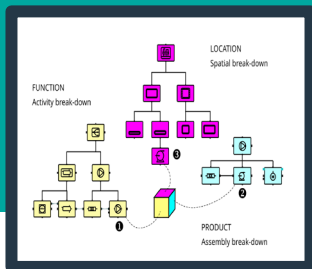
- ✓ The implementation of DT technology relies on industrial information systems, IoT, artificial intelligence, big data, and other technologies.

✓ Continuous improvements and deployment in industrial applications

- ✓ With the development of industrial technology and requirements, equipment design, testing, operation, maintenance, and other life cycle costs have increased significantly. Inspired by practical considerations, DTs of complex equipment and of systems-of-systems will become the focus of future research and use.

The Facility Asset Information Modelling Framework

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
aibel
equinor

IMF Version 2.1

DNV

IMF DNV RP

ISO IEC

IMF ISO/IEC standard

Q1 2021

Background

Q2 2023

As-is

Q1 2024

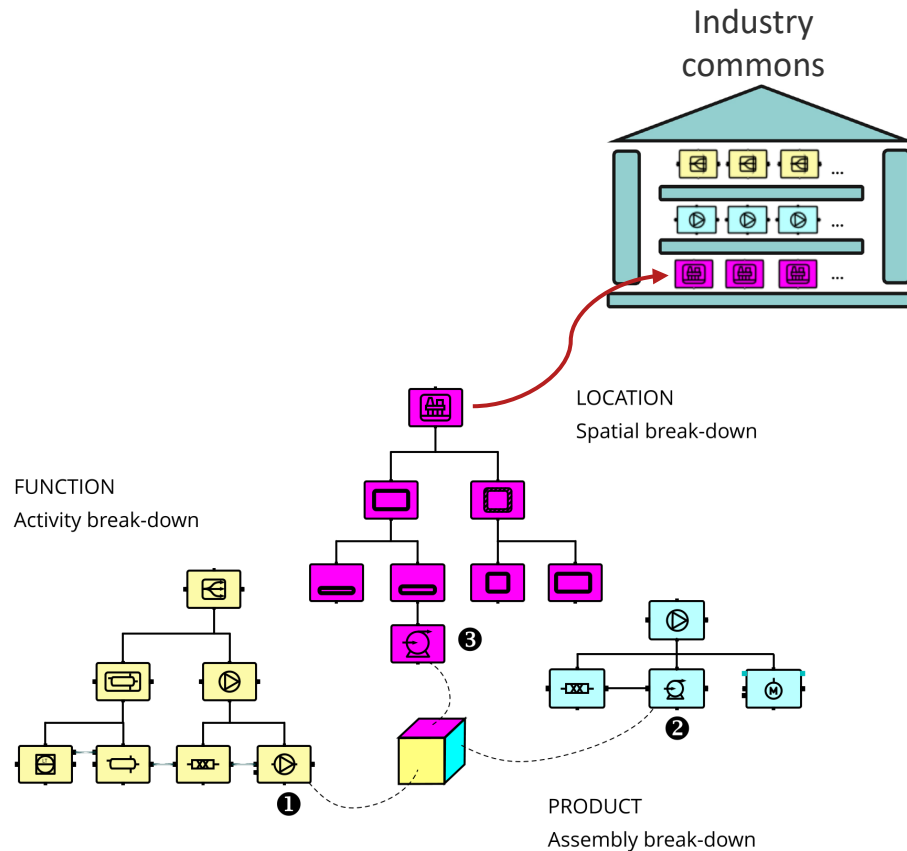
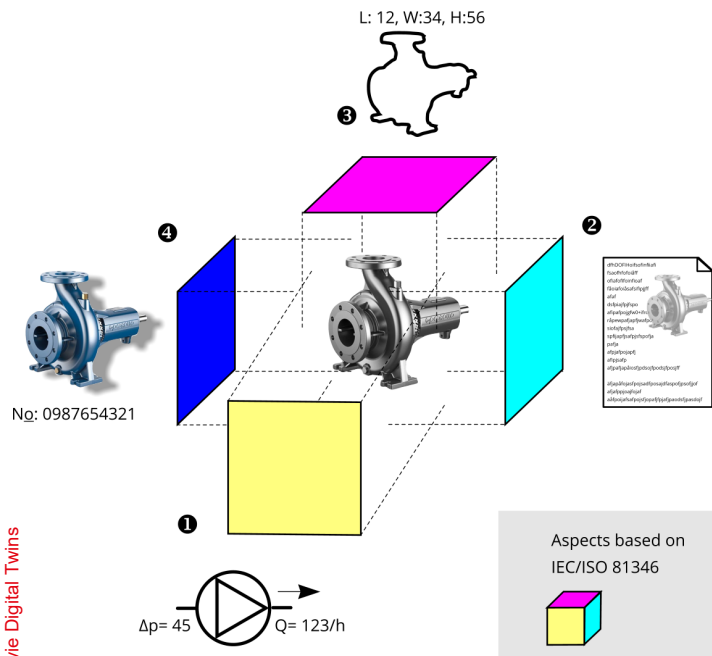
Interim step

...

Long term objective

- **The IMF Manual v0.3.0 is available:**
<https://www.imfid.org/#org8afd51b>
- **A Recommended Practice**
DNV-RP-0670
is planned to be published in September 2024

Reserved Aspects in IMF extending ISO/IEC 81346





UiO:

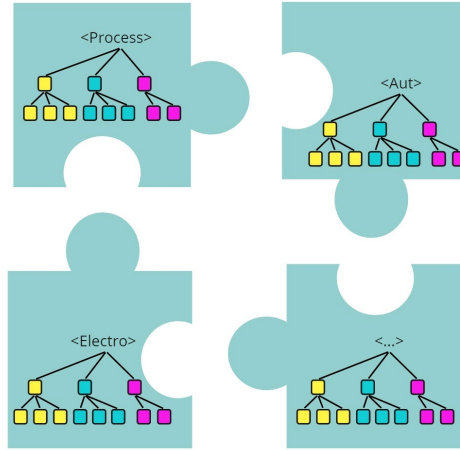
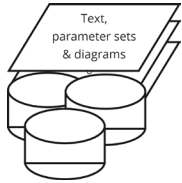
EPFL



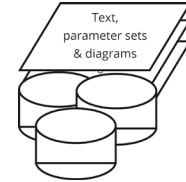
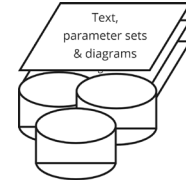
SIRIUS

Easier integration thanks to comparable structures

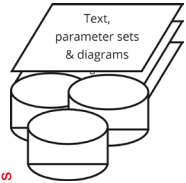
Process



Automation



Electro





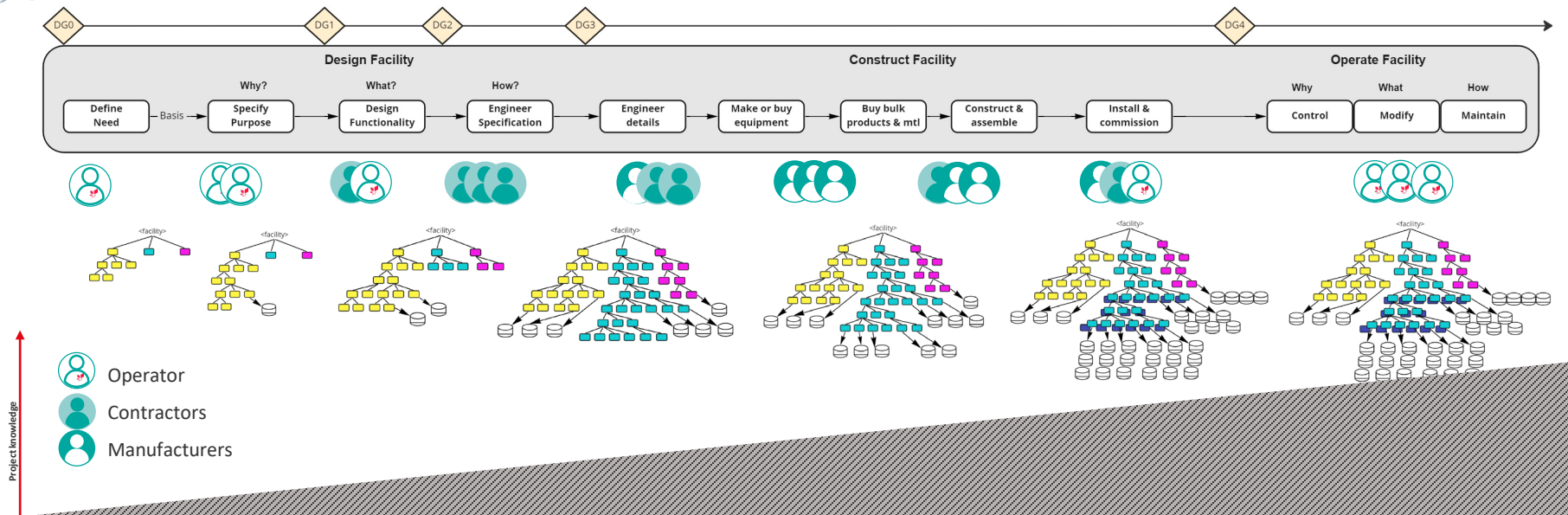
UiO:

The Vision and the Larger Picture

EPFL



SIRIUS



Added values:



Become more effective by hindering loss of information during handovers



Automation of manual procedures possible using machine integrable information models



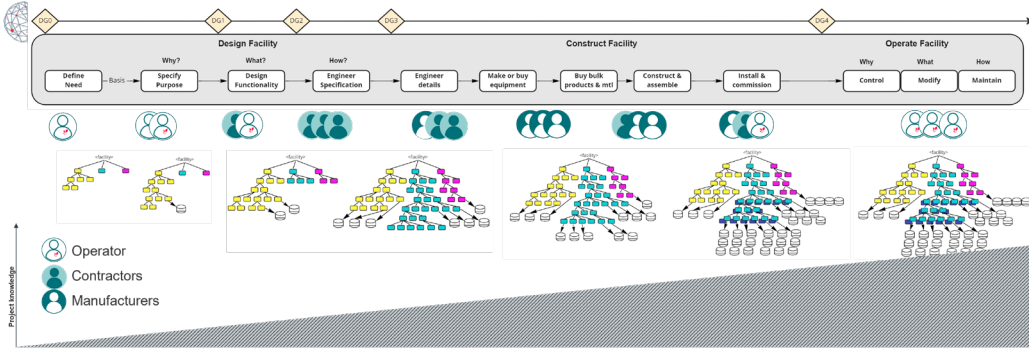
Reduce cost and time spent by the possibility of building in smartness



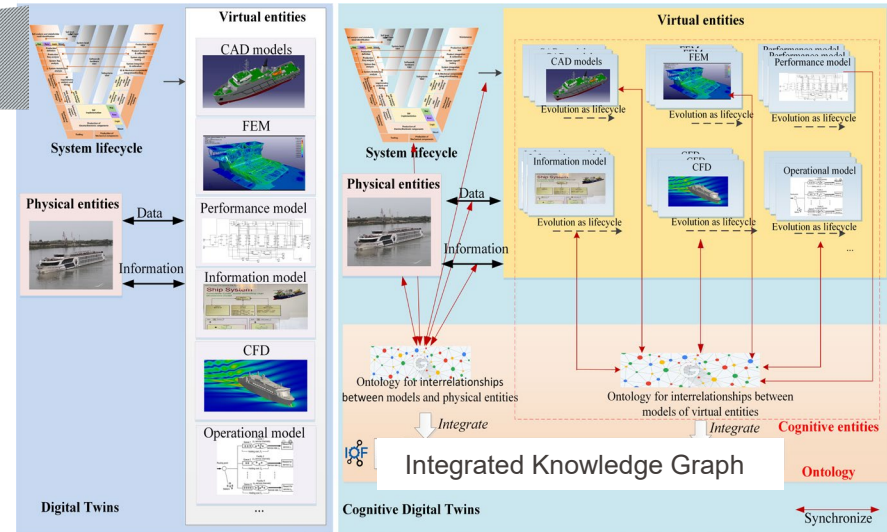
Improved safety and quality by better control of technical information



New business opportunities by combining information in new ways



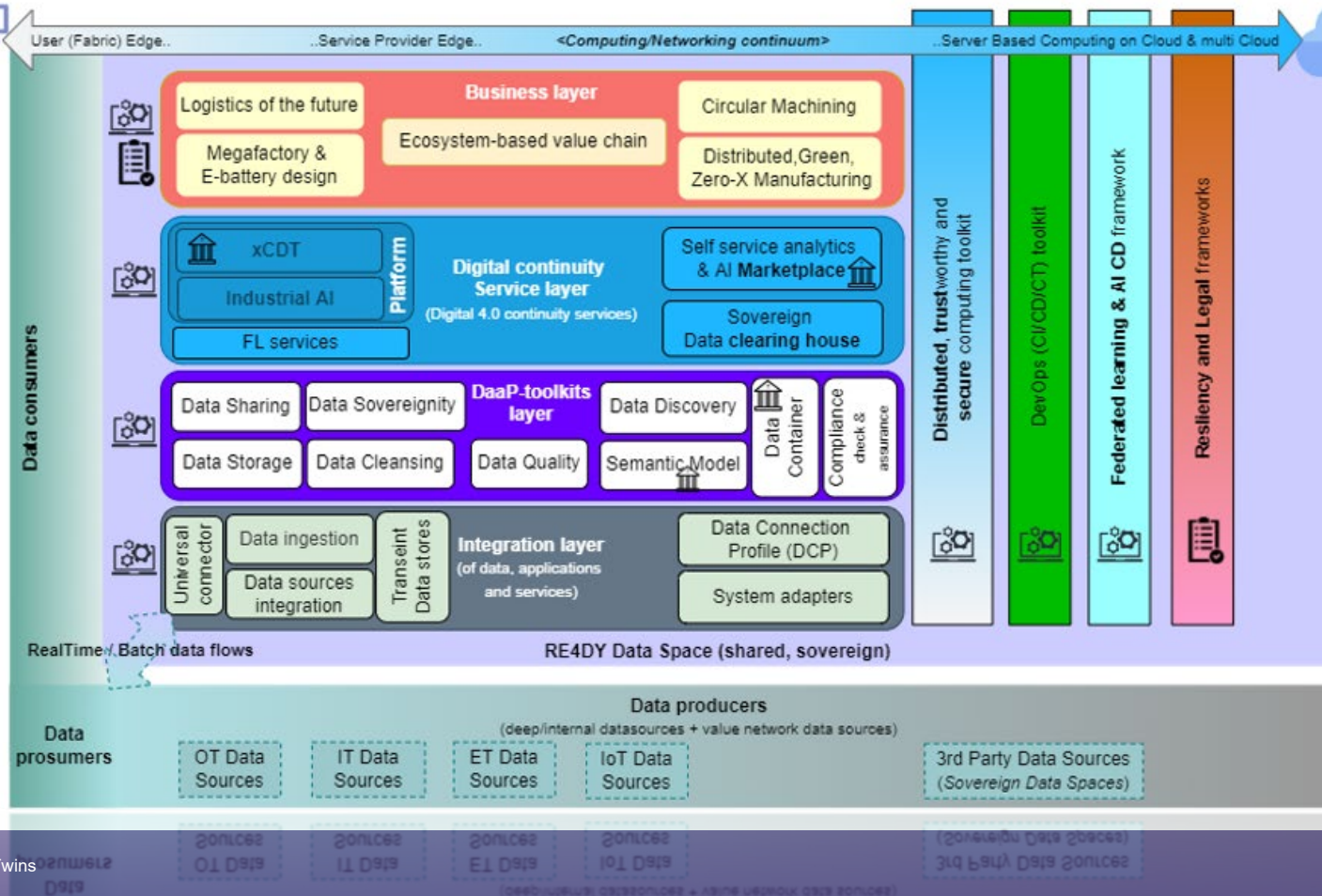
IMF Eco-System



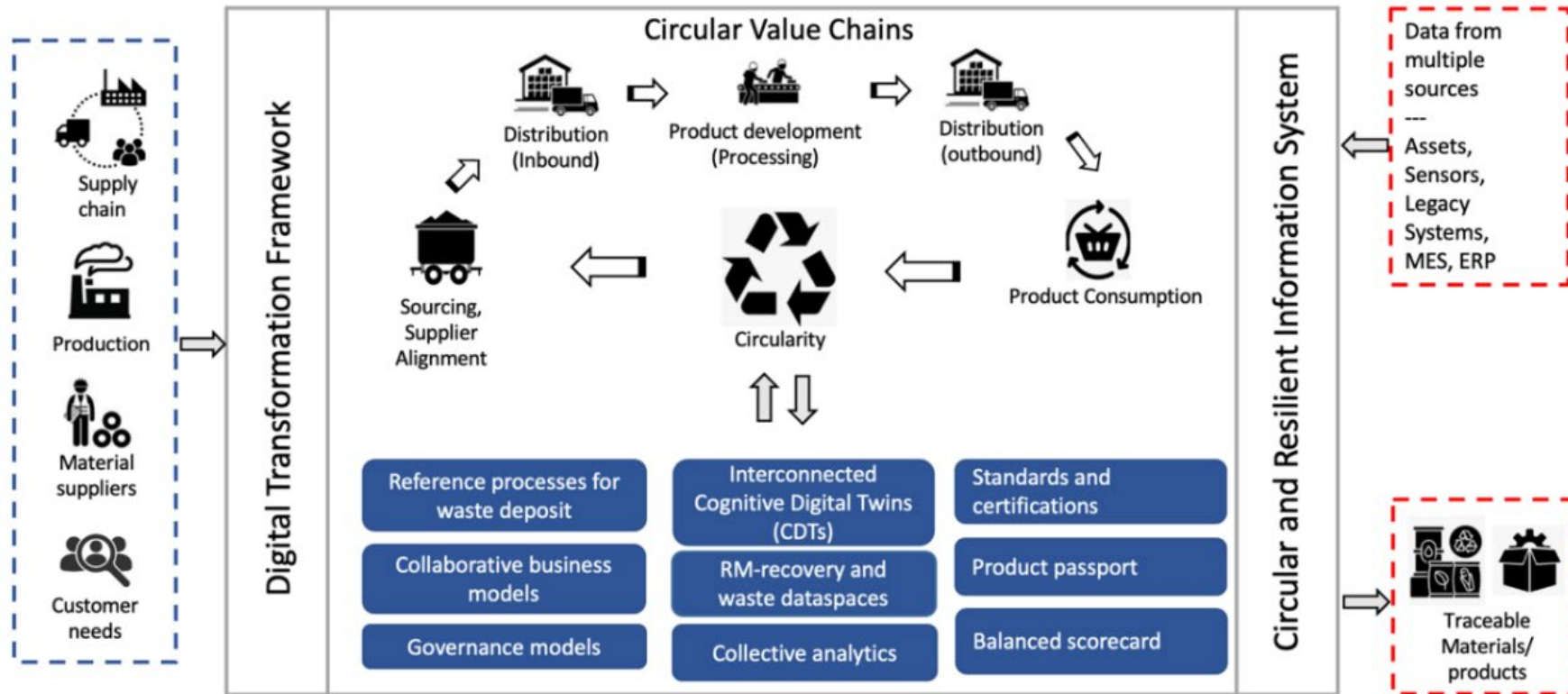
Cognitive Digital Twin - CDT



The RE4DY project - Manufacturing Data Networks



Product Passport through Twinning of Circular Value Chains

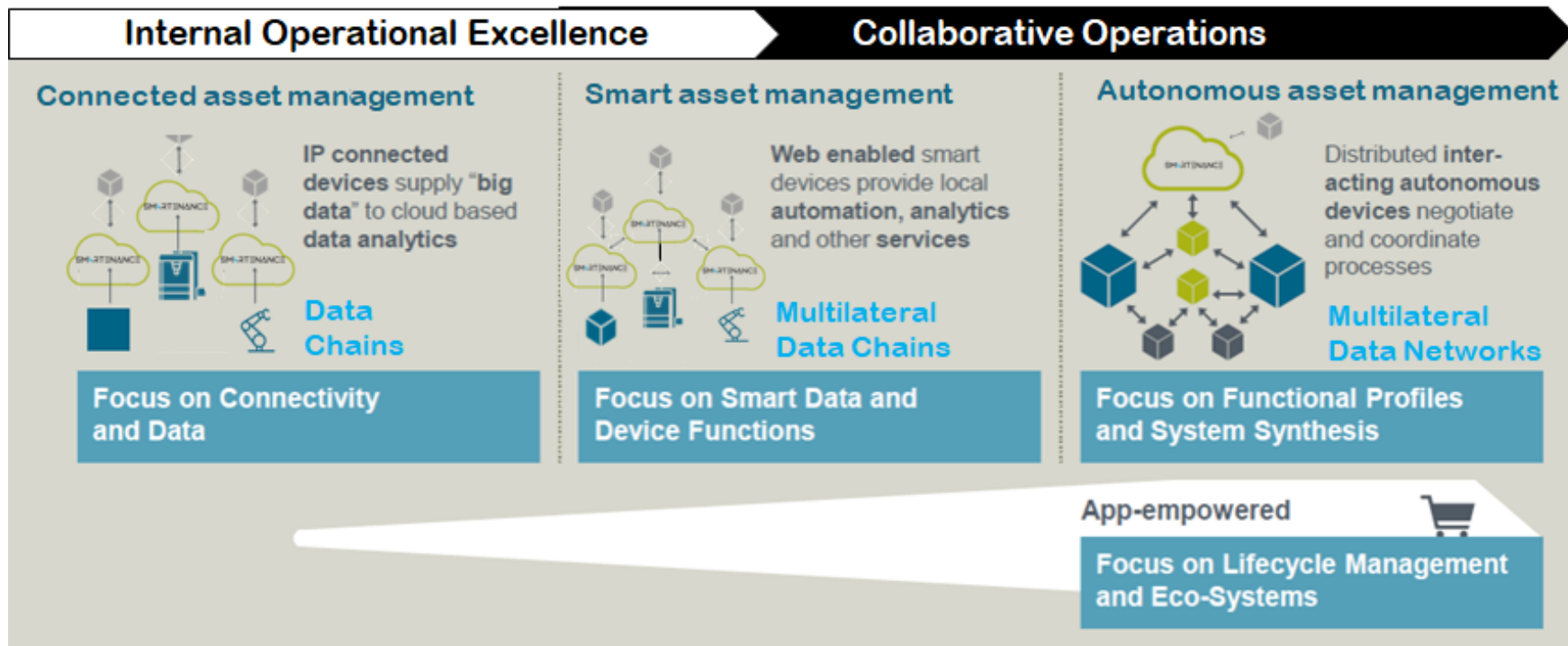


The SM4RTENANCE project

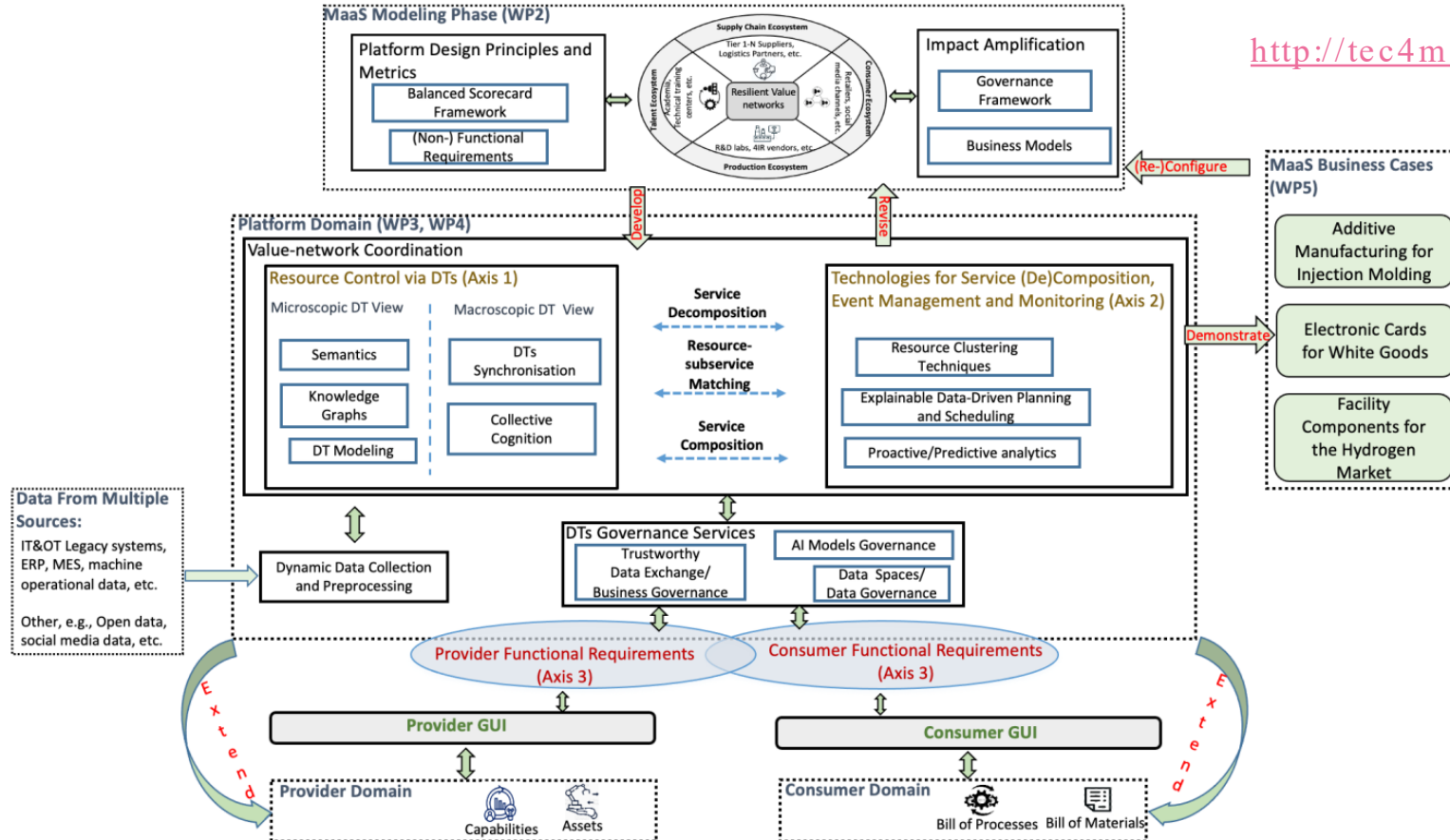
SM4RTENANCE

<https://sm4rtenance.eu/>

European Deployment of Smart Manufacturing Asset 4.0 Multilateral Data Sharing Spaces for an Autonomous Operation of Collaborative Maintenance and Circular Services



<http://tec4maases.eu/>



Thank you for your attention!
Merci pour votre attention!



<https://people.epfl.ch/dimitris.kiritsis/?lang=en>



<https://www.linkedin.com/in/dimitris-kiritsis-07124/>



dimitris.kiritsis@epfl.ch

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STORBYUNIVERSITETET

Information Modelling Framework: Method and Example

Baifan Zhou
Associate Professor @ Oslo Metropolitan University
Senior Researcher @ University of Oslo

baifanz@ifi.uio.no



What is IMF and Why IMF?

The Information Modelling Framework (IMF) is a framework for Model-based Systems Engineering

IMF aims to address challenges in systems engineering:

- Large amounts of documents
- Unstructured information
- Information overflow
- Long value chain where the key information get lost

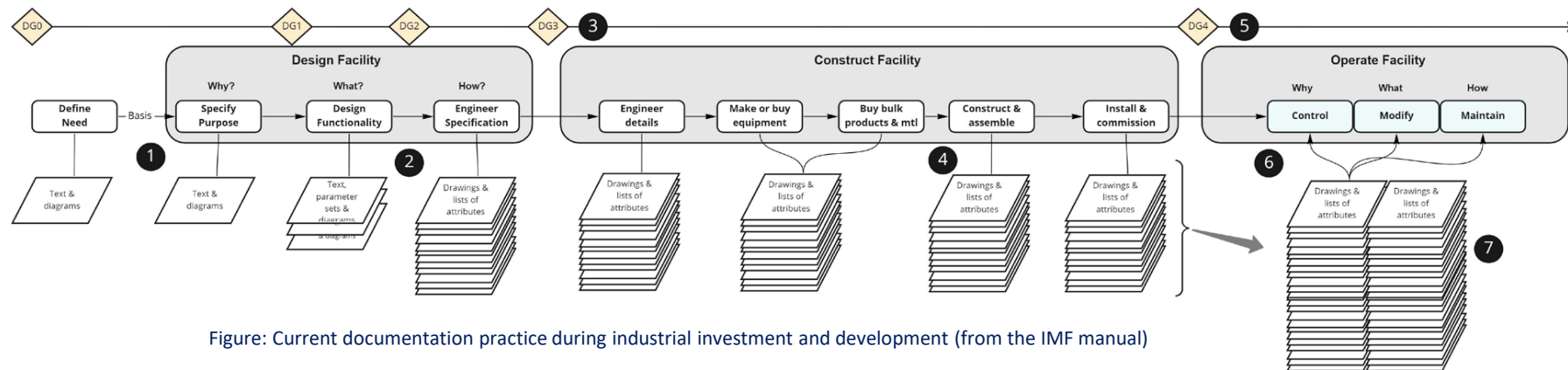


Figure: Current documentation practice during industrial investment and development (from the IMF manual)

What is IMF and Why IMF?

Current Situation of Designing, Purchasing, Manufacturing, and Managing Facility Asset:

- Large amounts of documents
- Unstructured information
- Information overflow
- Long value chain where the key information get lost

View from Client (e.g., energy production companies)

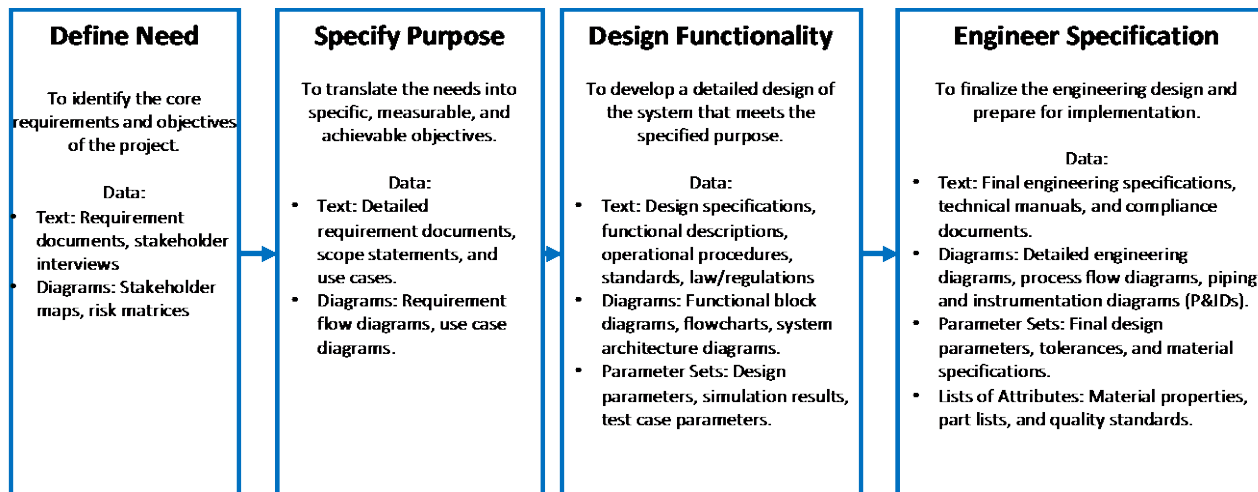


Figure: Complicated Activities and Overflow of Information Management

What is IMF and Why IMF?

Current Situation of Designing, Purchasing, Manufacturing, and Managing Facility Asset:

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View from Supplier (e.g., Siemens Energy)

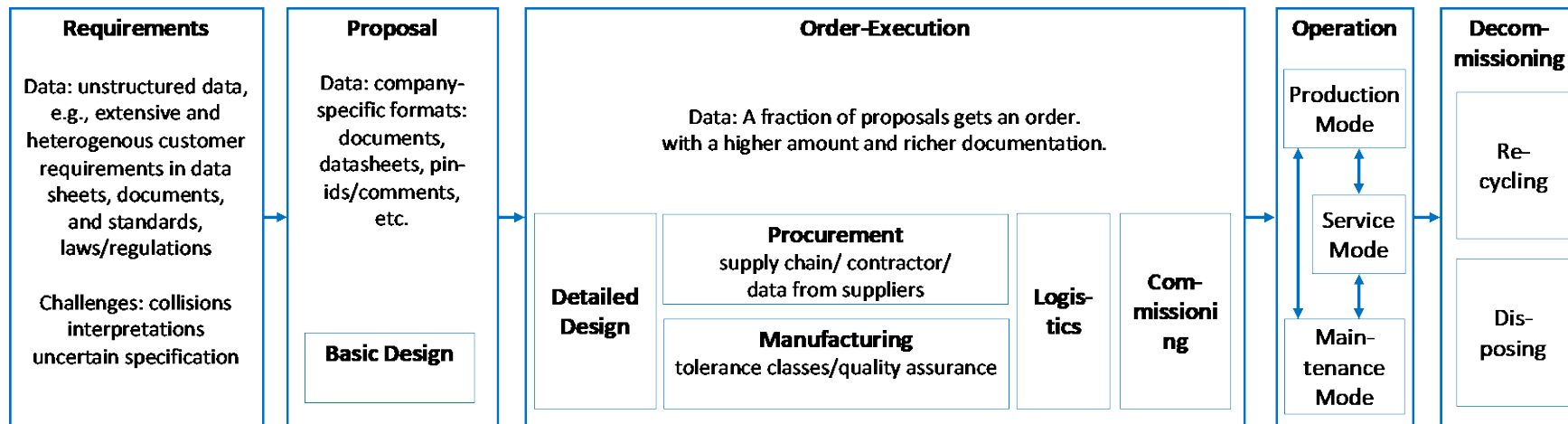
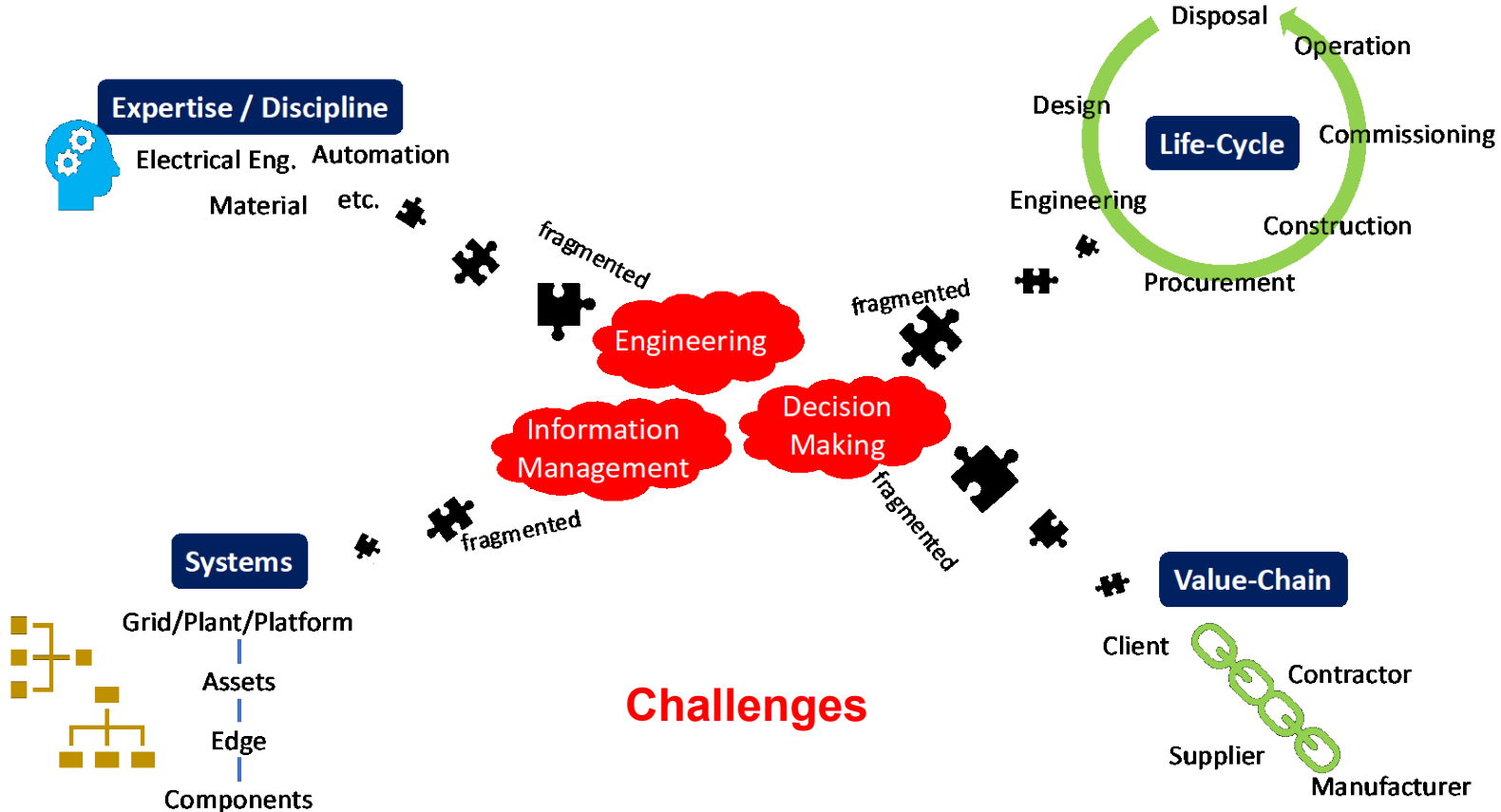
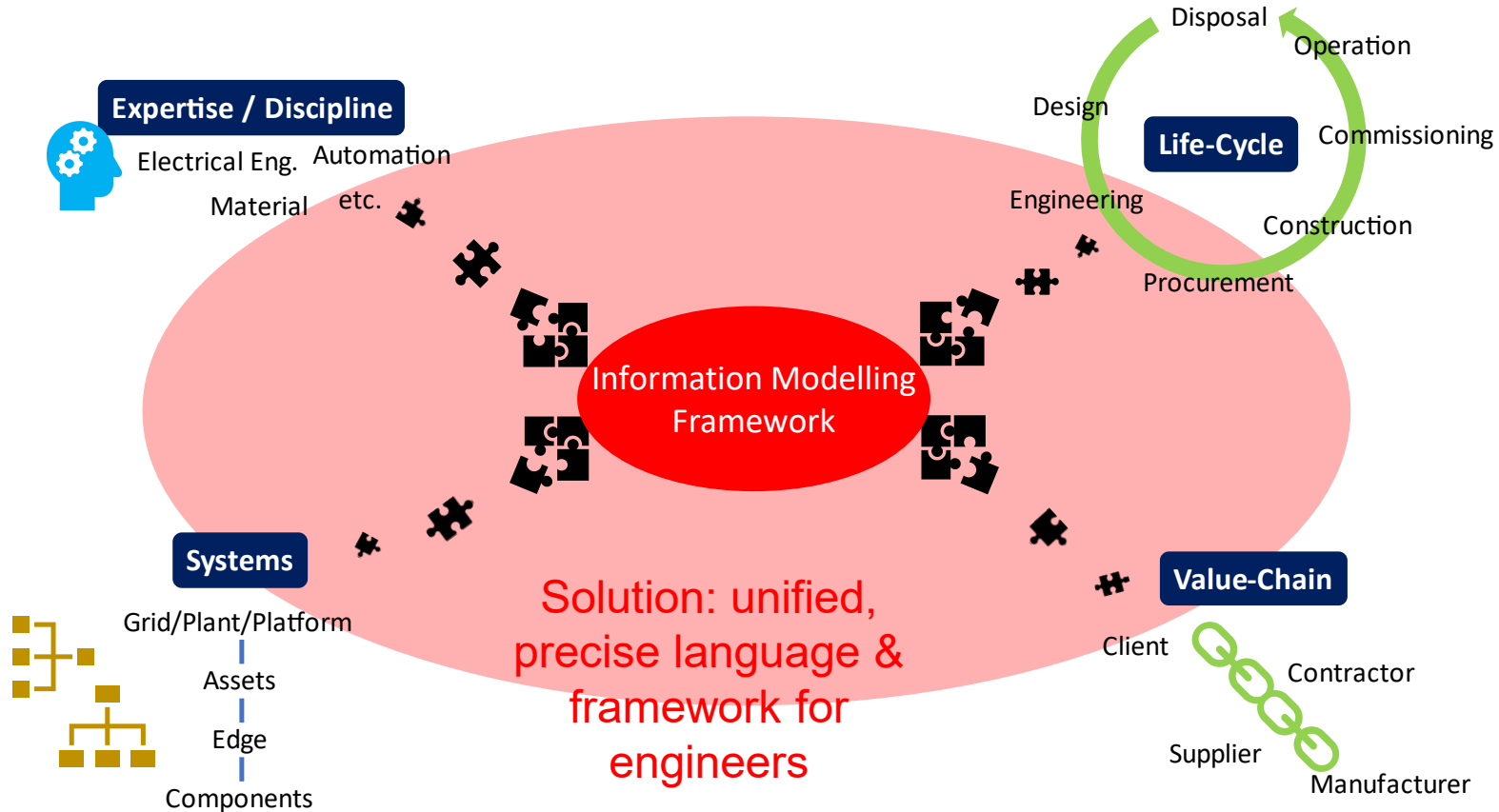


Figure: Complicated Activities and Overflow of Information Management

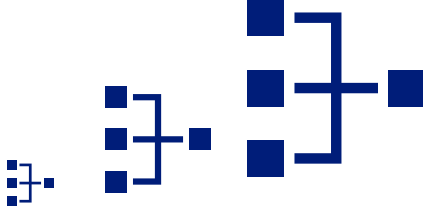
Information Modelling Framework (IMF) for Addressing Information Fragmentation in Systems Engineering



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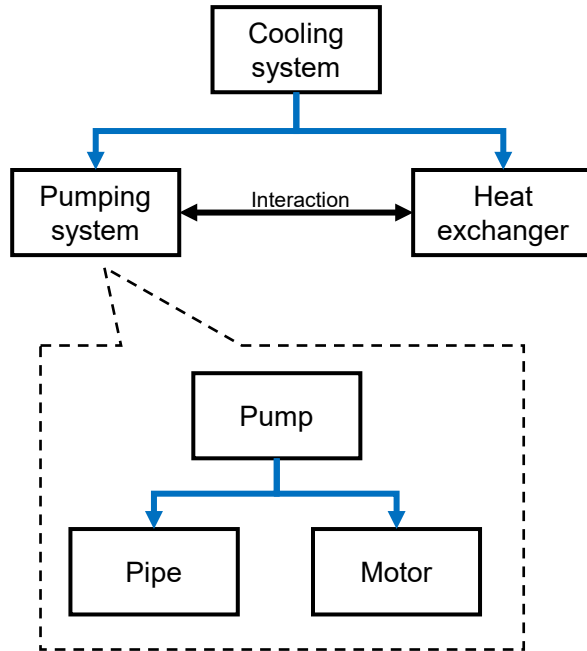


Requirements for the Approach

- **Guided-modelling:** properly defined methodology, convention 
- **Scalability:** works both for small scenarios and big scenarios 
- **User-friendliness:** subject matter experts are the users, involving the users from day one 
- **Flexibility/Adaptability:** can be adapted to many scenarios
- **Gaining incremental value:** one can model gradually, from high-level to detailed, not forced to build the complete model from the beginning, each step must give value 
- **Standardised** as industrial commons 
- **Precision** for machine automation

IMF Method: Core Idea of IMF

System Thinking:



System: a group of system elements to achieve a purpose

Breakdown: system can be breakdown to system elements

Granularity: a system element by itself is also a system

Interaction: system elements interact with other system elements

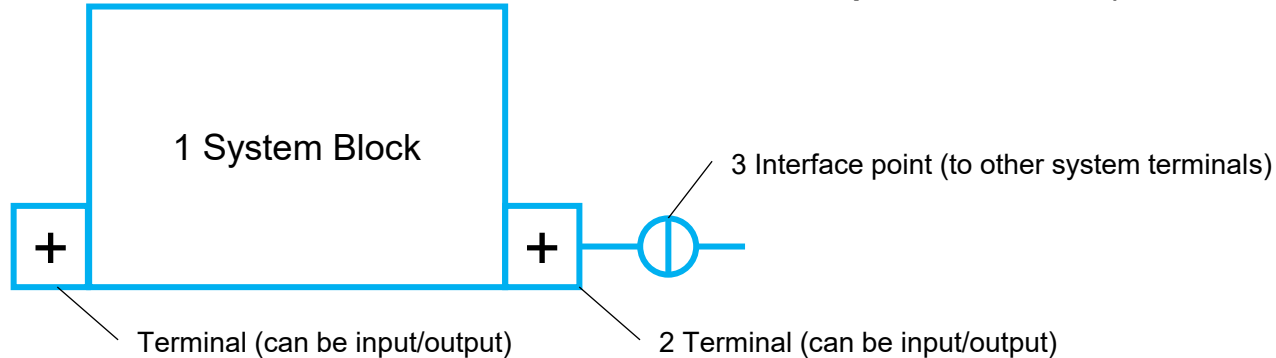
IMF Method: Core Idea of IMF

Unified language for industrial systems:

System Block: the boundary of a system element

Terminal: points that indicate input to/output from system boundary

Interface point: connection points between system terminals



IMF Method: Core Idea of IMF

Aspects: principles of system breakdown

Information domain:

Function (activity): breakdown of activities of a system

Product (physical implementation): breakdown of physical implementation of a system

Location (space): breakdown of spatial extension of a system

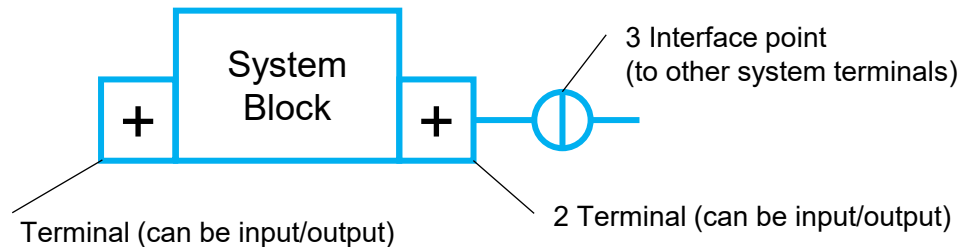
Interest: The purpose of breakdown for different **users**

Value-chain partners: Client, supplier, contractor

Modality:

Intended: intended specification or requirements

Actual: description of a produced/installed system



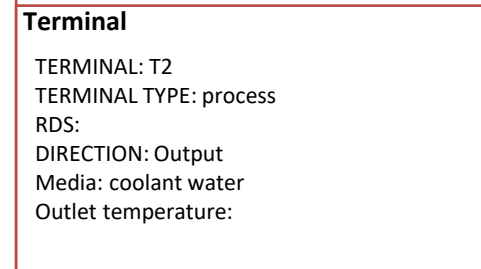
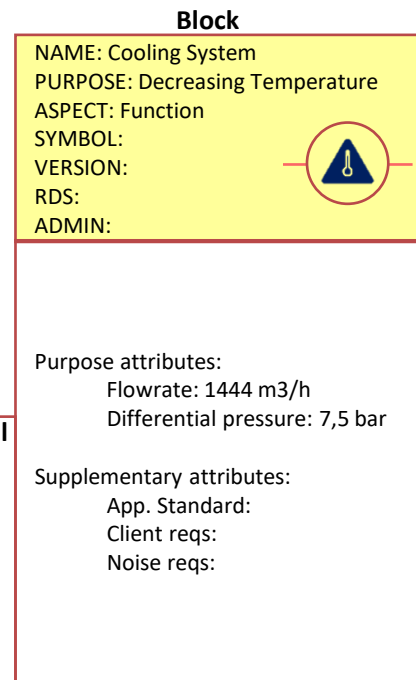
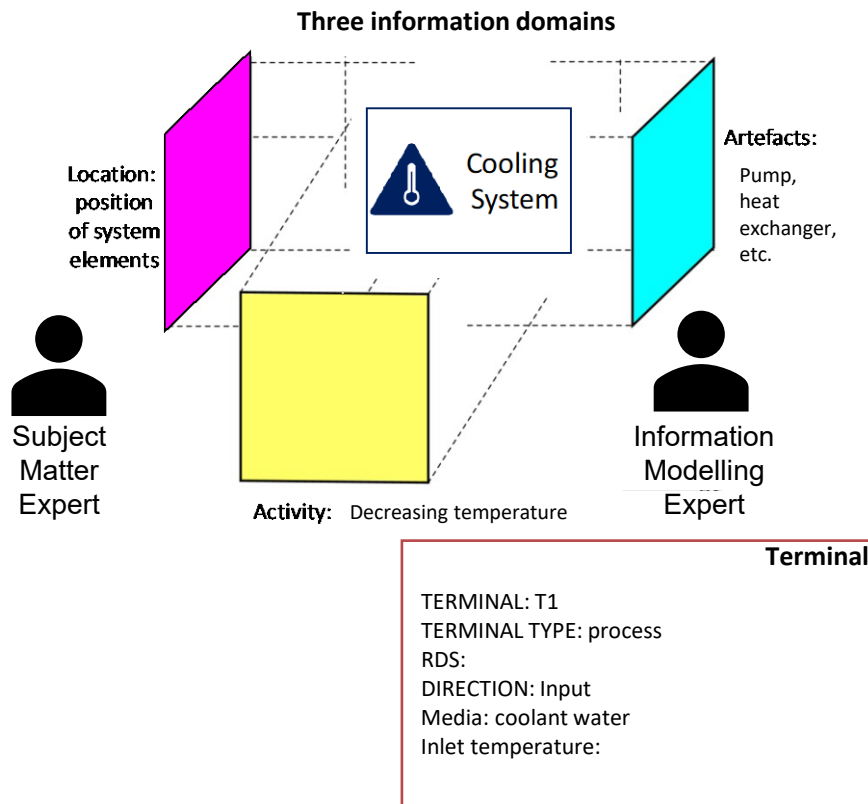
Function
Block

Product
Block

Location
Block

IMF Method: IMF Type, Information Templates

- Creating models with multi-disciplinary experts



Facility Asset Documentation

a new practice for
structured, concise,
information
documentation that
preserve key-
information

System Design/ Specification

digitally representing
requirements to
facilitate system design
and procurement

Semantic Verification

automatic verification of
the integrity of the IMF
model, fulfilment of
system requirements,
early warning of
requirement violation

Facility Asset Documentation: Example Use Case

Siemens Energy Use Case: Gearbox

- A gearbox is a common component of a gas compressor train interconnected with many other components.
- The gearboxes are normally supplied by external suppliers and incorporated into solutions provided by Siemens Energy.
- The design and manufacturing of a gearbox is extremely complicated and involves many stakeholders.

Facility Asset Documentation

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Example Gearbox

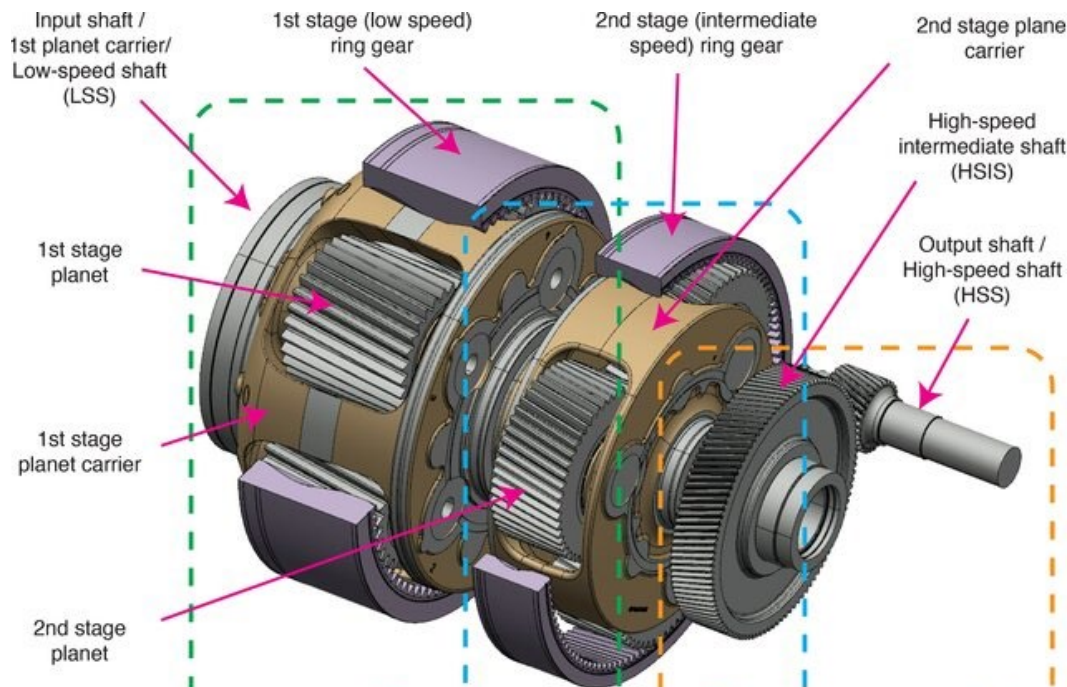


Figure source: 2022, Input torque measurements for wind turbine gearboxes using fiber-optic strain sensors, Wind Energy Science

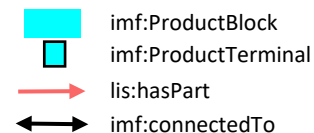
Facility Asset Documentation

Major elements:

- Gas Compressor Train Block: root node, overall product



Gas Compressor Train



Facility Asset Documentation

Major elements:

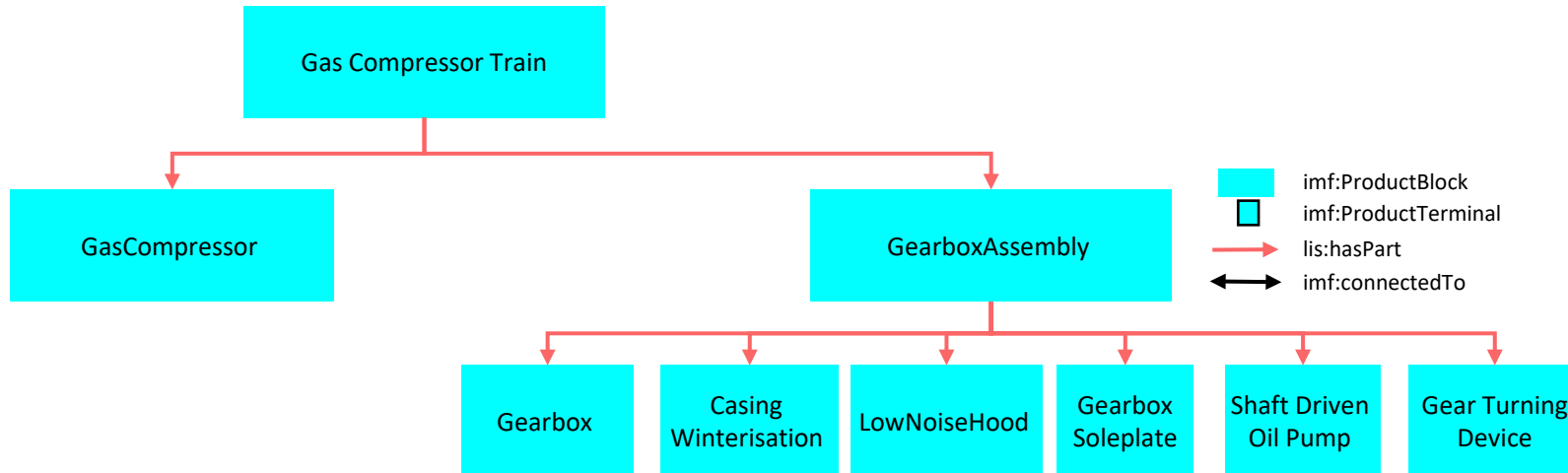
- Gas Compressor Train Block: root node, overall product
- Gas Compressor Block: central component of the gas compressor train
- Gearbox Assembly Block: subsystem that transmits power from the driver to the compressor



Facility Asset Documentation

Major elements:

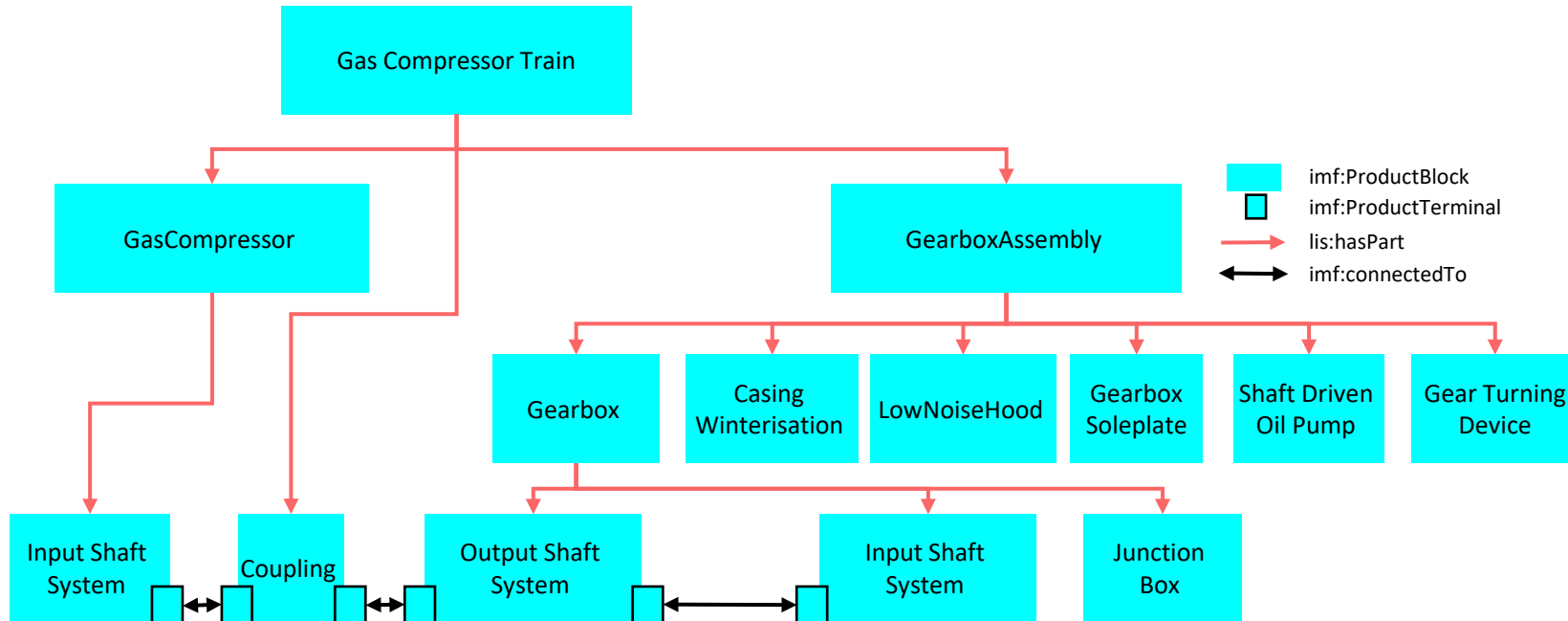
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- More detailed modelling: Gearbox, Winterisation, etc.



Facility Asset Documentation

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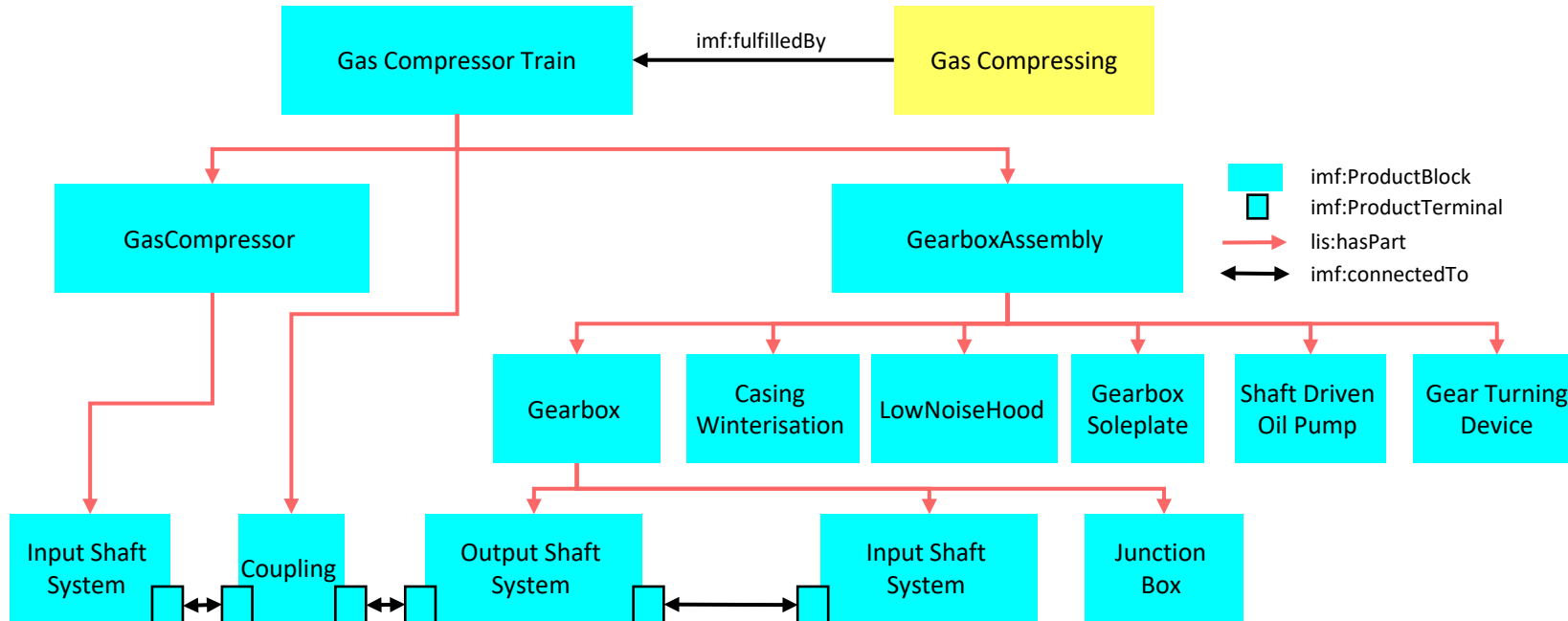
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Facility Asset Documentation

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Preliminary Results, Function Aspect: Requirements to the Activity

Major elements:

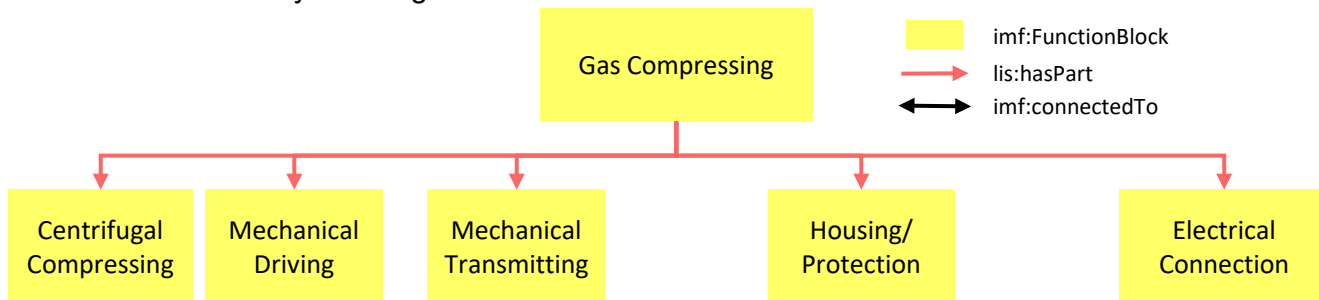
- Gas Compression Block: the root node of overall requirements to activity



Preliminary Results, Function Aspect: Requirements to the Activity

Major elements:

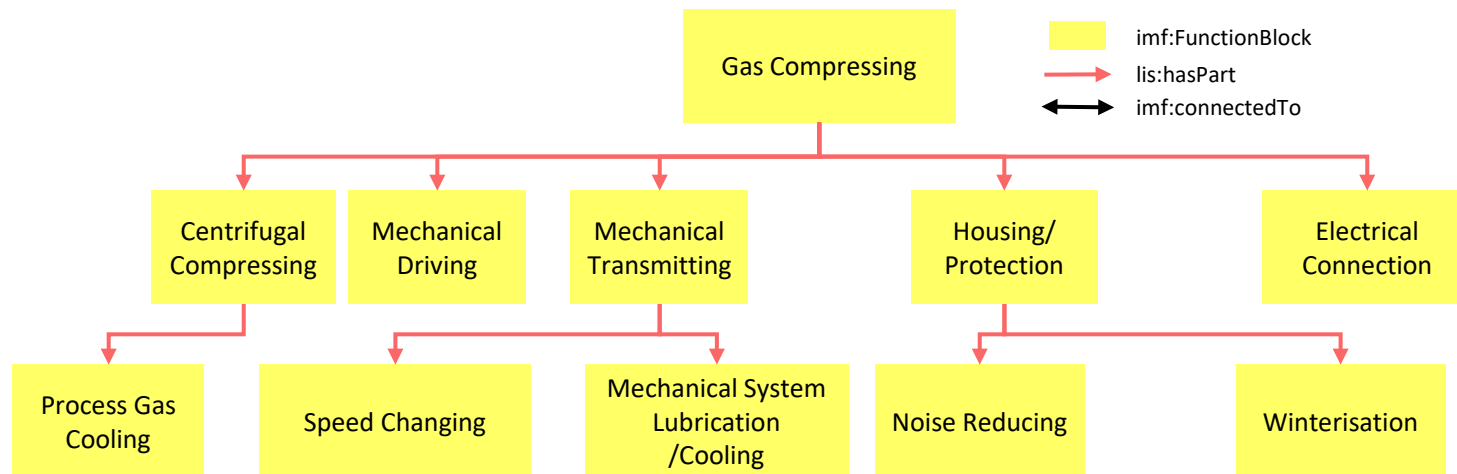
- Gas Compression Block: the root node of overall requirements to activity
- Centrifugal Compressing Block: the activity that the compressor uses the mechanical energy to increase the gas pressure
- Mechanical Driving Block: the activity to provide the mechanical energy.
- Housing/Protection Block: the activity to provide a sturdy and protective casing or enclosure
- Electrical Connection Block: the activity of wiring and connections



Preliminary Results, Function Aspect: Requirements to the Activity

Major elements:

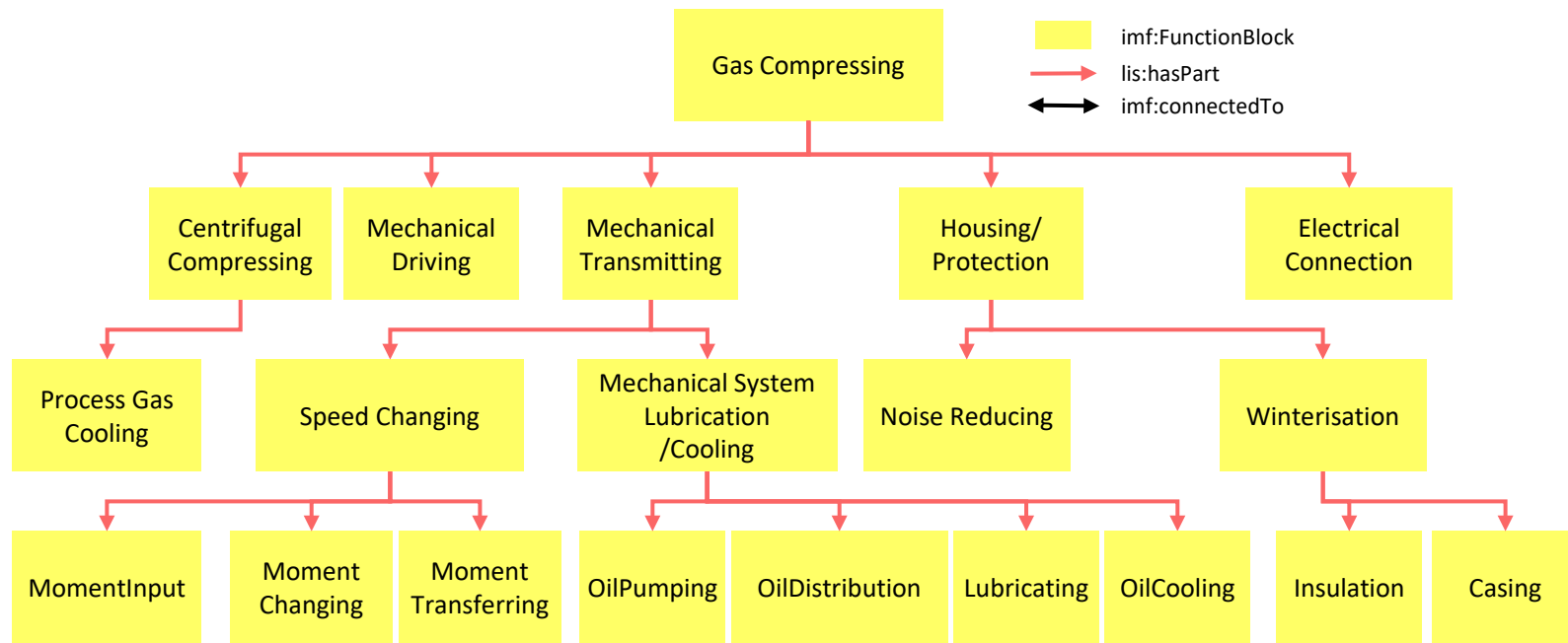
- Gas Compression Block: the root node of overall requirements to activity
- Major functional blocks: Centrifugal Compressing, Mechanical Driving, Housing/Protection, Electrical Connection
- More detailed modelling: Process Gas Cooling, Speed Changing, etc.



Preliminary Results, Function Aspect: Requirements to the Activity

Major elements:

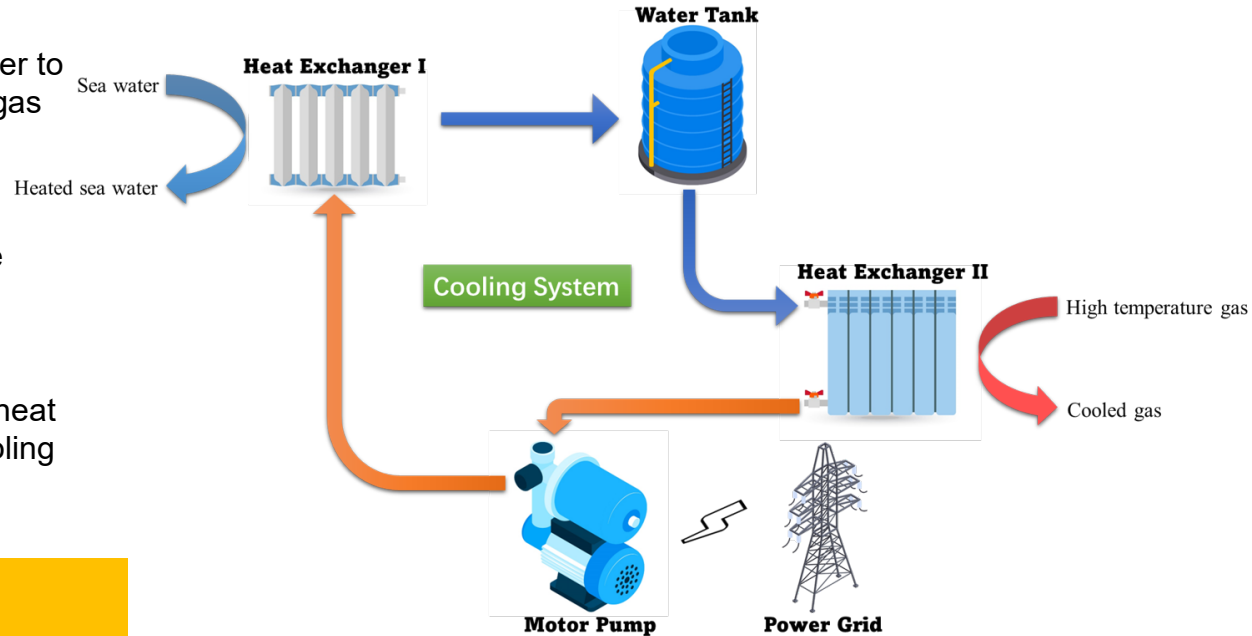
- Gas Compression Block: the root node of overall requirements to activity
- Major functional blocks: Centrifugal Compressing, Mechanical Driving, Housing/Protection, Electrical Connection
- More detailed modelling: Process Gas Cooling, Speed Changing, etc.
- Even more detailed modelling: Moment Input, Moment Changing, Oil Pumping, etc.



System Design/ Specification: Example Use Case

Use Case: Gas Cooling System

- The cooling system uses coolant water to reduce the temperature of incoming gas through a heat exchanger.
- The heat absorbed from the gas is transferred to another heat exchange where it is dissipated into sea water.
- The system ensures efficient thermal management by leveraging the high heat capacity of coolant water and the cooling potential of the sea.



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a new practice for structured, concise, information documentation that preserve key-information

System Design/ Specification

digitally representing requirements to facilitate system design and procurement

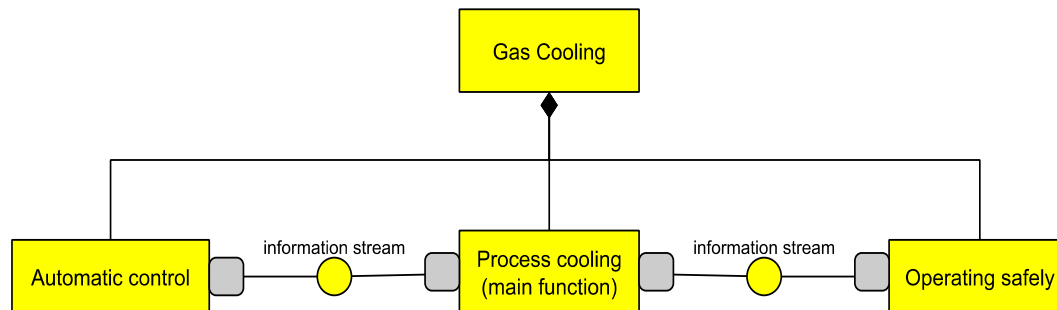
Semantic Verification

automatic verification of the integrity of the IMF model, fulfilment of system requirements, early warning of requirement violation

Use Case: Gas Cooling System

Overall system design:

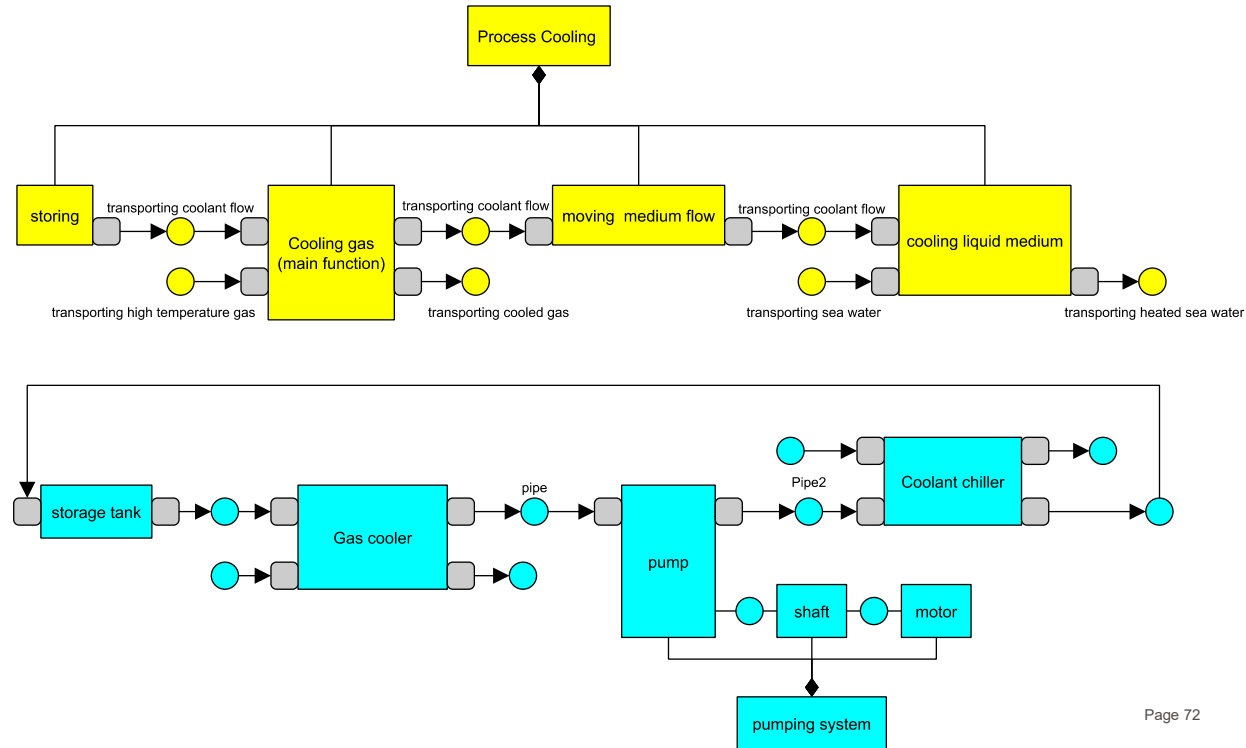
- The gas cooling system includes three functionalities
- Process cooling is the main function
- Automatic control monitors and controls the cooling process
- The system needs to be ensured that it operates safely



Use Case: Gas Cooling System

Main function design:

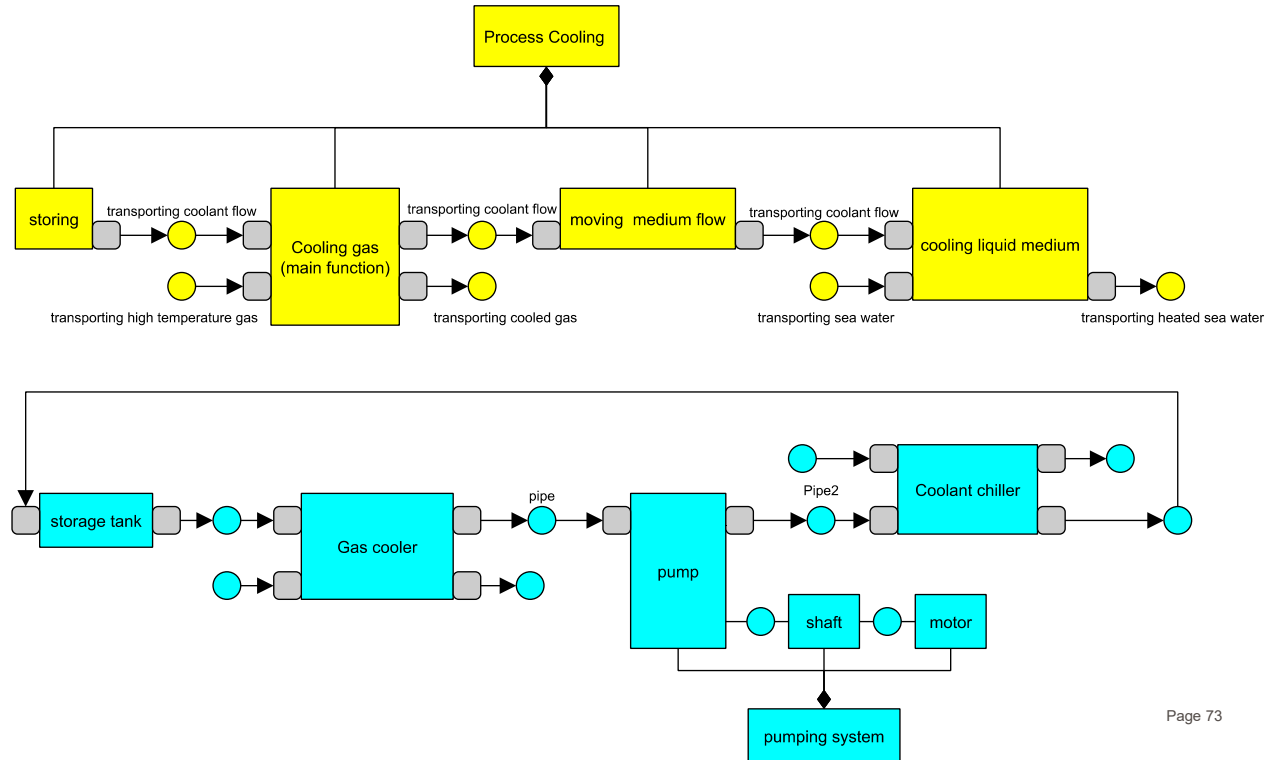
- The gas cooler (with cooling gas function) transfers heat from the high temperature gas to the liquid medium (water).
- The storage tank (with storing function) stores the liquid medium (water).
- The pump moves the liquid medium (water) flow.
- The coolant chiller (with cooling liquid medium) transfers heat from the liquid medium (water) to sea water.



Use Case: Gas Cooling System

Supporting function design:

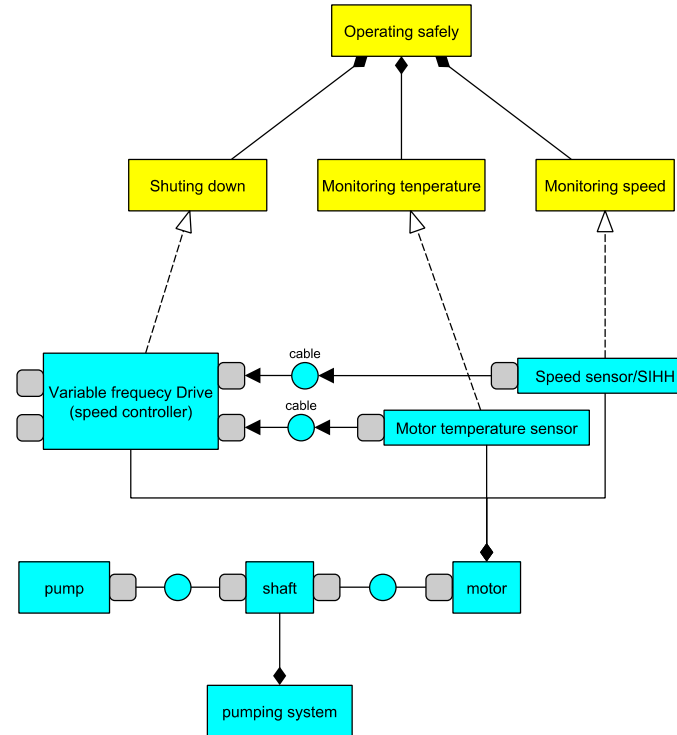
- The control system (automatic control function) monitors the system, processes the information and uses actuator to change the system states



Use Case: Gas Cooling System

Supporting function design:

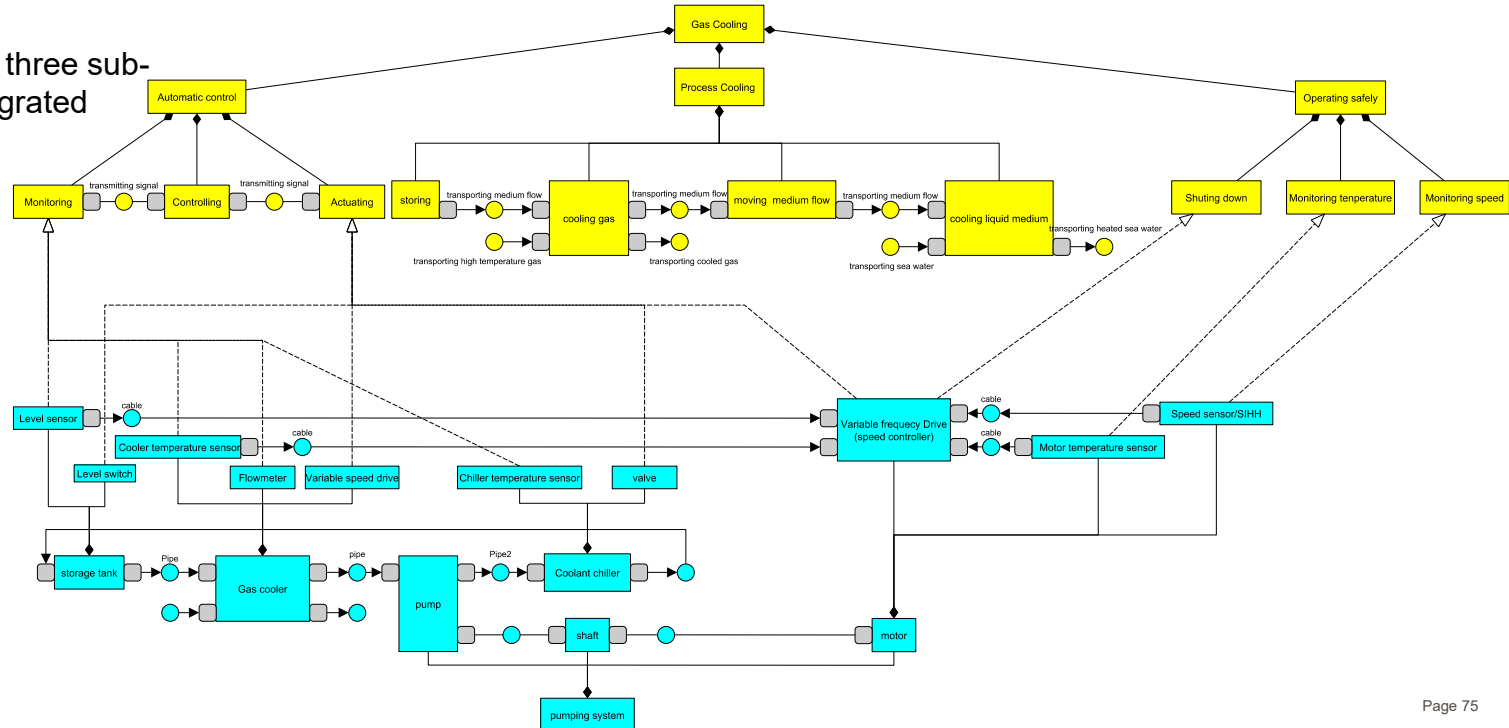
- The safety system monitors temperature and speed and shuts down the system in emergent cases.



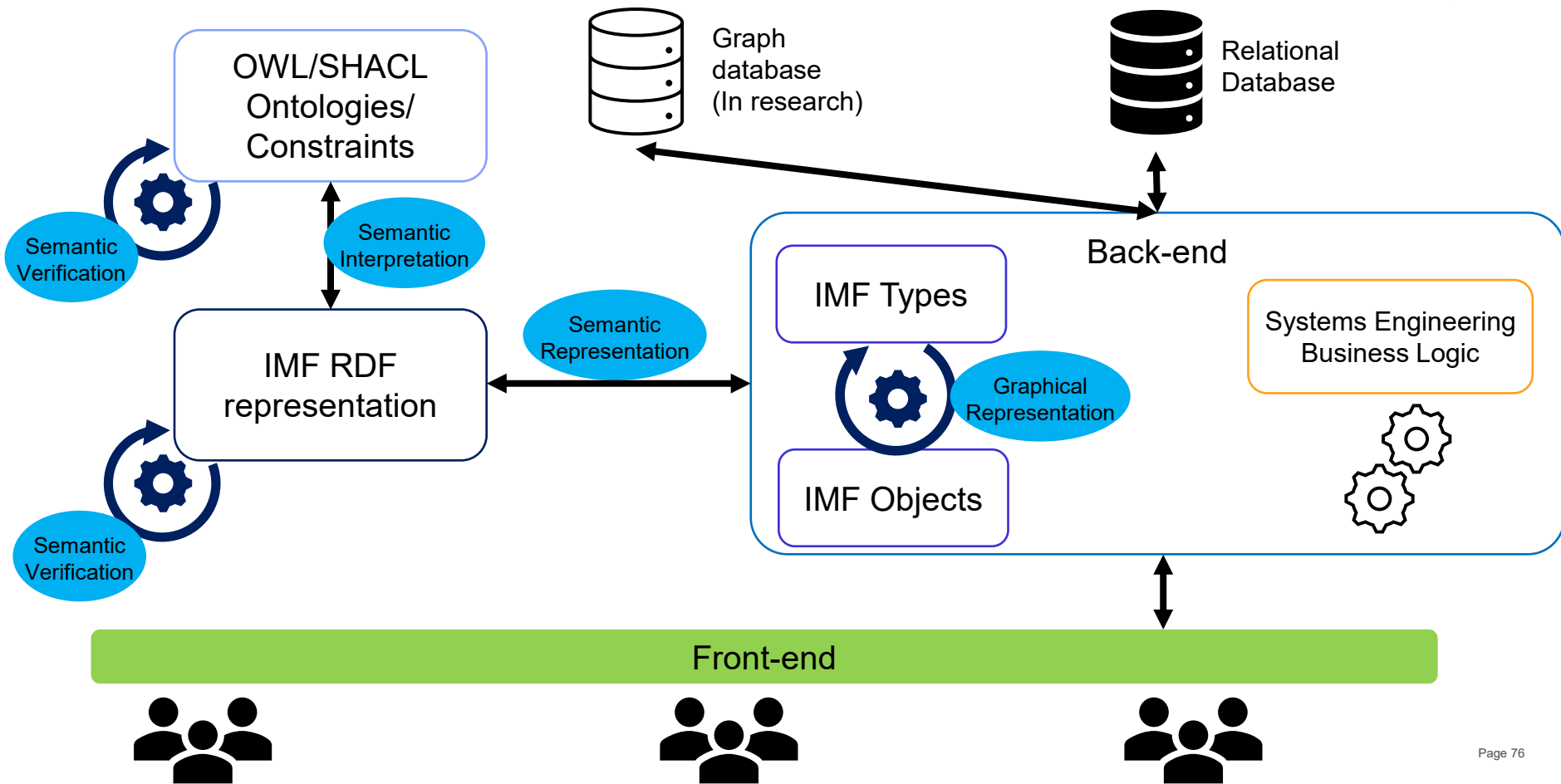
Use Case: Gas Cooling System

System integration:

- After design, the three sub-systems are integrated

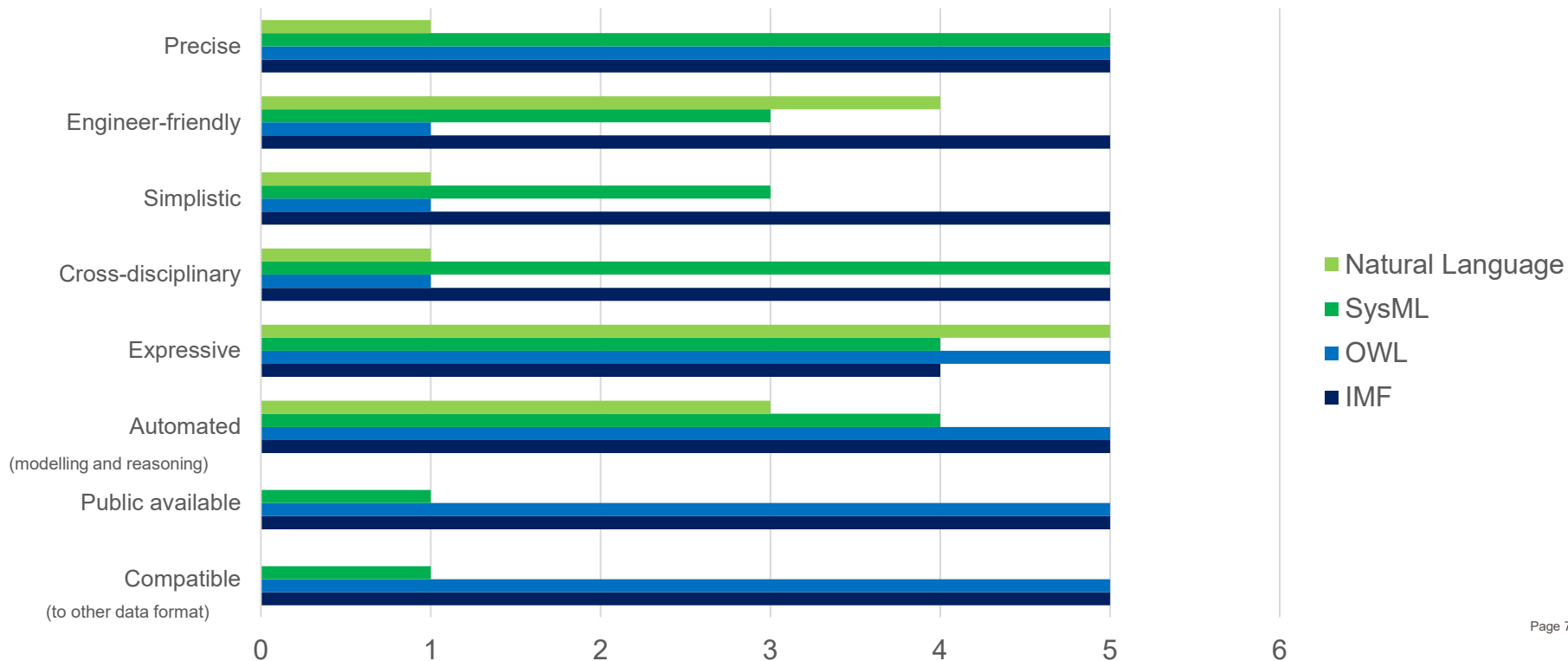


Semantic Verification Technology Stack (In research)



Why IMF? Comparison between Alternative Approaches for Information Management

IMF is precise, engineer-friendly, simplistic, cross-disciplinary, expressive, automated, open, and compatible to other data format.



Summary & Vision & Outlook

Information Modelling Framework (IMF)

Summary

- Extremely simple syntax, expressive for a wide range of engineered systems
- Engineer-friendly languages, can be used without extensive training

Vision

- IMF aims at standardised data models, and the “lingua franca” between organisations, business units along the product life-cycle and value-chain



Outlook

- Refining the language to accommodate more "interests" and support engineering activities in more detail
- User study with metrics for measuring usability: time, correctness and satisfaction
- Structure-reserving semantic interpretation to IOF-aligned ontologies



More Application Scenarios

- Facility Asset Documentation: a new practice for structured, concise, information documentation that preserve key-information
- System Design/Specification: digitally representing requirements to facilitate system design and procurement
- *Semantic Verification*: automatic verification of the integrity of the IMF model, fulfilment of system requirements, early warning of requirement violation

