IFAC/INSTICC IN4PL 2024

5TH IFAC/INSTICC INTERNATIONAL CONFERENCE ON INNOVATIVE INTELLIGENT INDUSTRIAL PRODUCTION AND LOGISTICS

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A long Road Towards Smart Manufacturing: Challenges and Future Prospects

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22th November 2024

UNINOVA

NOVA SCHOOL OF SCIENCE & TECHNOLOGY

UNINOVA - CTS

RICS Robotic & Industrial Complex Systems

Main Goals

- Highlighting that a manufacturing system is a **complex system** where order, organisation, and **relationships** are very important
- Highlighting the **evolution of manufacturing paradigms** and its contributing factors
- Highlighting the RICS **contribution** in the long road towards Smart Manufacturing
- Highlighting what is **Smart Manufacturing** (Industry 4.0) and how RICS is contributing to this revolution

Complexity & Manufacturing

Manufacturing as a Complex Systems

General Systems Theory + Cybernetics + Complexity Theory

System, as quoted in (Ackoff, Russel, 1981)

A system is a set of two or more interrelated elements with the following properties:

1. *Each element has an effect of the functioning of the whole;*
2. *Each element is affected by at least one other element in the system;*
3. *All possible subgroups of elements also have the first two properties.*

System, as quoted in (Morin, 2014)

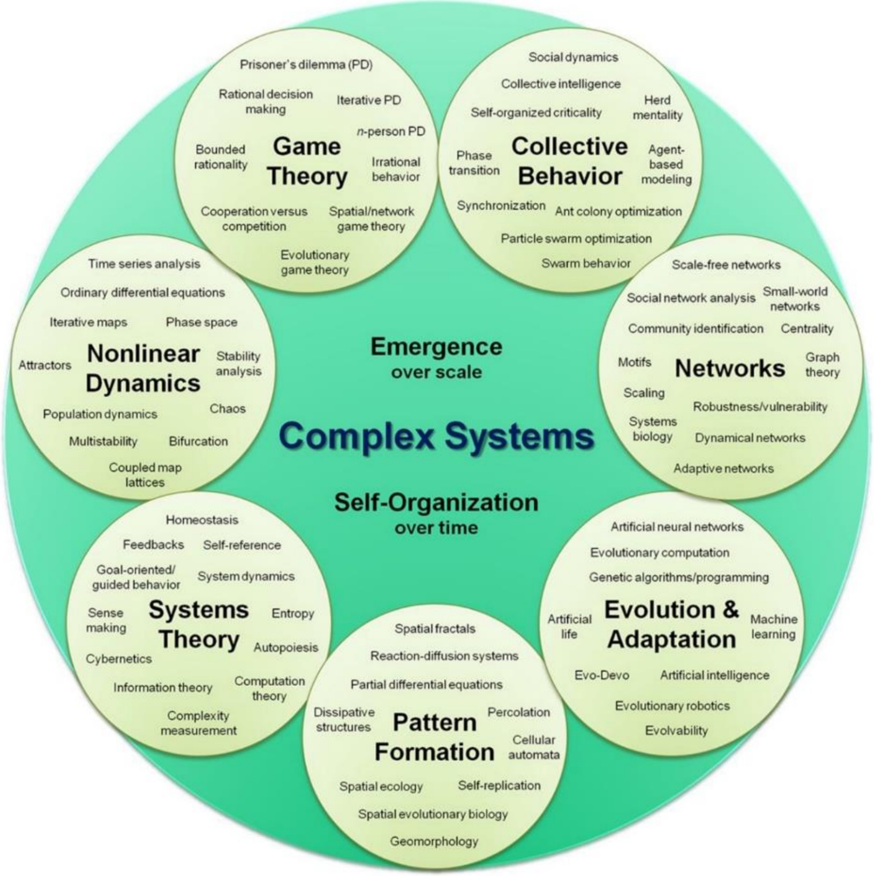
A system is composed of four main things:

1. *Parts, elements, or variables within the system;*
2. *Attributes-the qualities or properties of the system and its parts;*
3. *Internal relationship of connections among its parts;*
4. *Systems exist in an environment.*

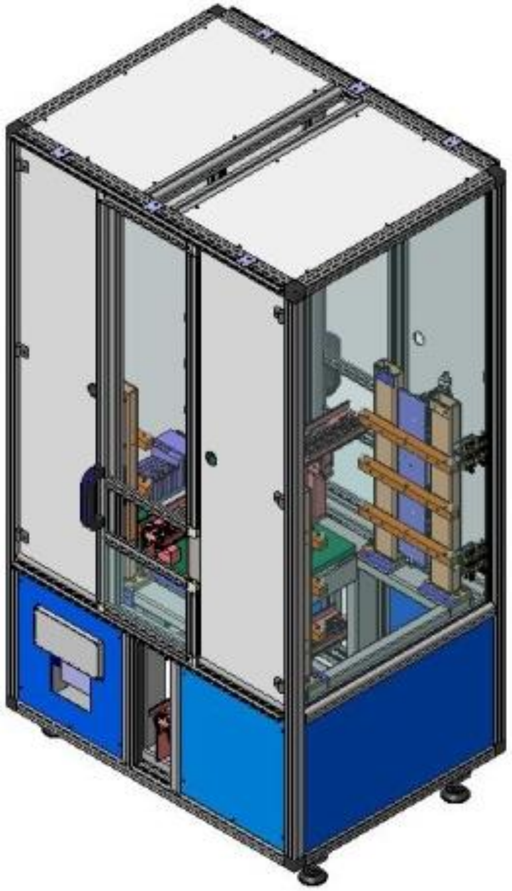
Complexity

- A complex system usually consists of **a large number of simple members**, elements or agents, which **interact** with one another and with the environment, and which have the potential to **generate qualitatively NEW collective behaviour**, the manifestations of this behaviour being the spontaneous creation of new spatial, temporal, or functional structures.

- A complex system is an 'open' system involving **'nonlinear interactions'** among its subunits which can exhibit, under certain conditions, a marked degree of coherent or ordered behaviour extending well beyond the scale or range of the individual subunits.



Visual, organizational map of complex systems broken into seven sub-groups, created by Hiroki Sayama, D.Sc.

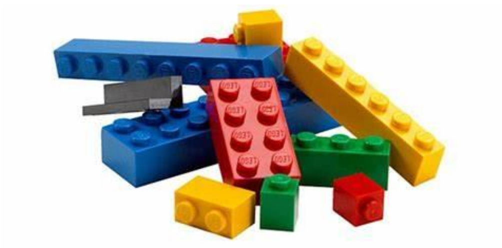


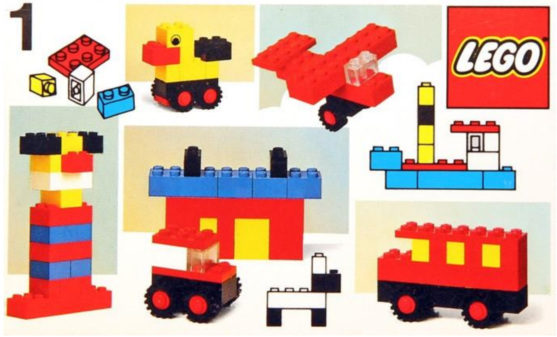
Manufacturing as a Complex System

We see a manufacturing system as a set of

Intelligent Entities Cooperating

(interacting) with each other.



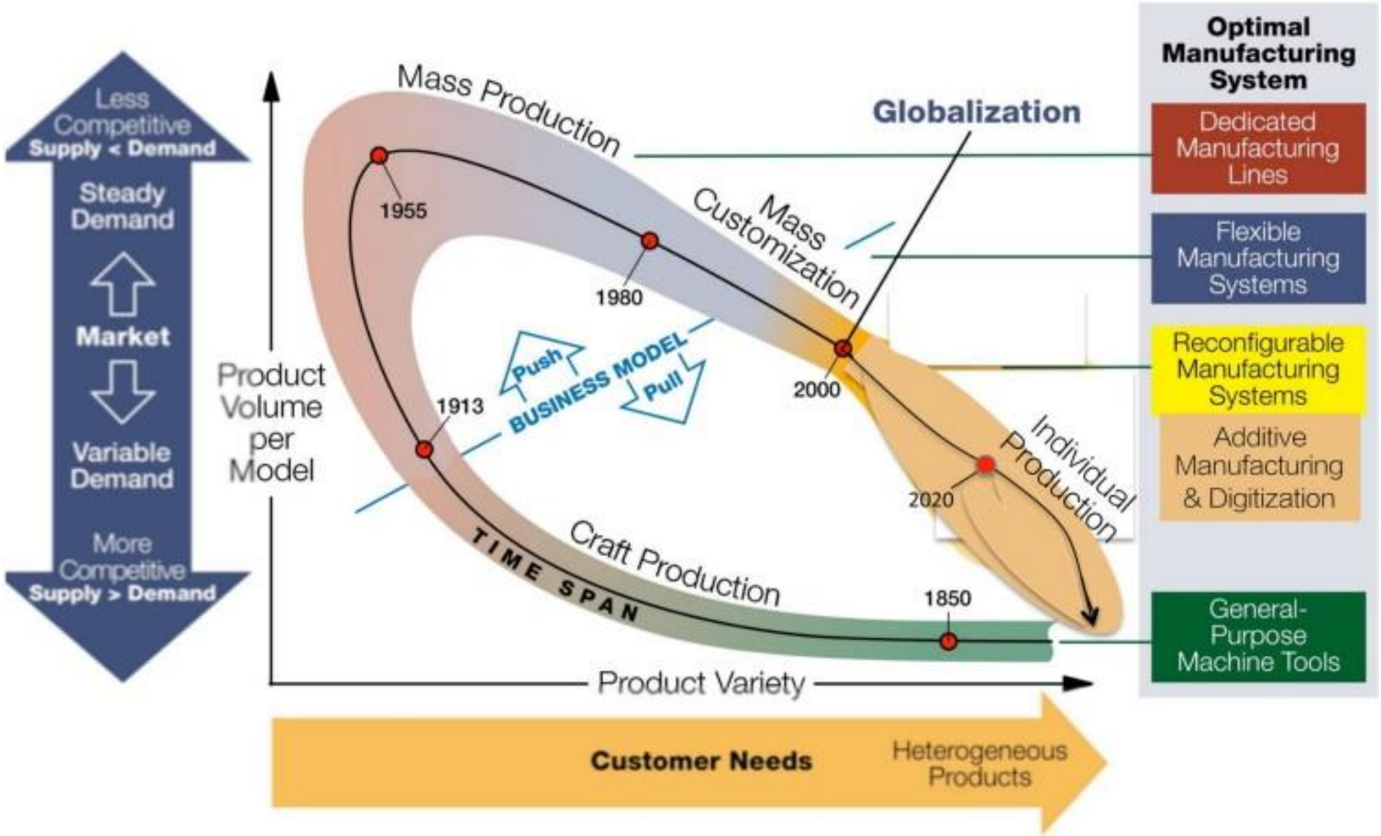


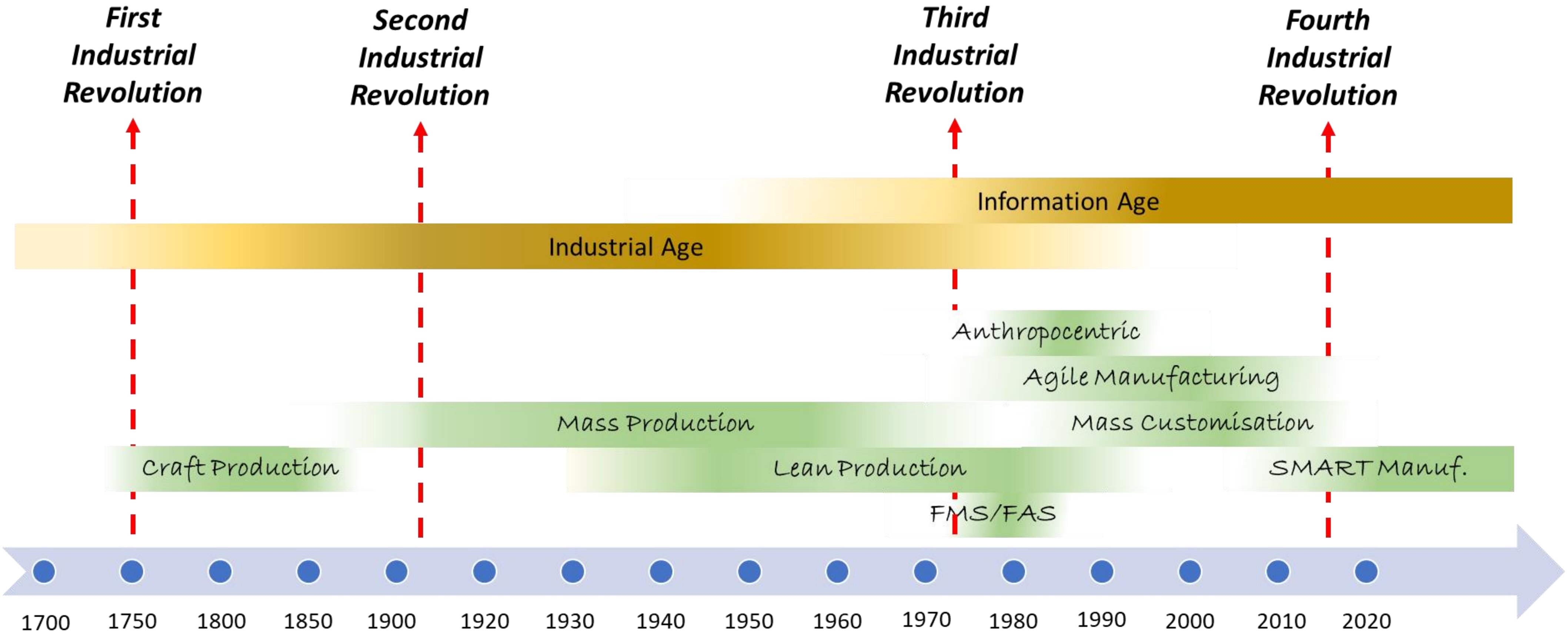
Modularity is an Important Issue.

Evolution of Manufacturing Paradigms

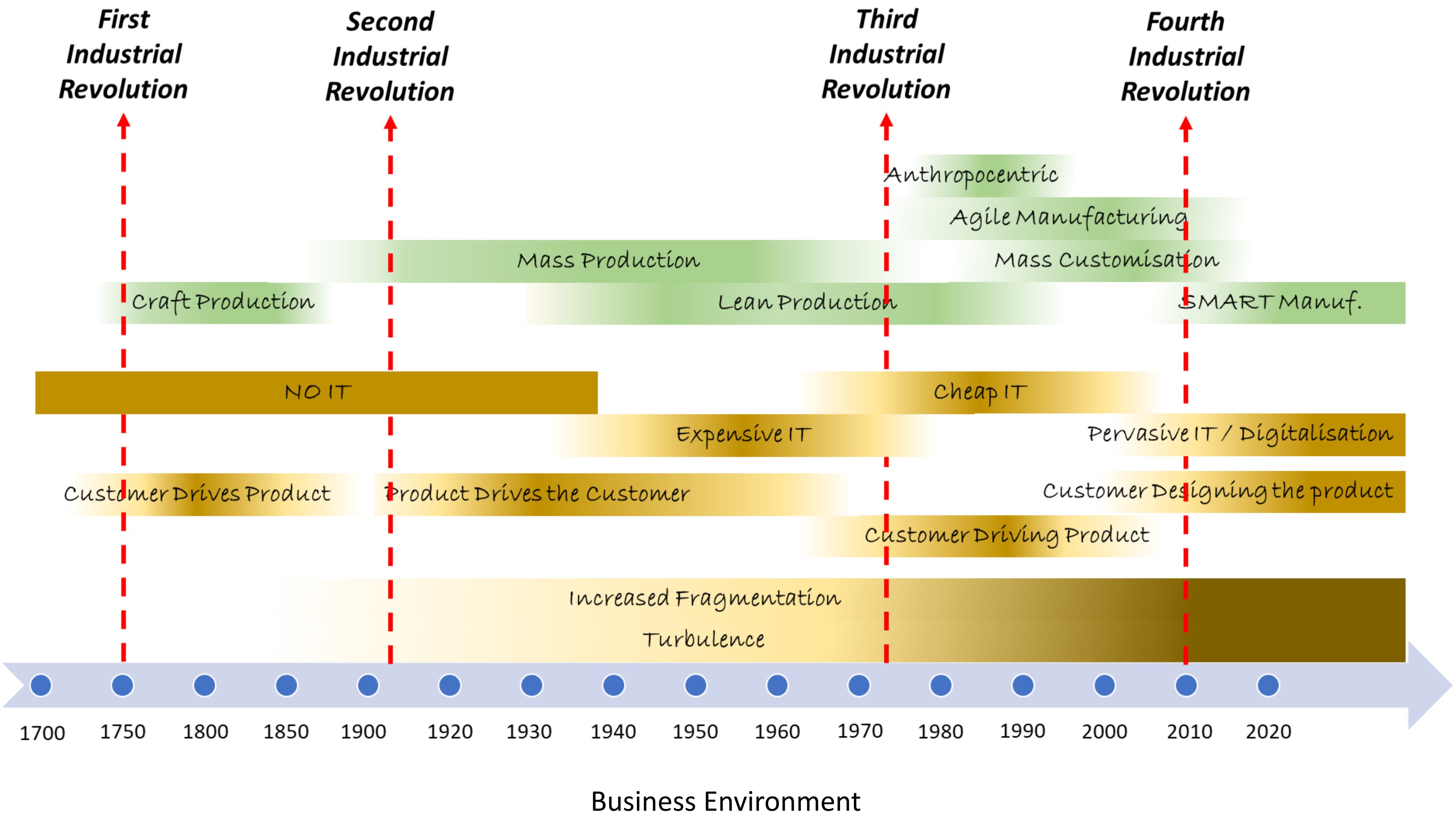
Manufacturing Paradigms

From Professor Emeritus Yoram Koren

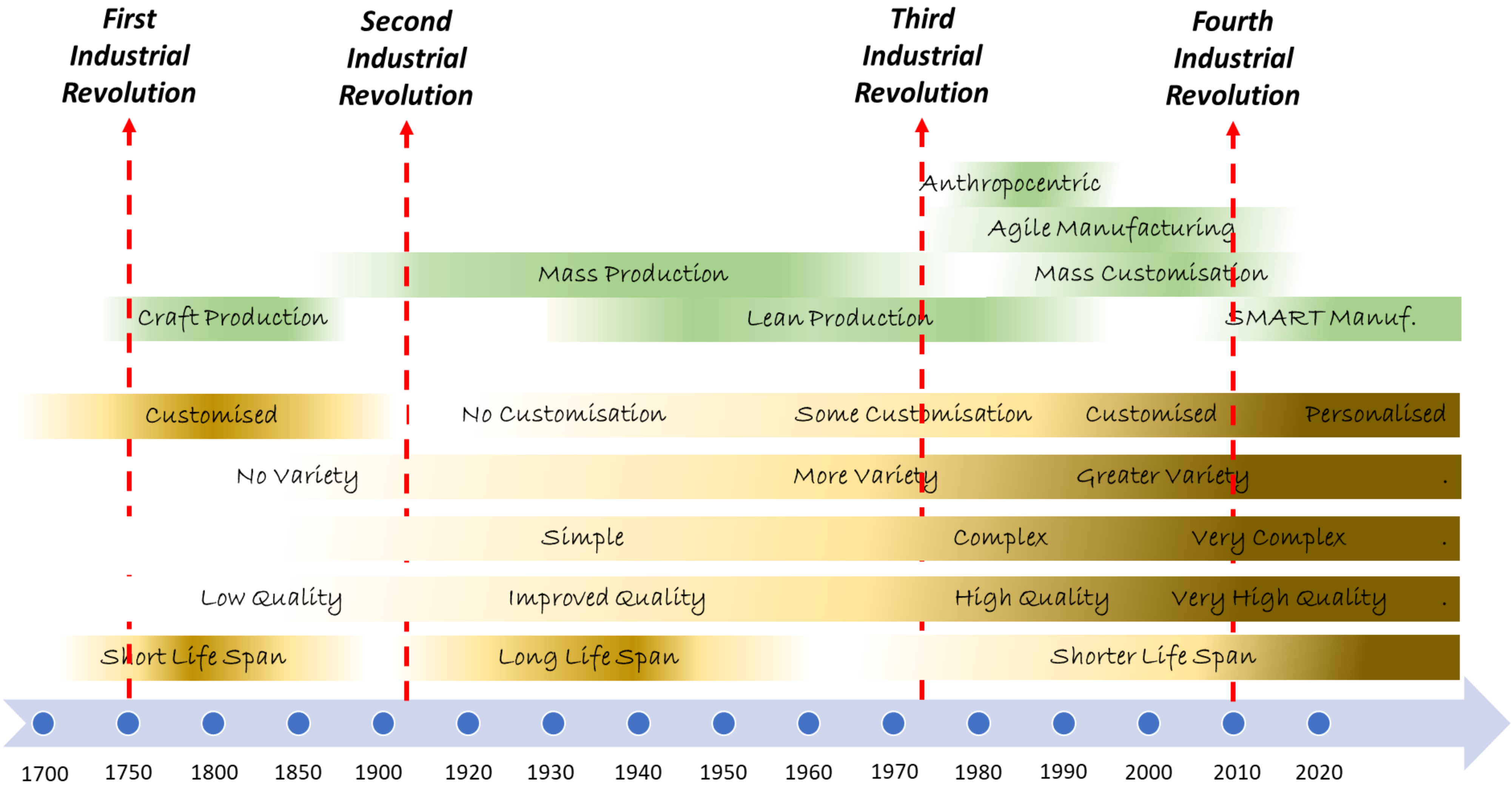




Manufacturing Paradigms

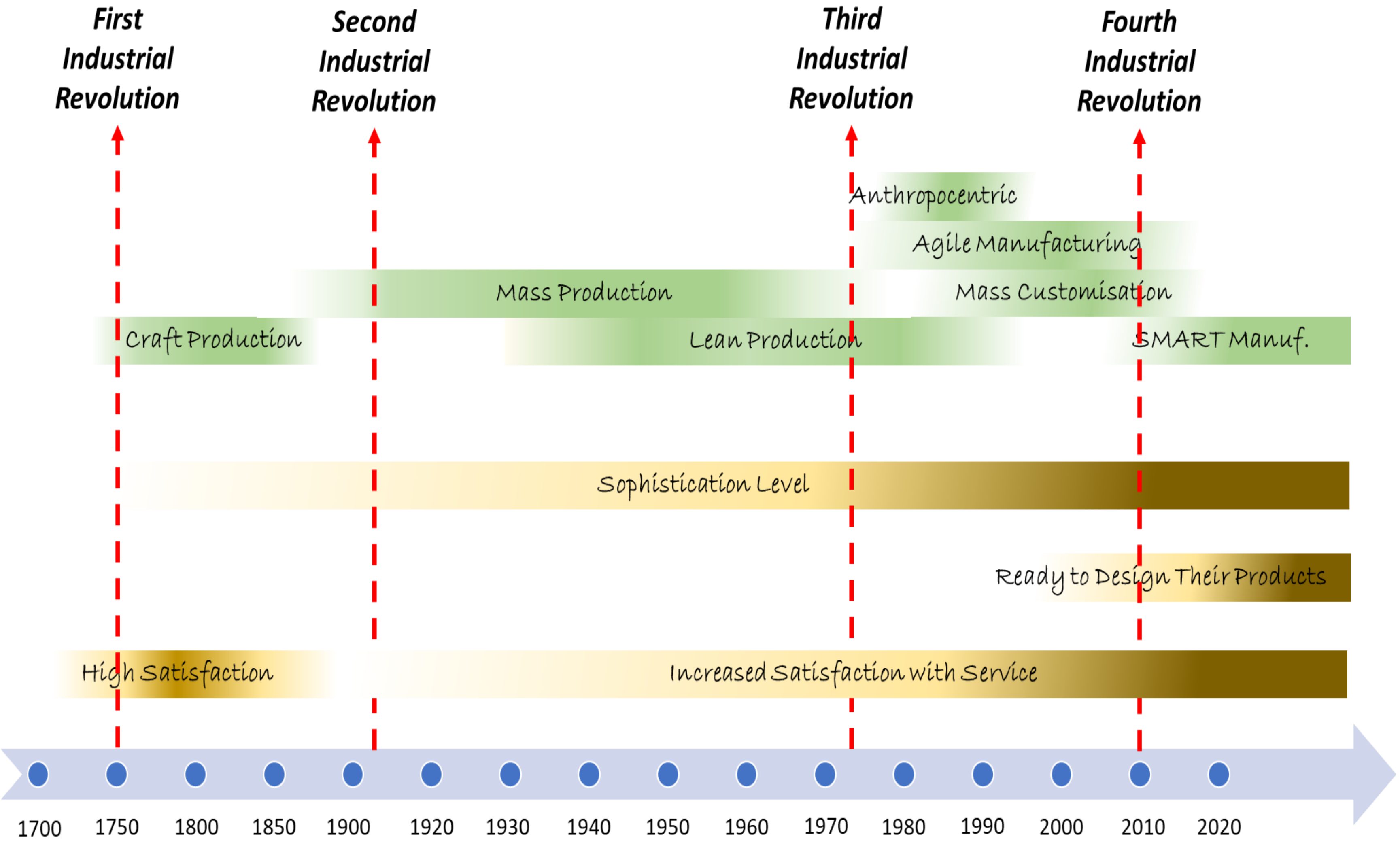


Manufacturing Paradigms



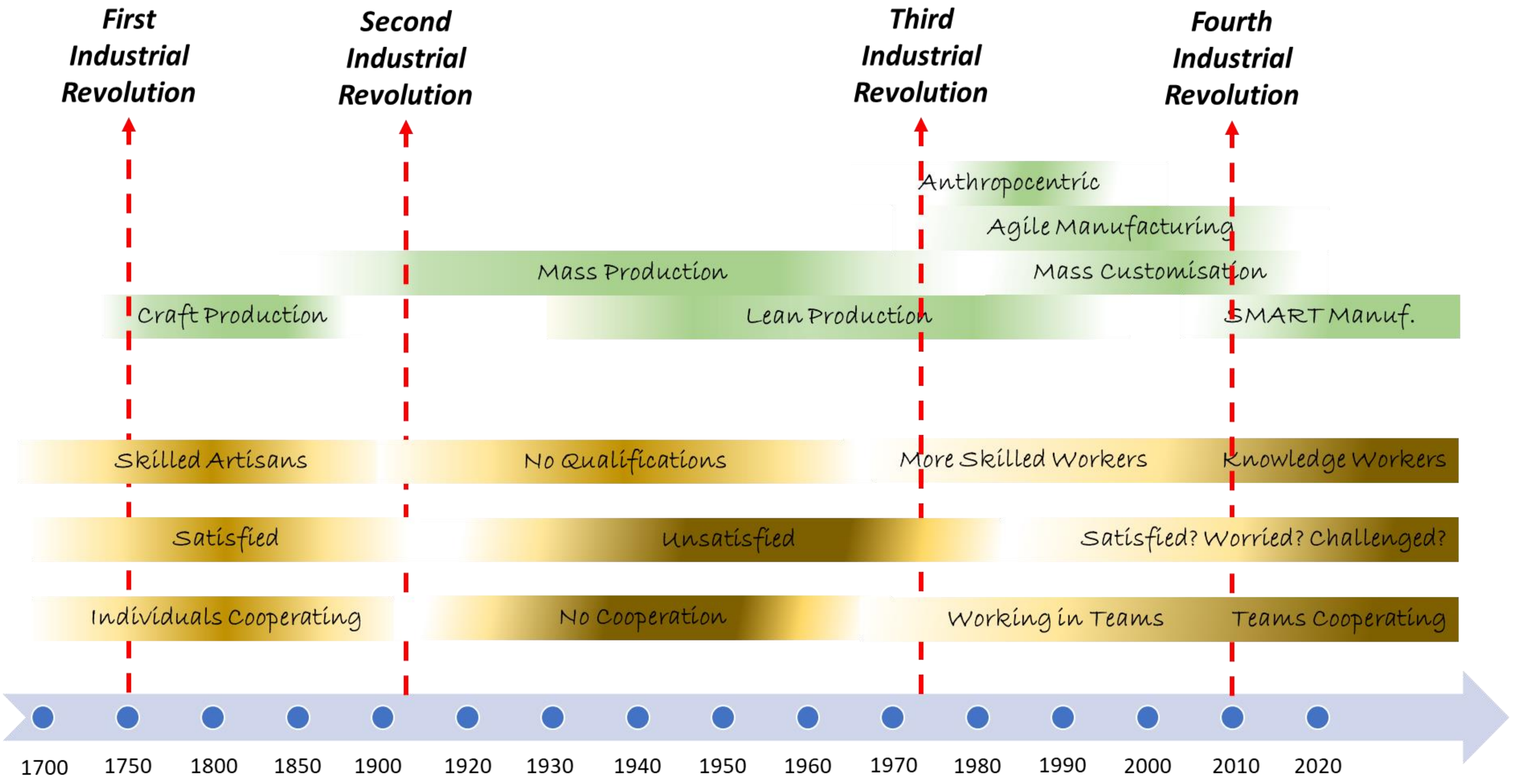
Product Related External Conditions

Manufacturing Paradigms



Customer Related External Conditions

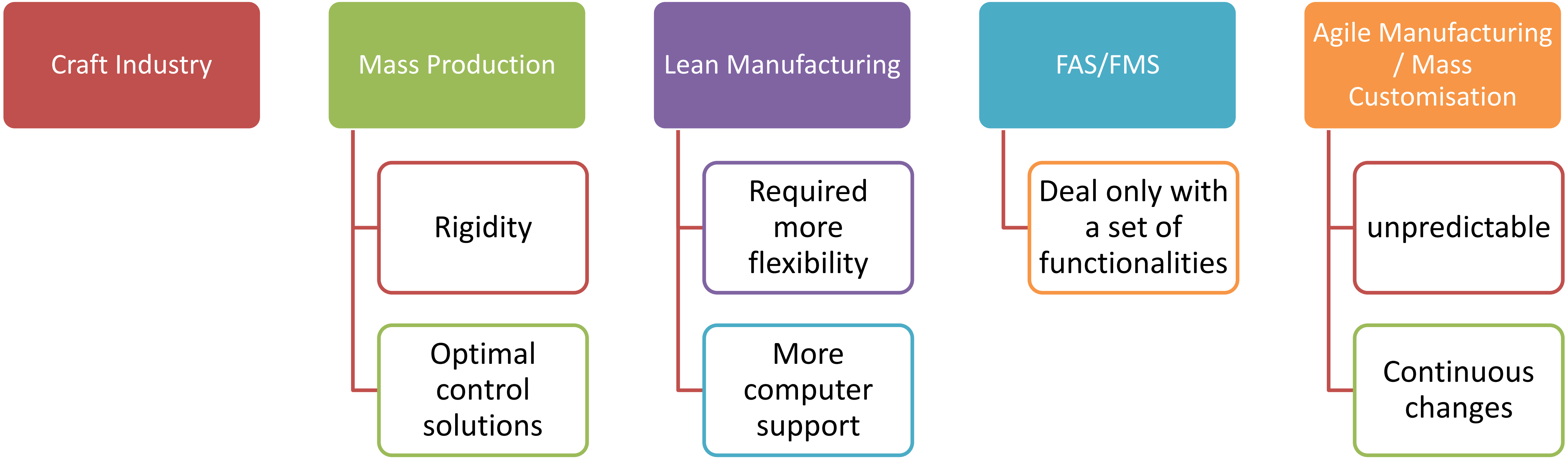
Manufacturing Paradigms

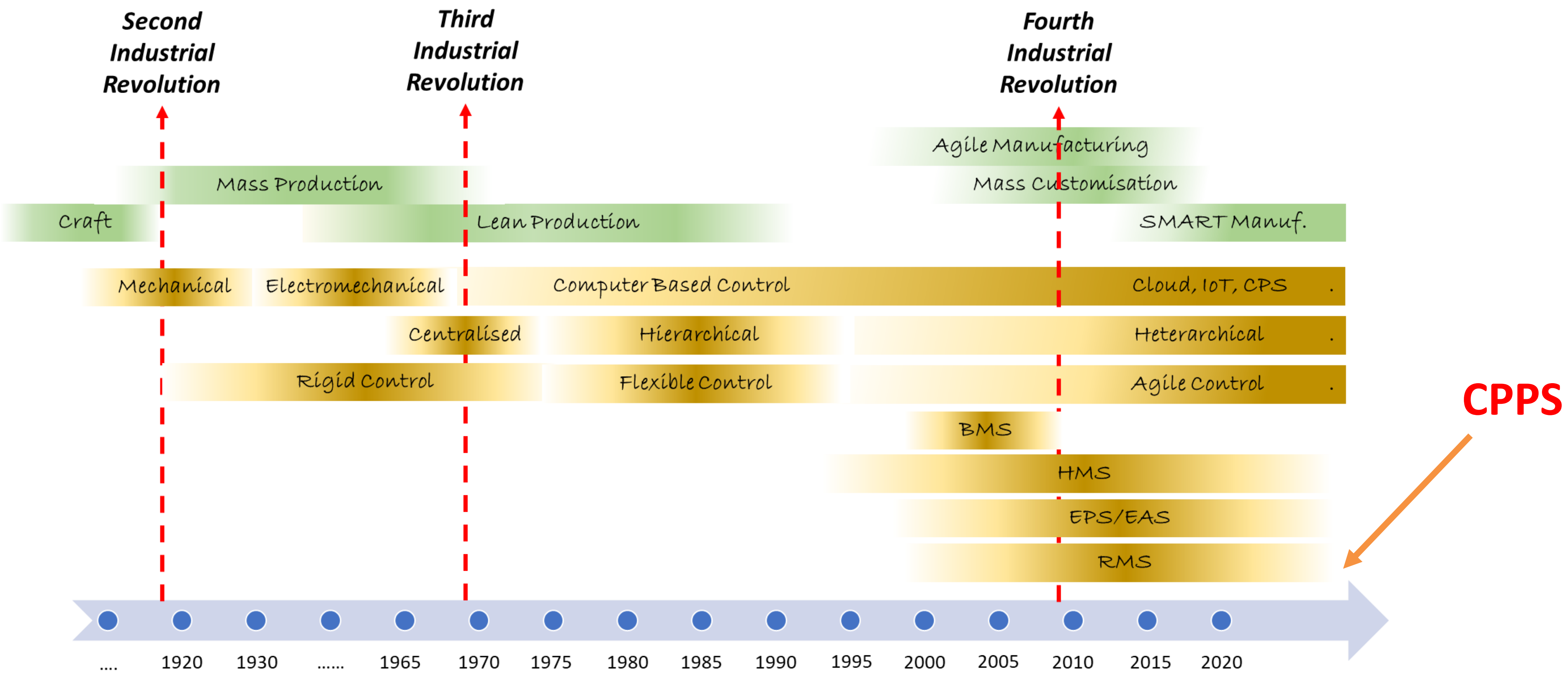


Workers Related External Conditions

Manufacturing Paradigms

Manufacturing Paradigms

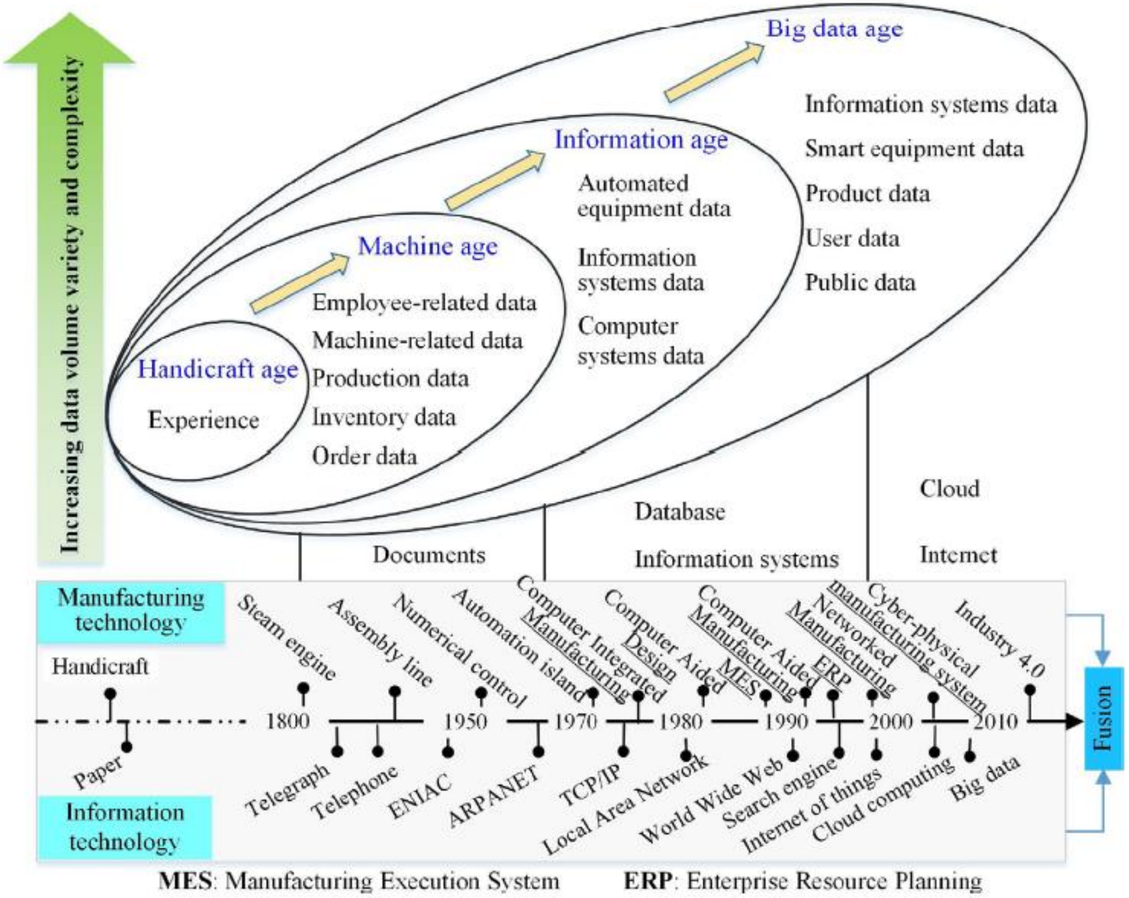




Shop Floor Control Evolution

Manufacturing Paradigms

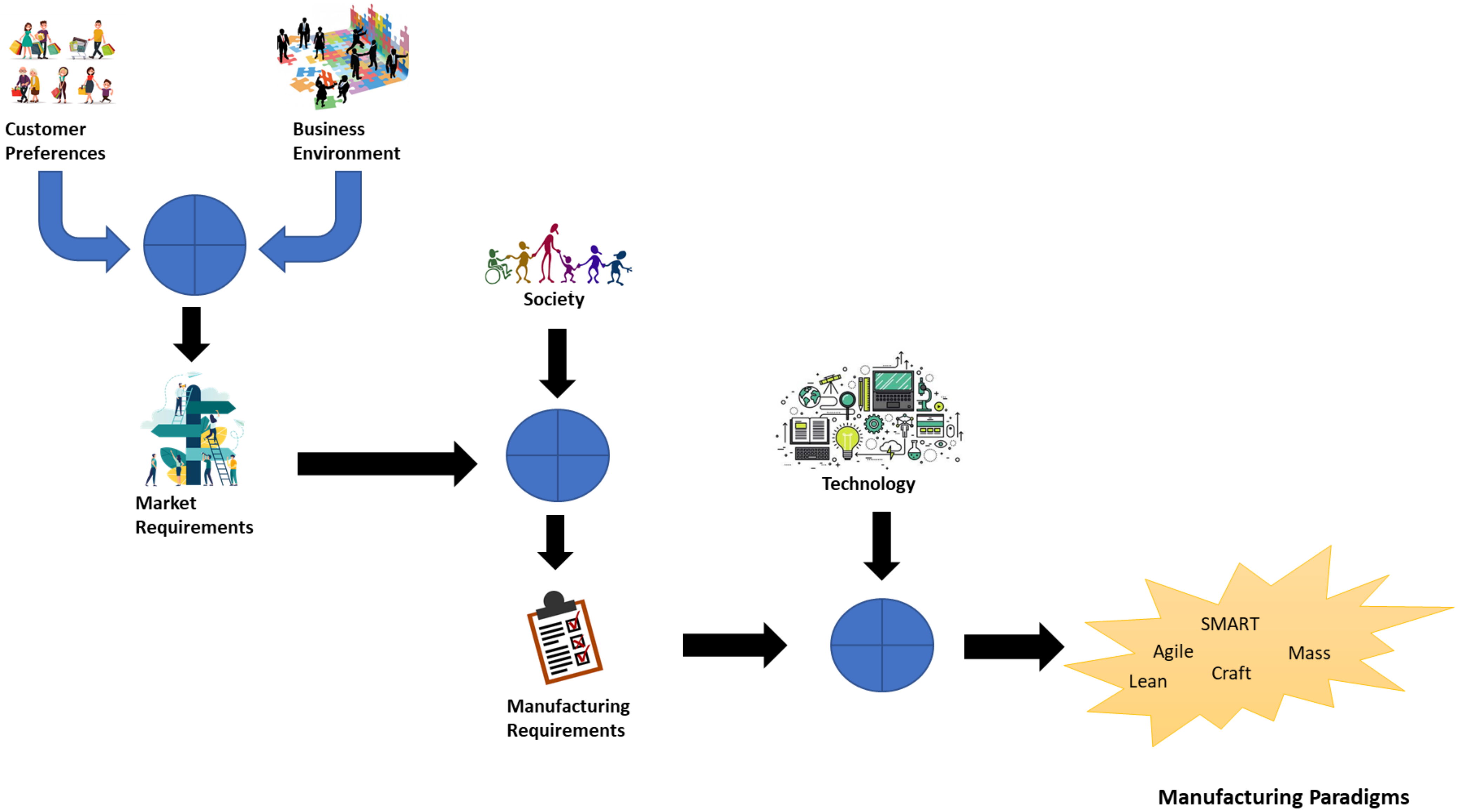
Manufacturing Paradigms - Data



Fei Tao	Barata	Ind. Vs Info. Age
❑ Handicraft Age	❑ Craft Production	❑ Pre-Industrial Age
❑ Machine Age	❑ Mass Production ❑ Lean Manufacturing	❑ Industrial Age
❑ Information Age	❑ Mass Customisation ❑ Agile Manufacturing	❑ Information Age
❑ Big Data Age	❑ SMART Manufacturing	❑ Post-Information Age

***Evolution of Data in Manufacturing. From** (Tao, Qi, et al., 2018)*

Understanding Paradigm Shifts in Manufacturing



Manufacturing Paradigms

Current Manufacturing Requirements

- **Market Environment**
  - Customers preferences
    - Individualised products /Customisation and Demand for Personalisation
    - Better quality
    - More intelligent products
  - Business Environment
    - Product Extended Service
    - More competition
    - The move from large monolithic organizations toward multistakeholder collaborations in which cooperation is fostered by market requirements

Current Manufacturing Requirements

- **Technology/ Processes Environment**
  - ICT technologies / Digital Transformation
    - Cloud, CPS, IoT, SoS, Big data, SOA, Agents, …
    - AI and Autonomous Robots
    - VR / Augmented reality
  - Integration
  - Cybersecurity
  - New Robots
    - Collaborative
    - Use of Autonomous Robots
  - New Processes
    - 3D Printing
    - …

Current Manufacturing Requirements

- **Societal Requirements**
  - Environment Regulations
  - Better working places
  - Labour Shortage and Skill Gaps
  - Sustainability
    - Produce more with less resources

To Overcome These Challenges

- **Smart Manufacturing**: Leveraging IoT, AI, and data analytics for real-time decision-making.
- **Industry 5.0**: Focusing on human-centric and sustainable manufacturing practices.
- **Automation & Robotics**: Enhancing efficiency and reducing dependency on manual labor.
- **Digital Twins**: Using virtual simulations to optimize production lines and predict issues before they arise.
- **Cybersecurity Measures**: Implementing robust cybersecurity frameworks to protect connected systems.

Smart Manufacturing – Industry 4.0

Digitalization, Cyber-Physical Systems (CPS), IoT, and AI.

Emergence of smart factories and data-driven manufacturing.

Focus on automation, connectivity, and real-time data analytic

Industry 5.0

- Extending the Technological Capability of Industry 4.0 to be more:
  - **Human Centric**
    - integrating technology to enhance—not replace—human capabilities.
  - **Sustainable**
    - Circular Economy
    - Energy Efficiency
  - **Agile and Resilient**
    - Hyper Customisation/Personalisation
    - Autonomous Logistics

Where Are We NOW?

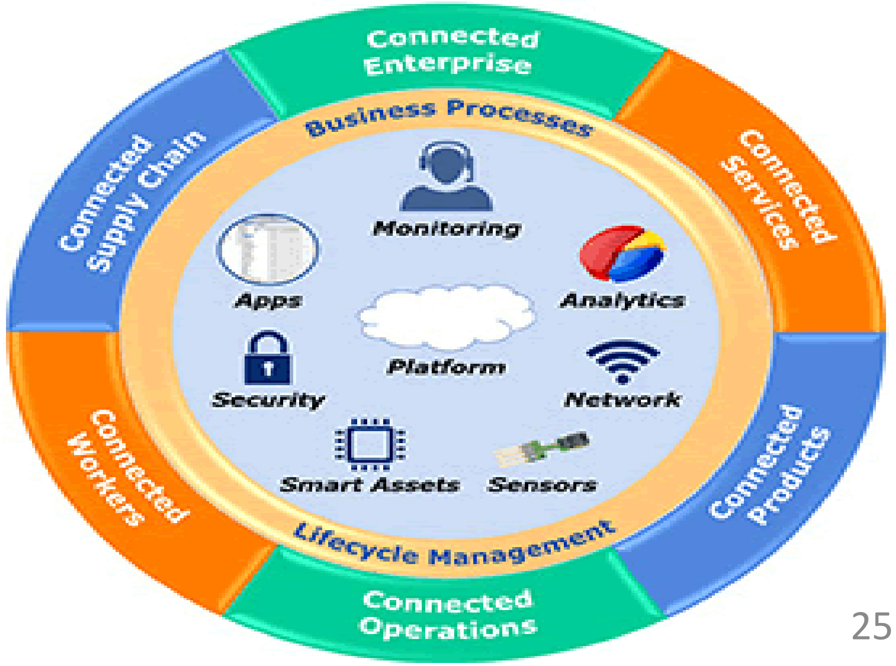
SMART Manufacturing

- Adaptive
- Knowledge-based
- Support Variance
- Easily Changed
- Sustainable
- Flexible
- Efficient

- Intra and Inter factory
- Involving a digitised supply chain

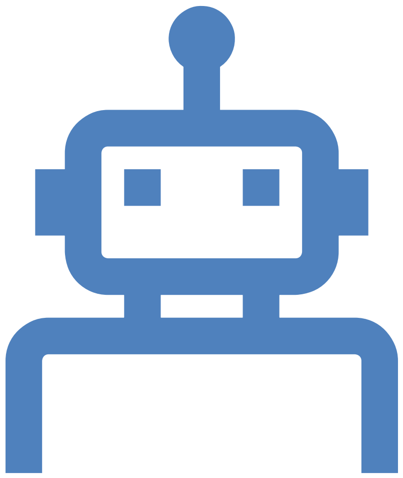
- System Wide Collaboration
- Information Driven interactions among all stakeholders

Collaboration Digitization
Distribution Intelligence



How Have We Arrived Here?

RICS’ Contributions



RICS
Robotic & Industrial Complex Systems

EAS – Evolvable Assembly Systems

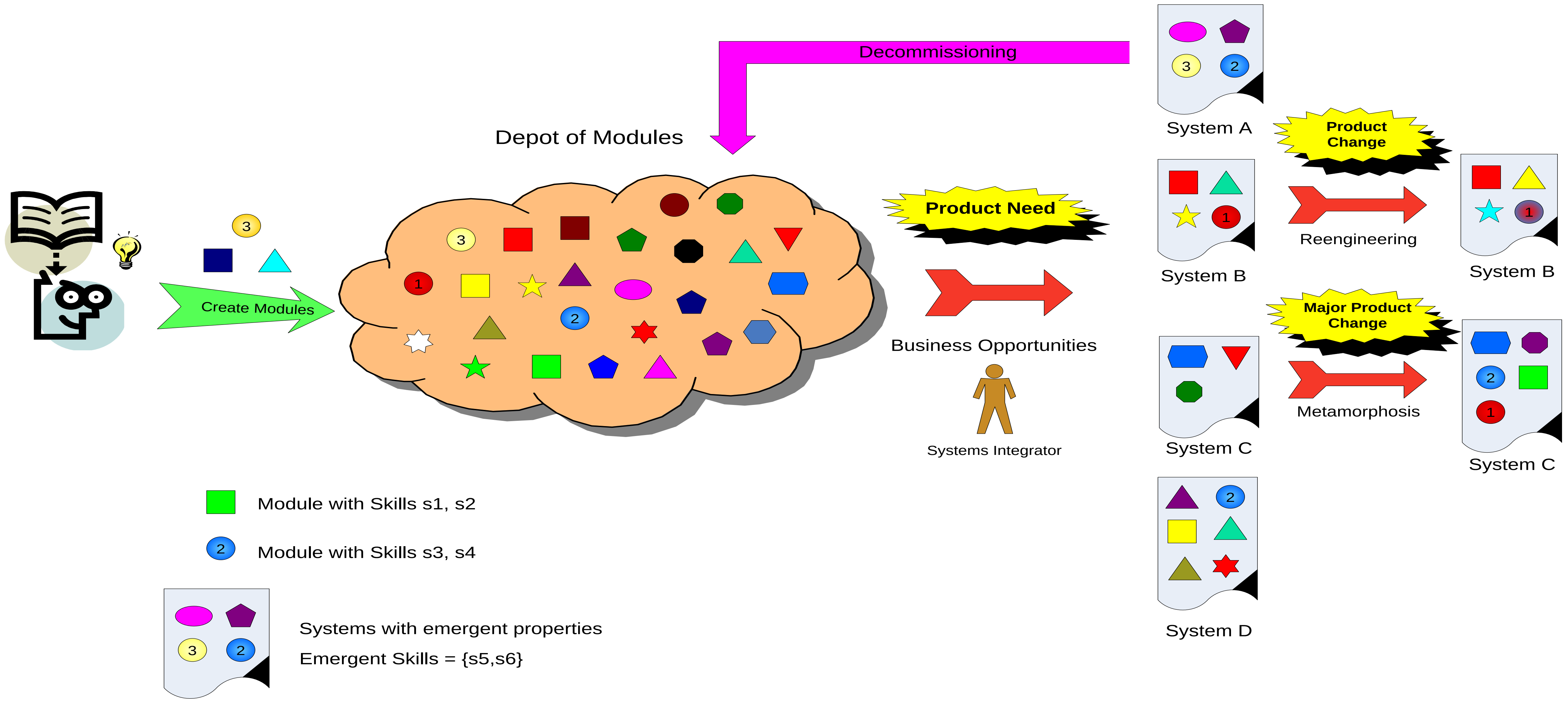
- The basis for EAS lies in a multi-disciplinary study of the needs and requirements of assembly systems
- It shifts the technological focus from complex, flexible, multi-purpose systems to simpler, process-oriented, dedicated swarms of machine modules.
- From a paradigm point of view, the EAS approach rejects machine flexibility (sub-optimal at any specific task) for application agility

EAS – Evolvable Assembly Systems

Evolvable Assembly Systems (EAS) has the following characteristics:

- Process-oriented modularity
- Task-specific (small) elements (modules)
- **Decentralised, distributed control system**
- Interoperability
- **Continuous evolution** of the system by exchange, addition or removal of modules
- Self-configuring system units
- Ability to exploit agent technology to capture emergent behaviour
- Mechatronic, advanced enabling interface (AEI)
- Modules with **on-board "intelligence"**

EAS – Evolvable Assembly Systems



Mechatronic Modules

- What we need is:
  - Mechatronic Modules that can be composed to create complex systems
    - To support reutilisation
    - Low cost
    - High quality
    - Changeability

The Module Concept

The most important concept in an EPS is the concept of **Module.**

Basic building block.

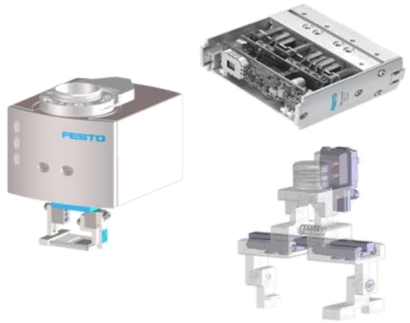
A module is an intelligent process-oriented entity able to be aggregated.

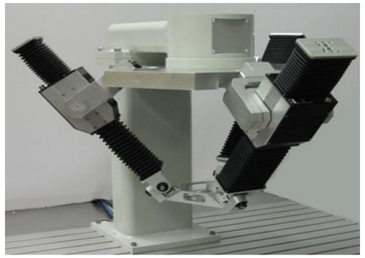
- It has a functionality or skill
- It is autonomous since it includes computational power
- It is inherently distributed
- Must have the functionalities to be able to interconnect to create complex entities
    - Mechanical interfaces
    - Control interfaces

A module is characterised by its **skills**

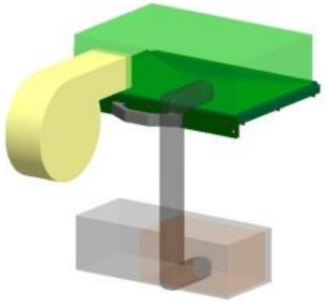
CPS ??

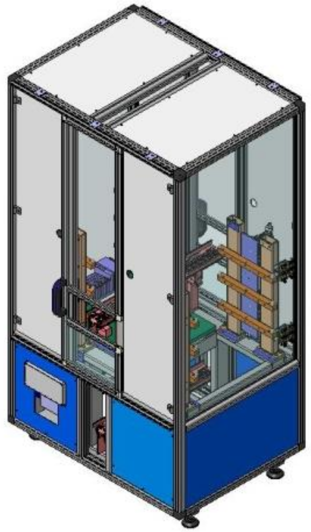
The Module Concept





PKM Module





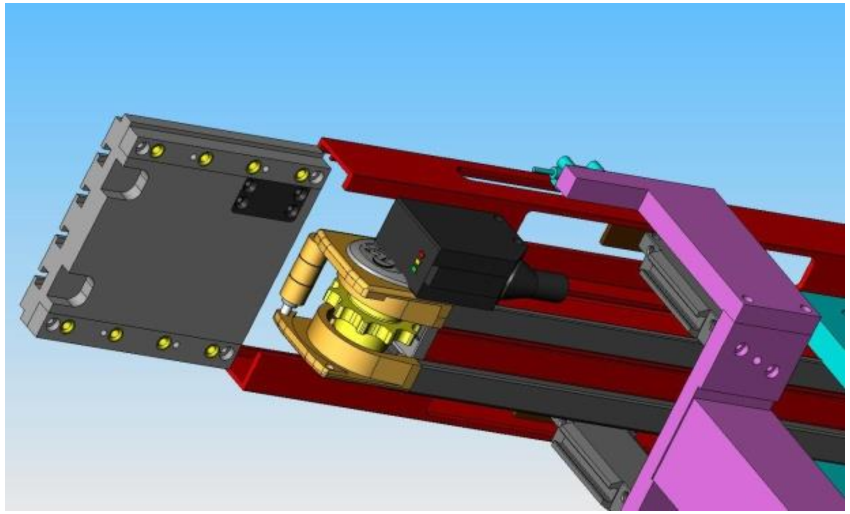
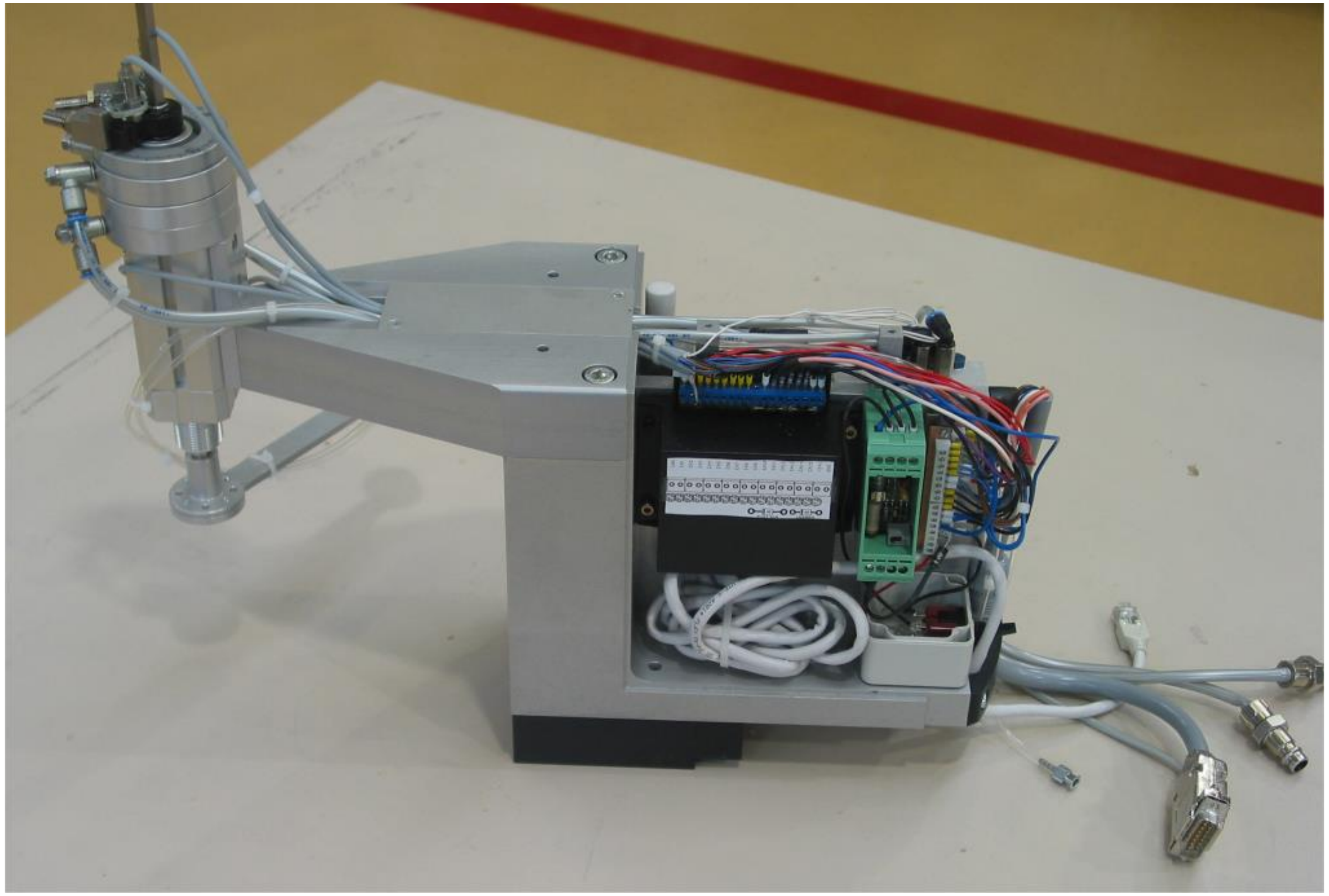


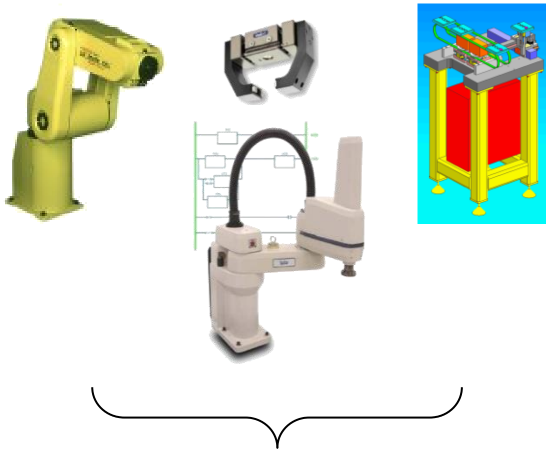
Illustration of a module



- **Mechanical unit, workspace**
- **Individual supply unit (controller, pneumatic / elctric installation, docking mechanism ..)**
- **Standardized interface (mechanical, electric, pneumatic, hydaulic, ethernet control)**

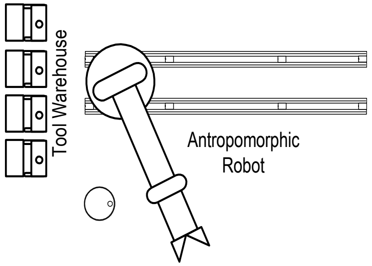
Society of Modules

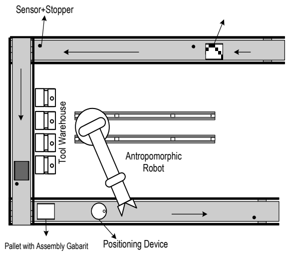
- **Individual Architecture**
  - How they are internally built?
  - How do we represent their abilities? (skills)
  - What do they need to be able to participate in compositions: systems or societies?



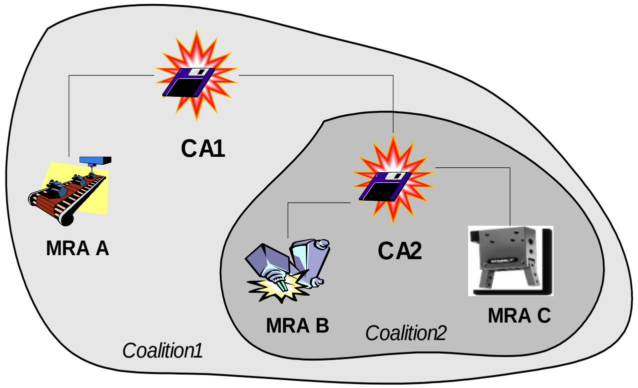
Life in the Silicon World

- **Society of Modules – System**
  - These are the systems that can be built from the existing modules. Society creation.
  - How to support interaction?
  - Addition and removal of modules should be easy.
  - The problem is much more than communication between the members of a system.

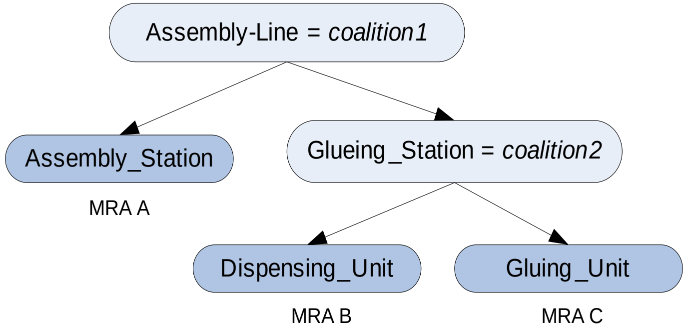




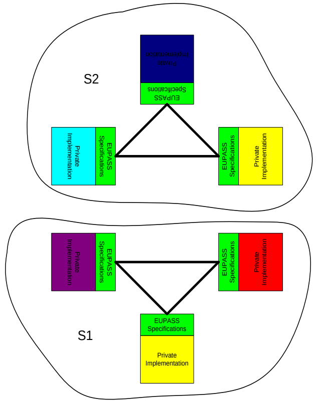
Society of Modules



A)



B)



When these modules connect they establish a system **with emergent properties**

Therefore anytime we create a society with modules with different **skills** the emergent properties are different

Notion of **basic skills** and **complex** or **emergent** skills

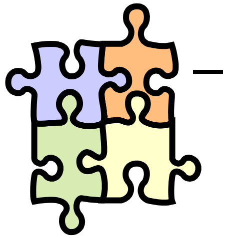
The set of the skills emerging from each of the two different systems is different

Multiagents

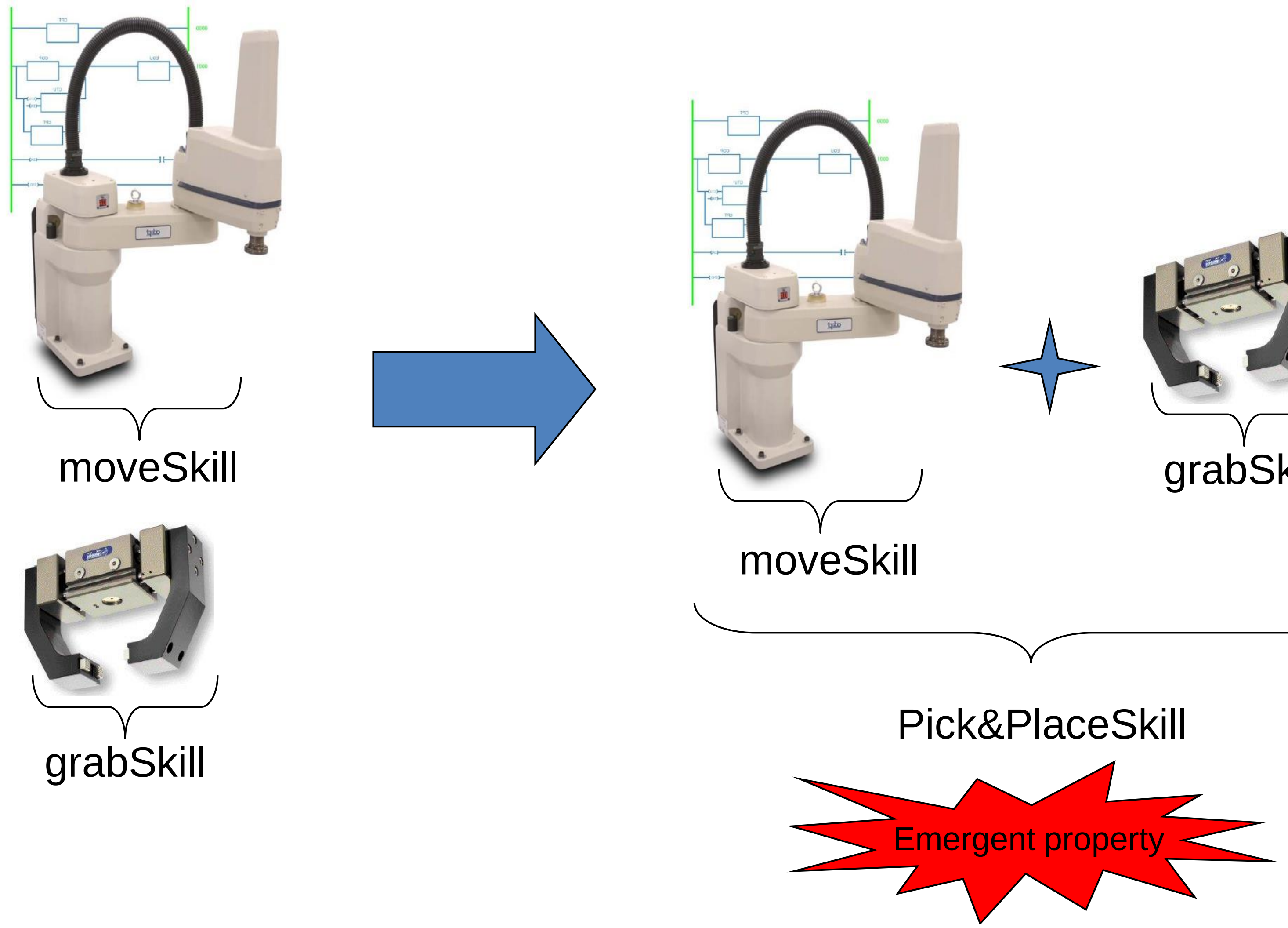
- The **multiagent** paradigm fits well because:
  - They are a good model to support the “silicon” life of existing mechanical modules. Their individual behaviour is encapsulated within the agent.
  - This paradigm already supports the idea of **interaction** within a society of individual agents. A system is nothing else than a set of agents interacting.
  - The focus is not on the communication but on the type of messages that are exchanged.
  - **Emergence** is best coped with by multiagent approaches since another relevant task within the society of agents is defining and identifying the complex functionalities (skills). The great advantage of this approach is the possibility to create complex functionalities (skills) based on the interaction among two or more modules.

Emergence

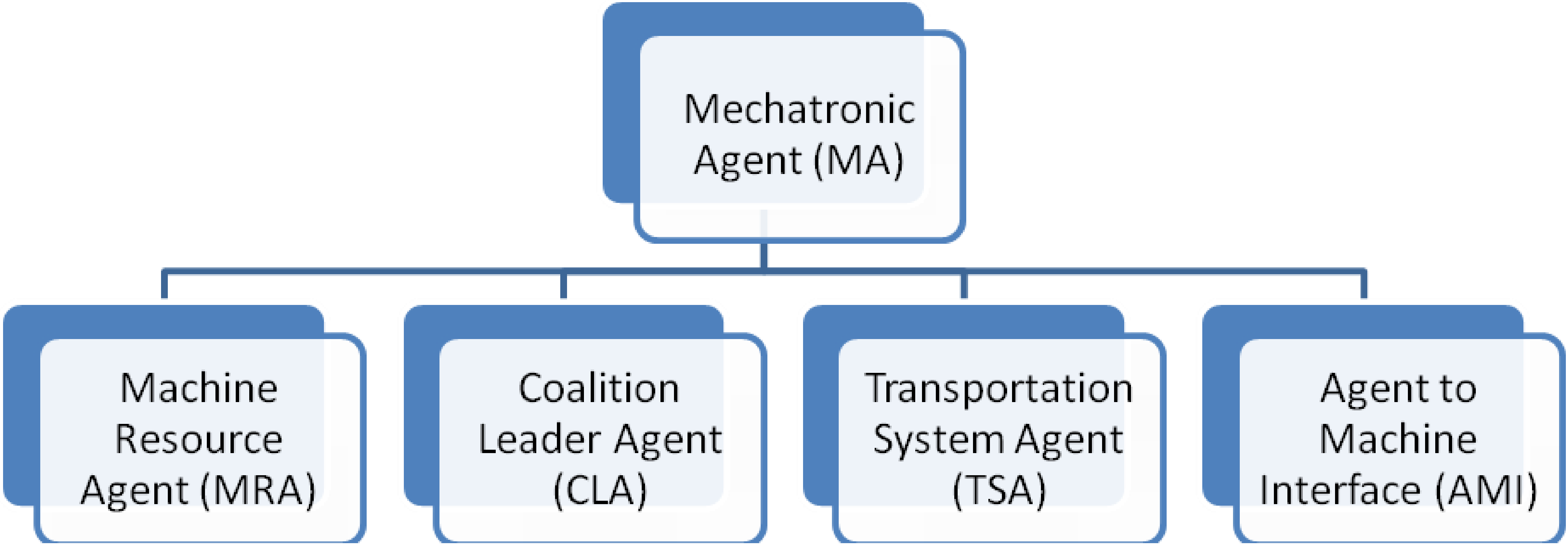
- A property shown by **systems** when their behaviour is bigger than the sum of the individual behaviours that compose their parts
- Typical of systems that are composed of parts that interact
- Examples
  - **Car** – wheels + seats + engine + ... -> emergent property of driving
  - Group of people solving a problem – person 1 knowhow + person 2 knowhow + ... -> solve the problem
  - **Jigsaw** – each part by itself is meaningless, even if we add them together only if matched in the appropriate order we can see the image.



Emergence


moveSkill
grabSkill
moveSkill
grabSkill
Pick&PlaceSkill
Emergent property

IDEAS

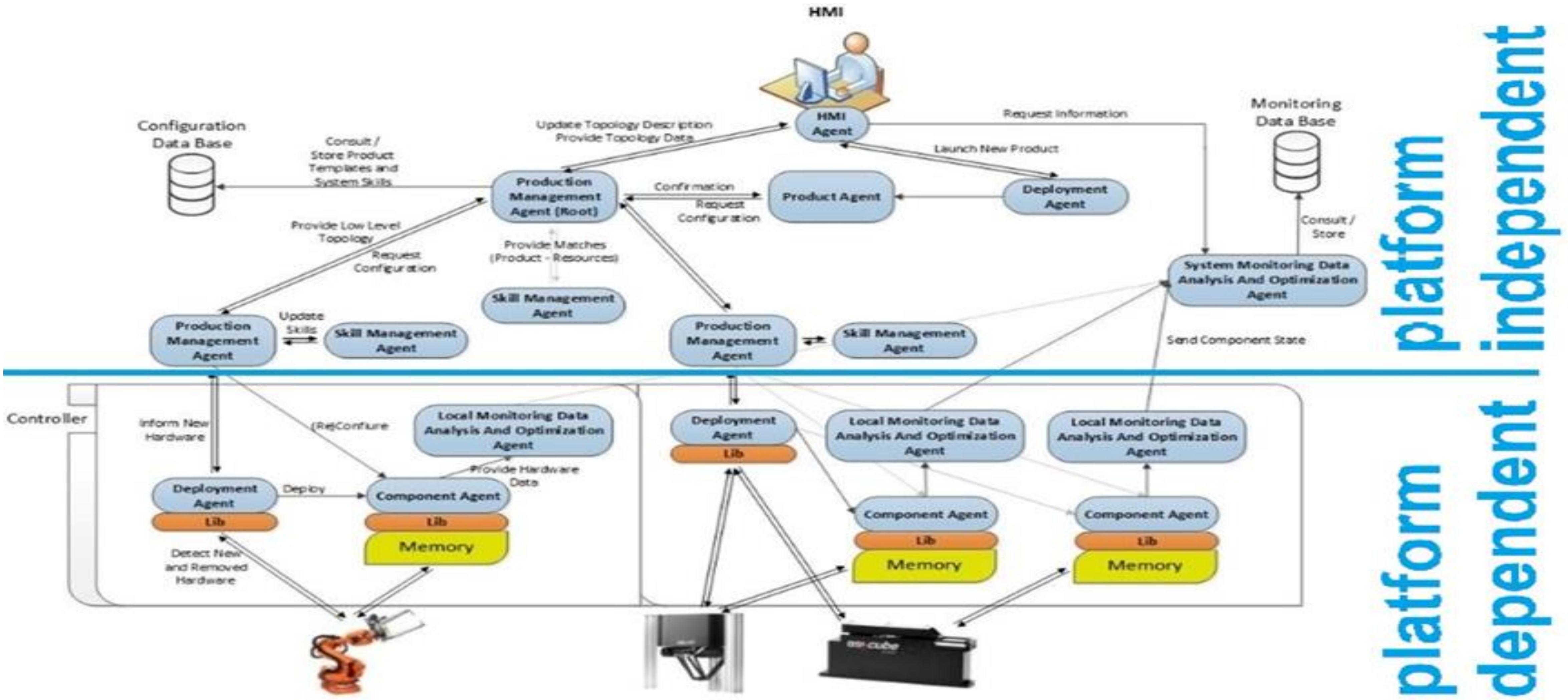

Mechatronic Agent (MA)
Machine Resource Agent (MRA)
Coalition Leader Agent (CLA)
Transportation System Agent (TSA)
Agent to Machine Interface (AMI)

IDEAS

PRIME

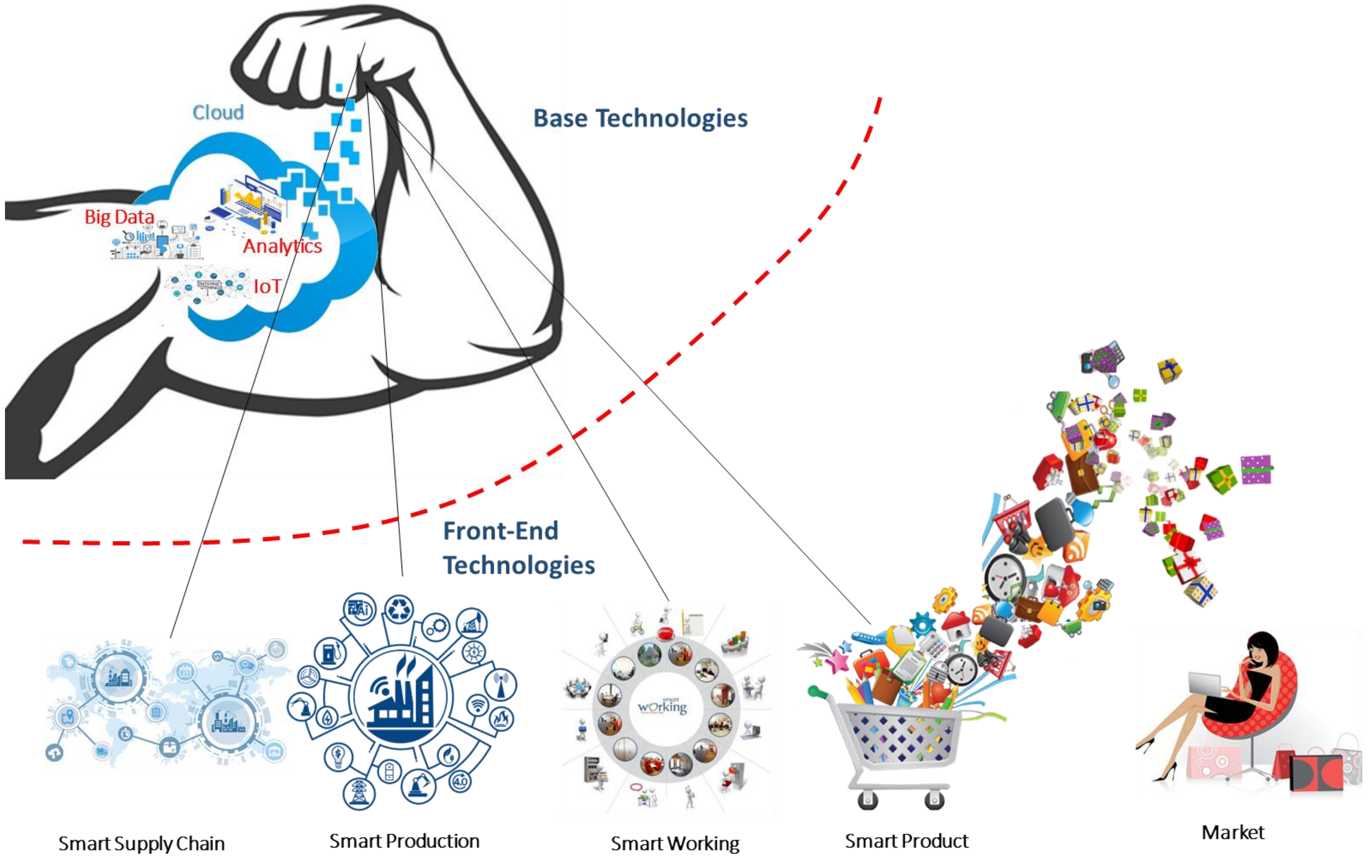
Plug and produce intelligent multi-agent environment based on standard technology

Concept of the Architecture



Smart Manufacturing – Our Contributions

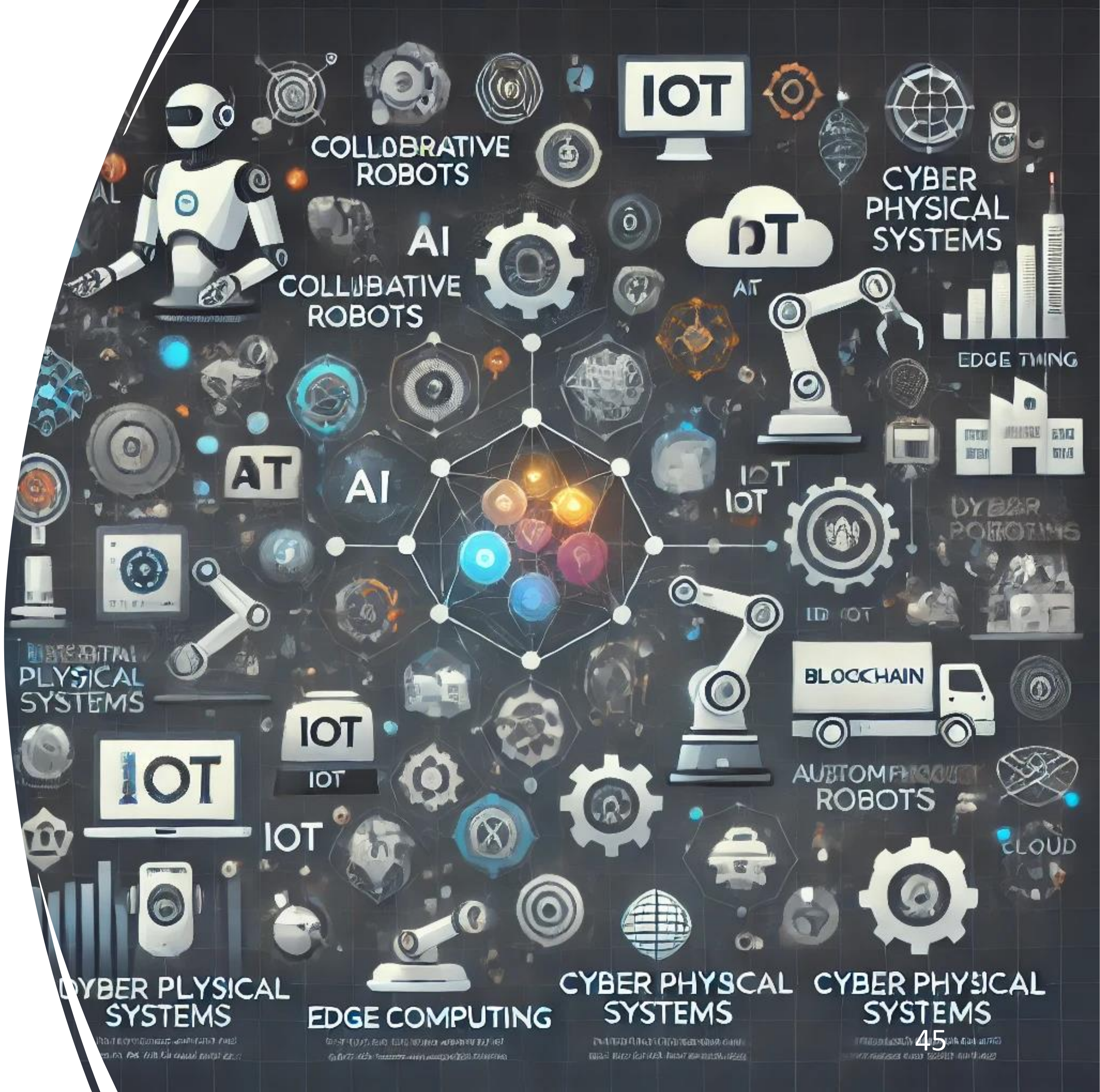
SM – Theoretical Framework



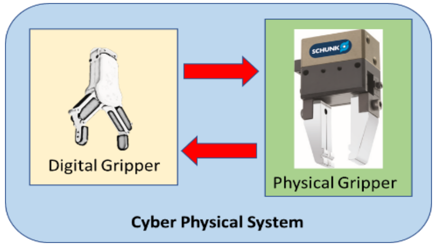
Based on (Frank, Dalenogare and Ayala, 2019)

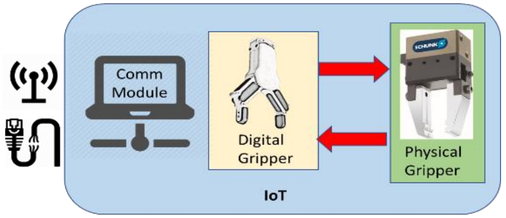
SM – Base Technologies

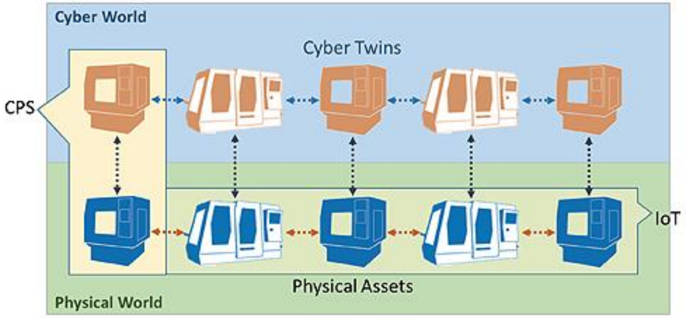
- Collaborative Robots (Cobots)
- AI – Big Data, Data Mining, Generative
- Digital Twins
- Edge Computing
- IoT
- Cyber Physical Systems
- Advanced Interfaces - AR VR
- Blockchain
- Sensors
- Autonomous Robots
- Cloud Computing

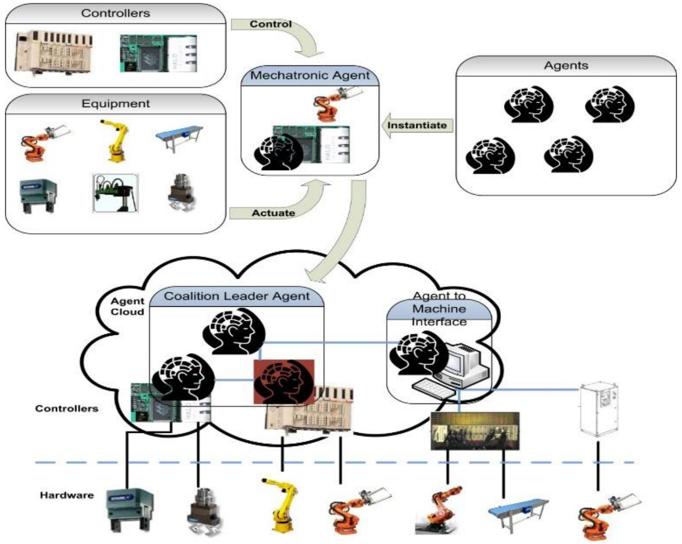


SM – CPS/IoT/Blockchain









EUPASS
Evolvable Ultra-Precision Assembly SystemS

IDEAS

PRIME
Plug and produce intelligent multi-agent environment based on standard technology

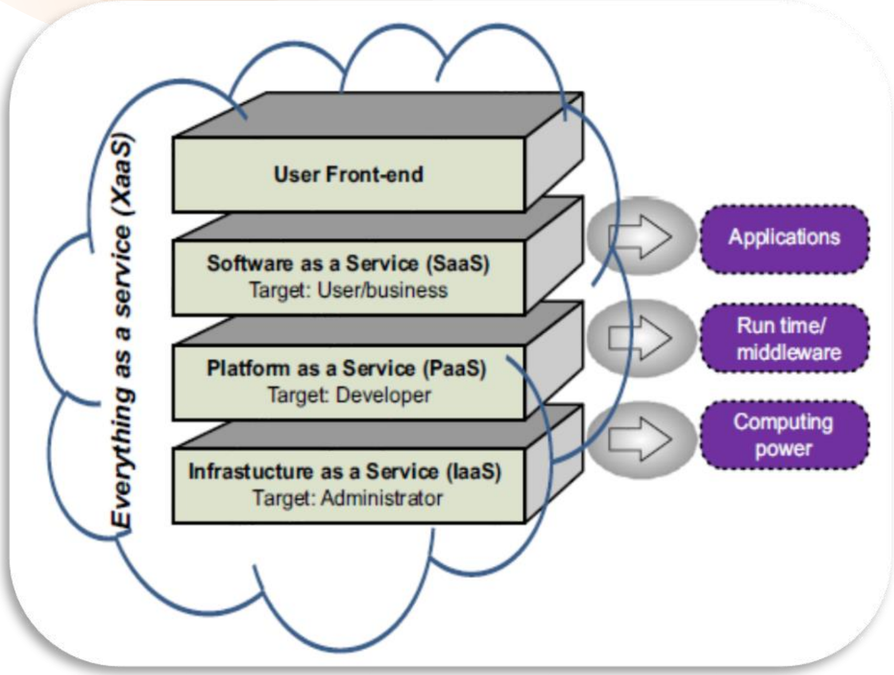
PERFoRM

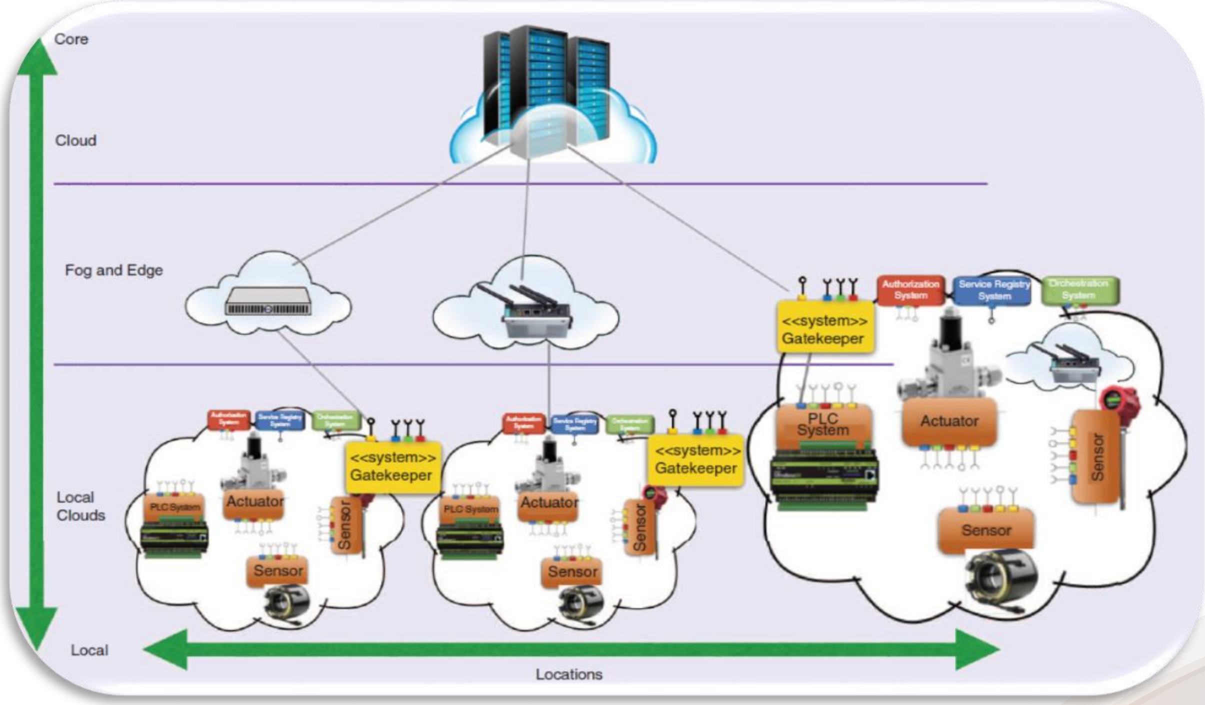
openMOS

GOØDMAN
AGENT ORIENTED ZERO DEFECT MULTI-STAGE MANUFACTURING

AVANGARD

SM – Cloud Computing



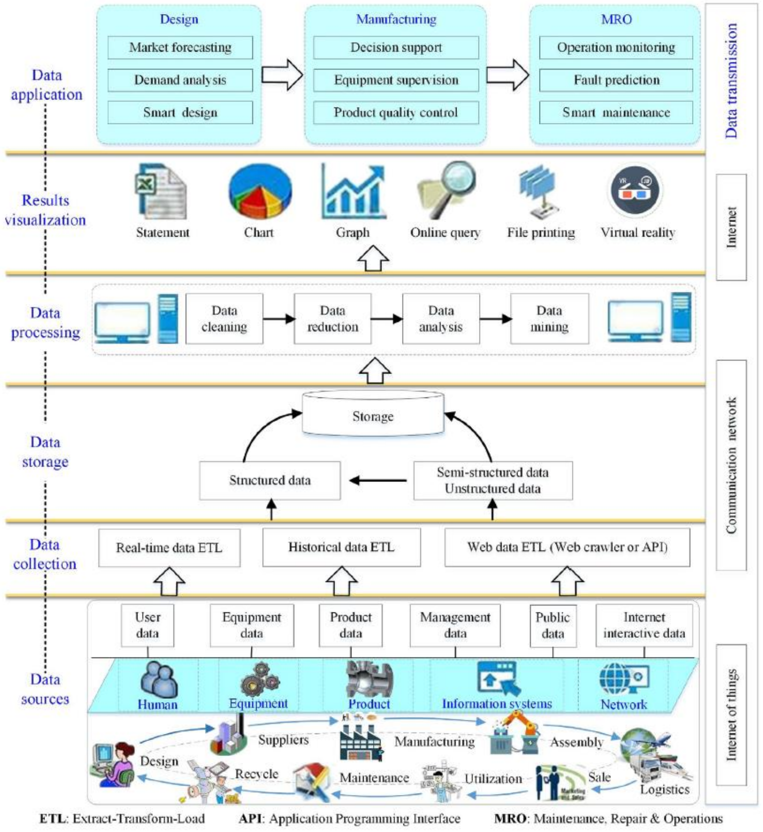


ProSEcO

GOØDMAN
AGENT ORIENTED ZERO DEFECT MULTI-STAGE MANUFACTURING

AVANGARD

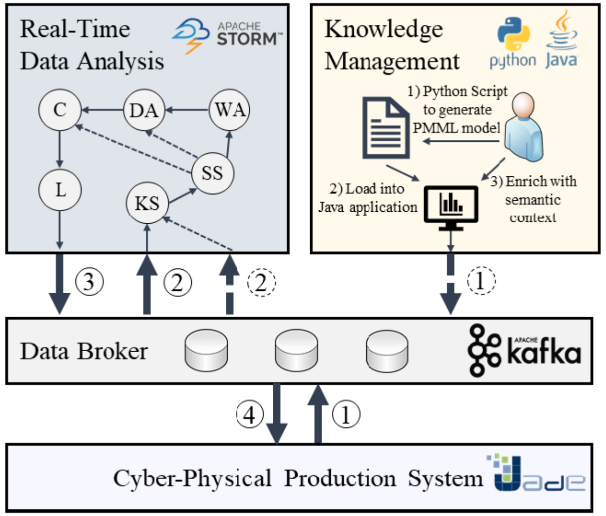
SM – Big Data

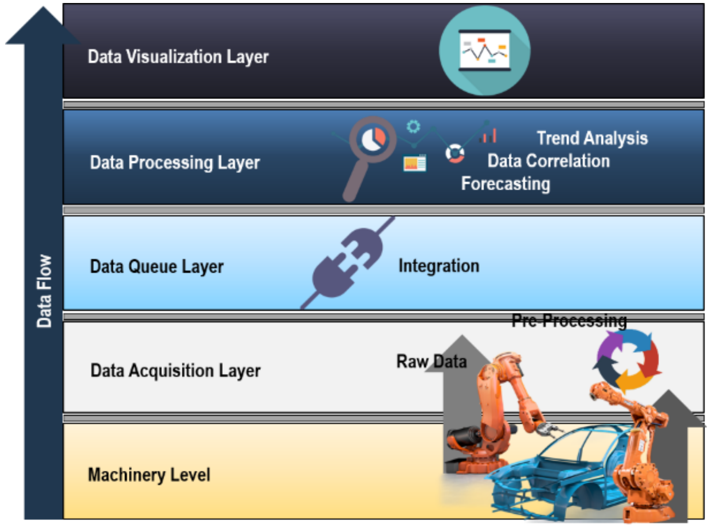


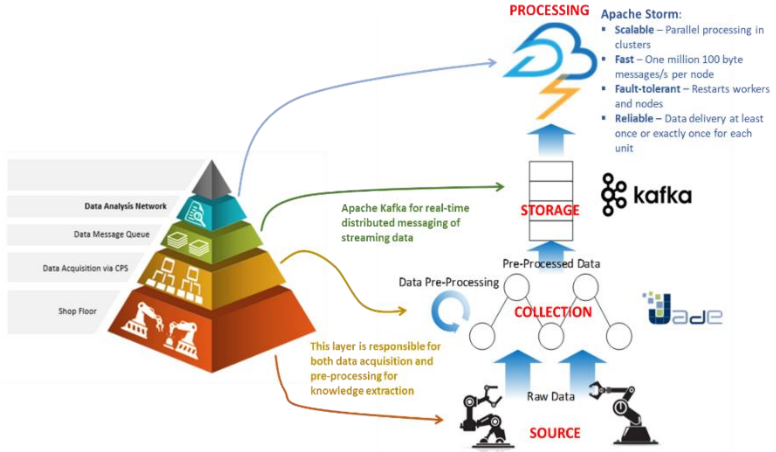
Data Life Cycle From (Tao, Qi, et al., 2018)

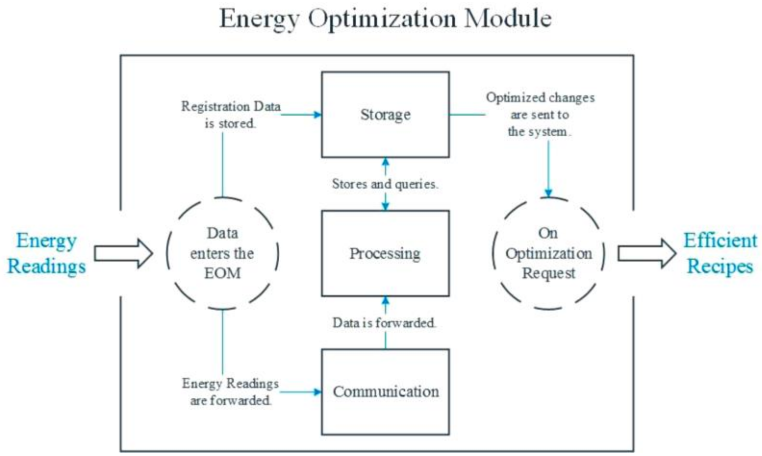
Ages	Source	Collection	Storage	Analysis	Transfer	Management
Handicraft	Human Experience	Manual	Human Memory	Arbitrary	Verbal	N/A
Machine	Human and Machines	Manual	Written Documents	Systematic	Written Documents	Human Operators
Information	Information and Computer Systems	Semi-Automated	Databases	Conventional Algorithms	Digital Files	Information Systems
SM	**Machines, Product, User, Information Systems, Public Data**	**Automated**	**Cloud Services**	**Big Data**	**Digital Files**	**Cloud and AI**

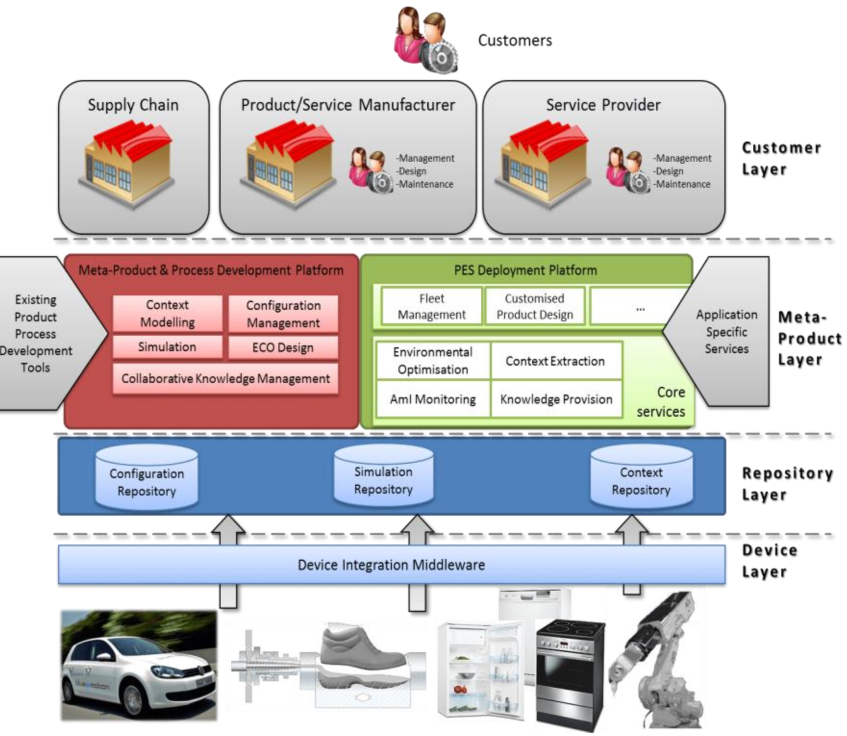
SM – Big Data (Contributions)

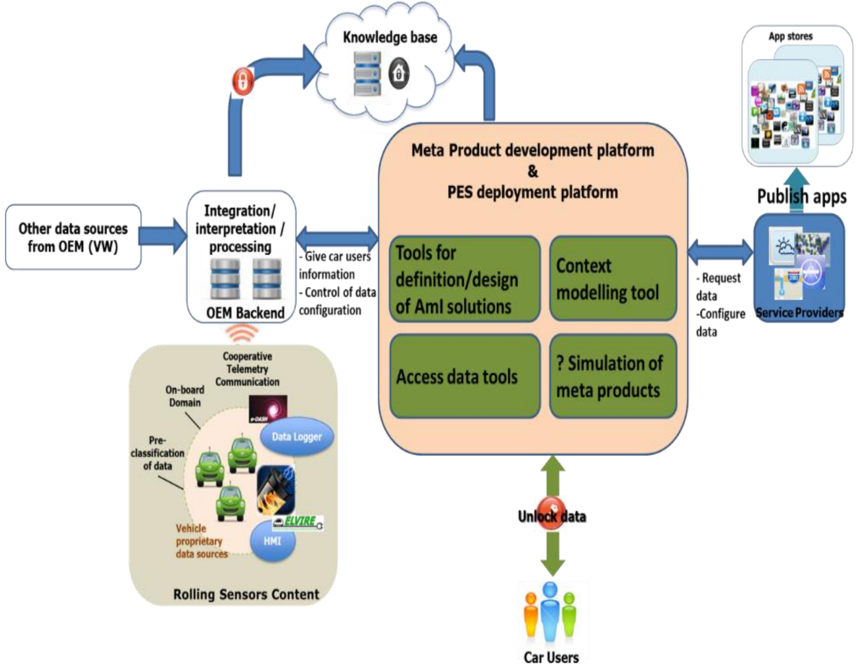


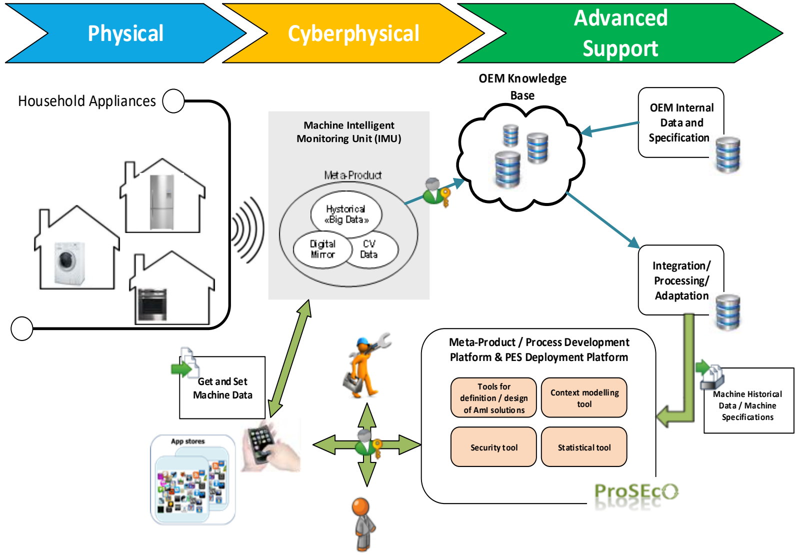










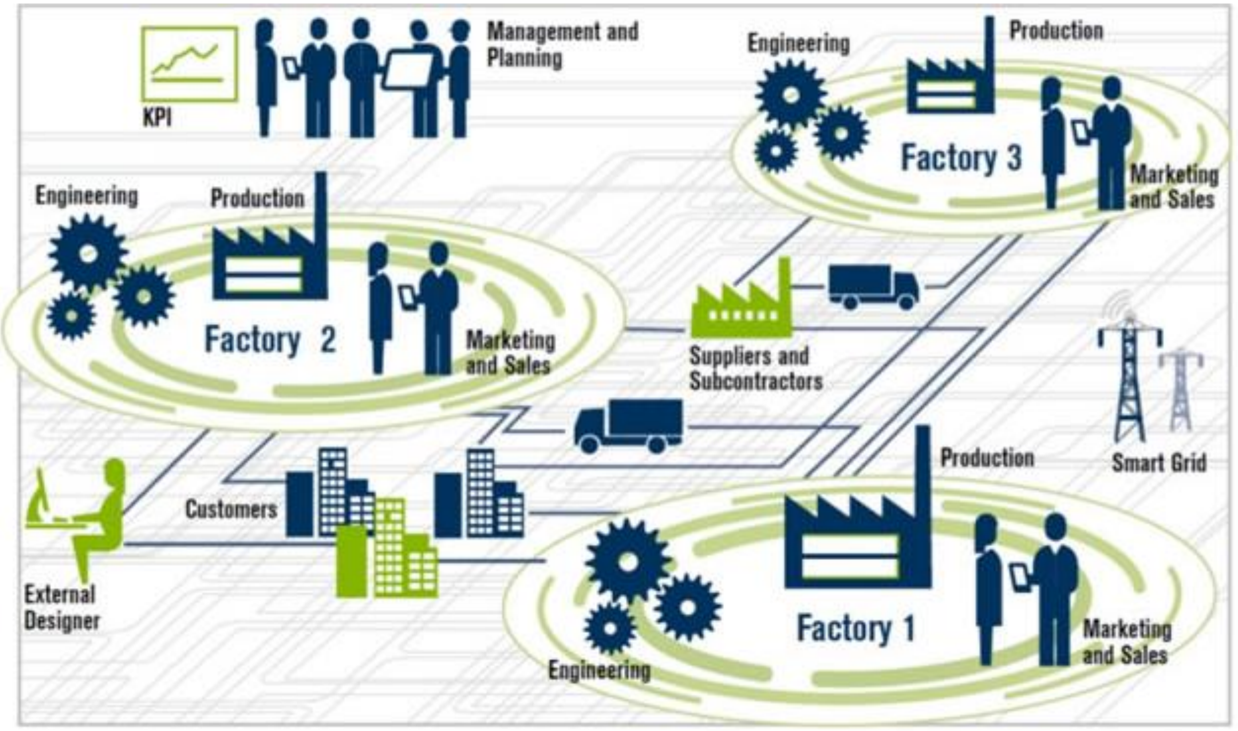


SM – Smart Product

Product Capabilities

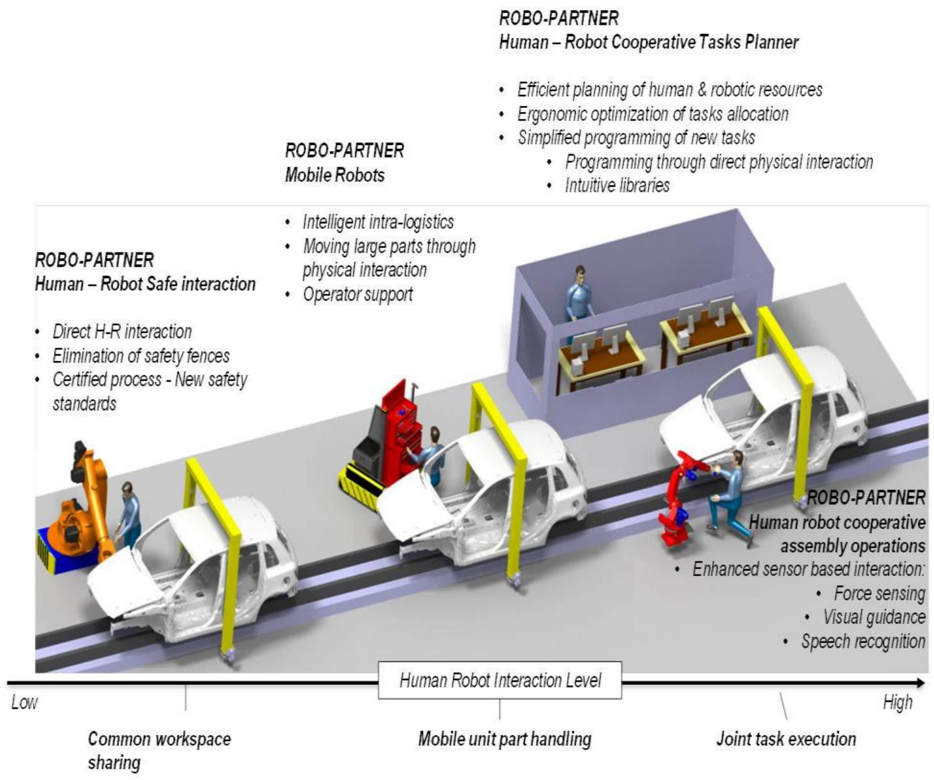
- Connectivity
- Monitoring
- Control
- Optimisation
- Autonomy

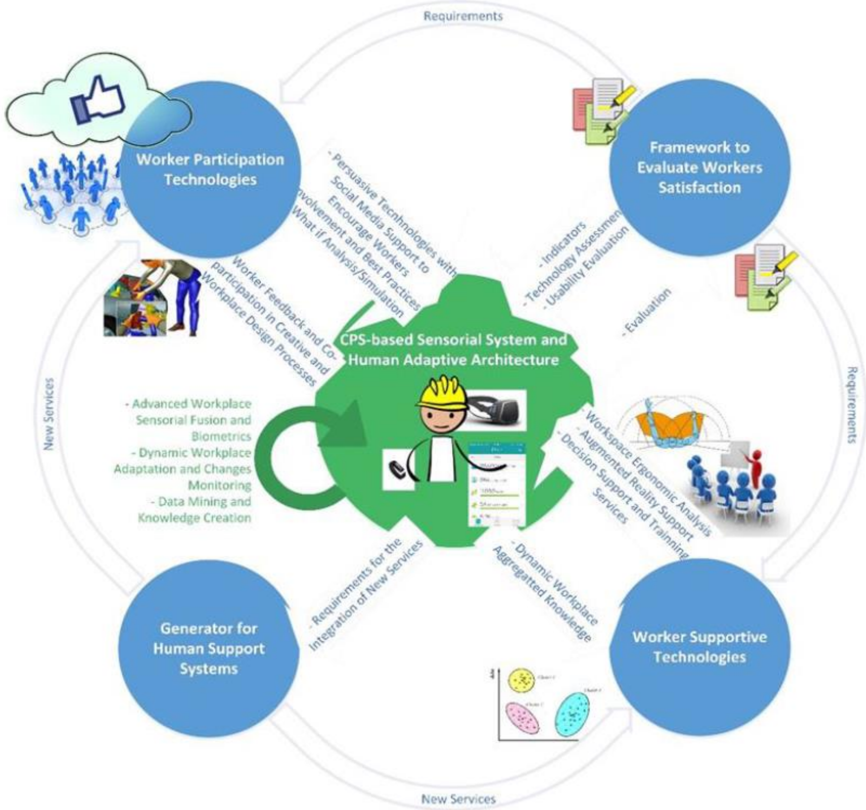
SM – Smart Supply Chain



Source: Hewlett-Packard 2013

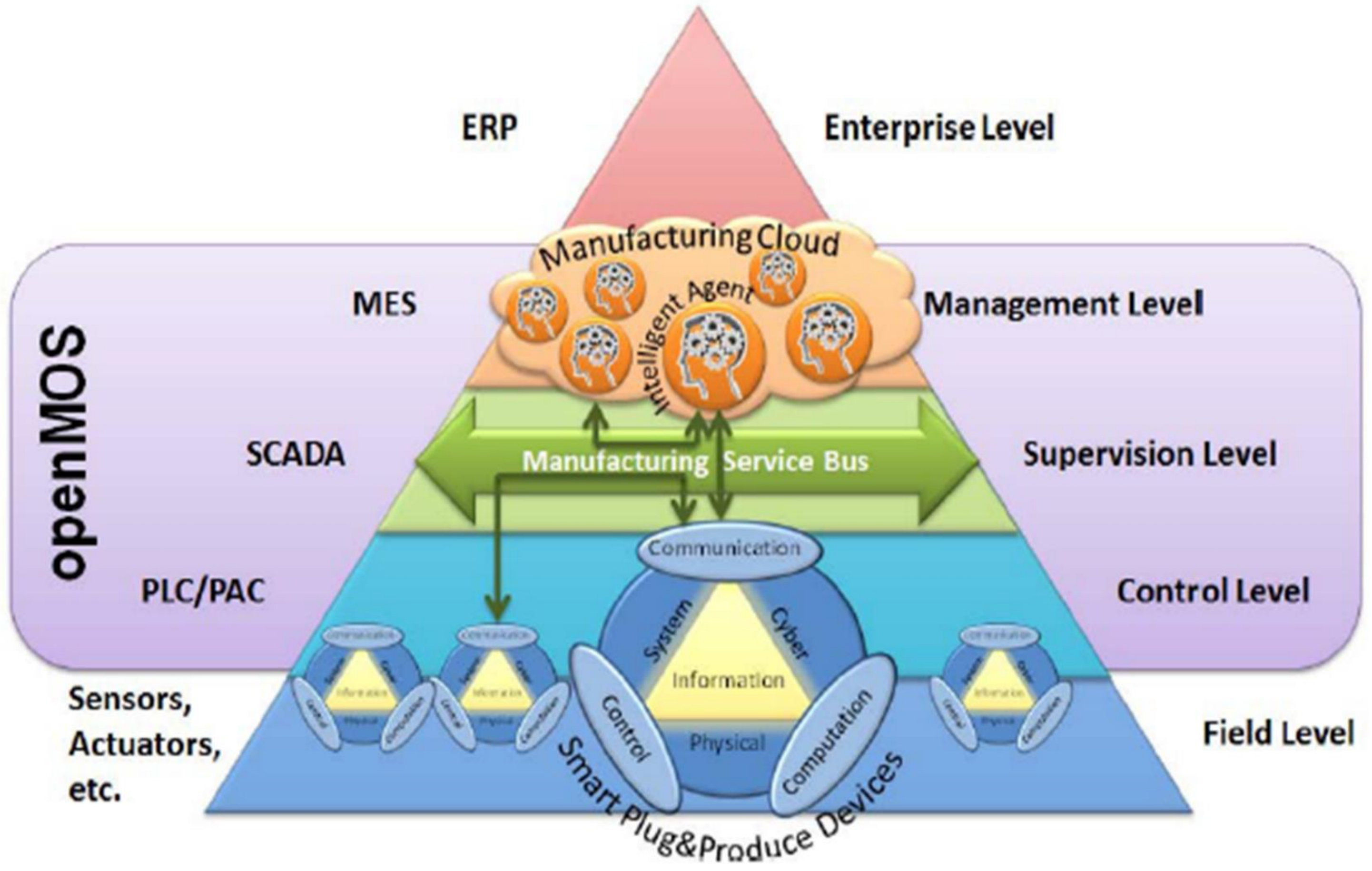
Across multiple production facilities, SMART Supply Chain includes capabilities to support the horizontal integration of the factory with external suppliers to improve the raw material and final product delivery in the supply chain.





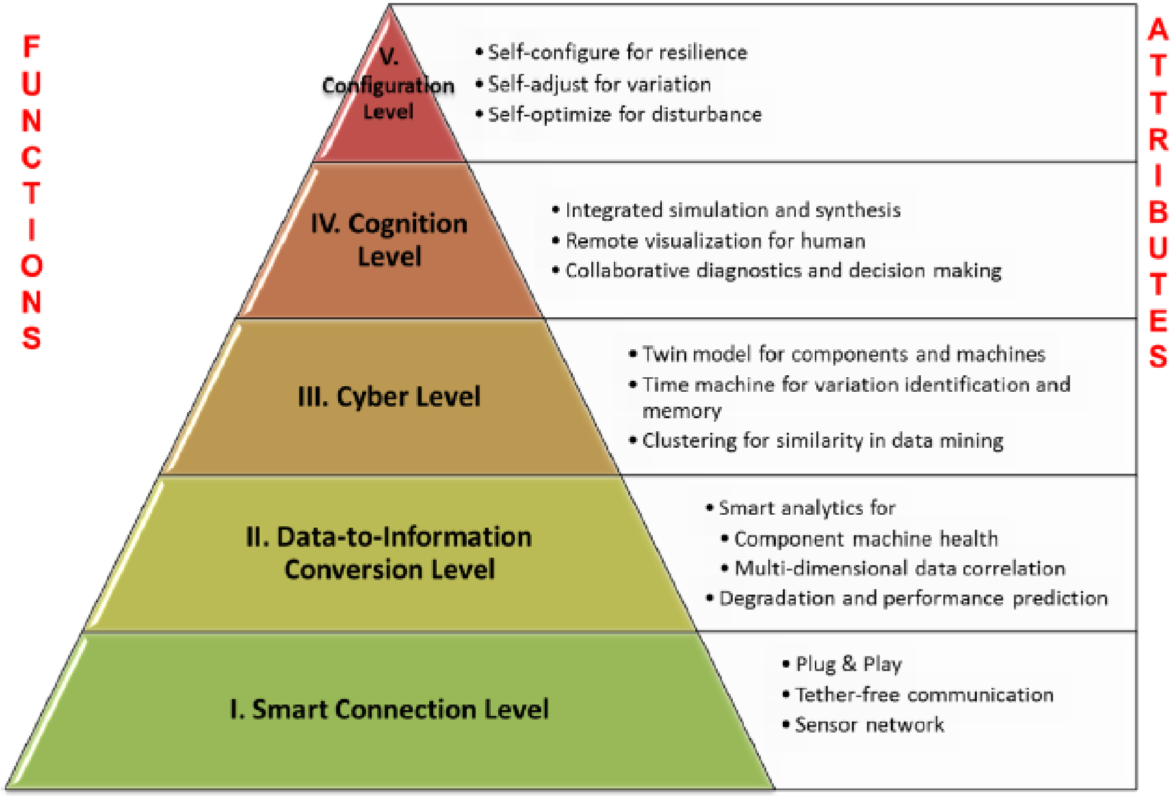
SM – Smart Working

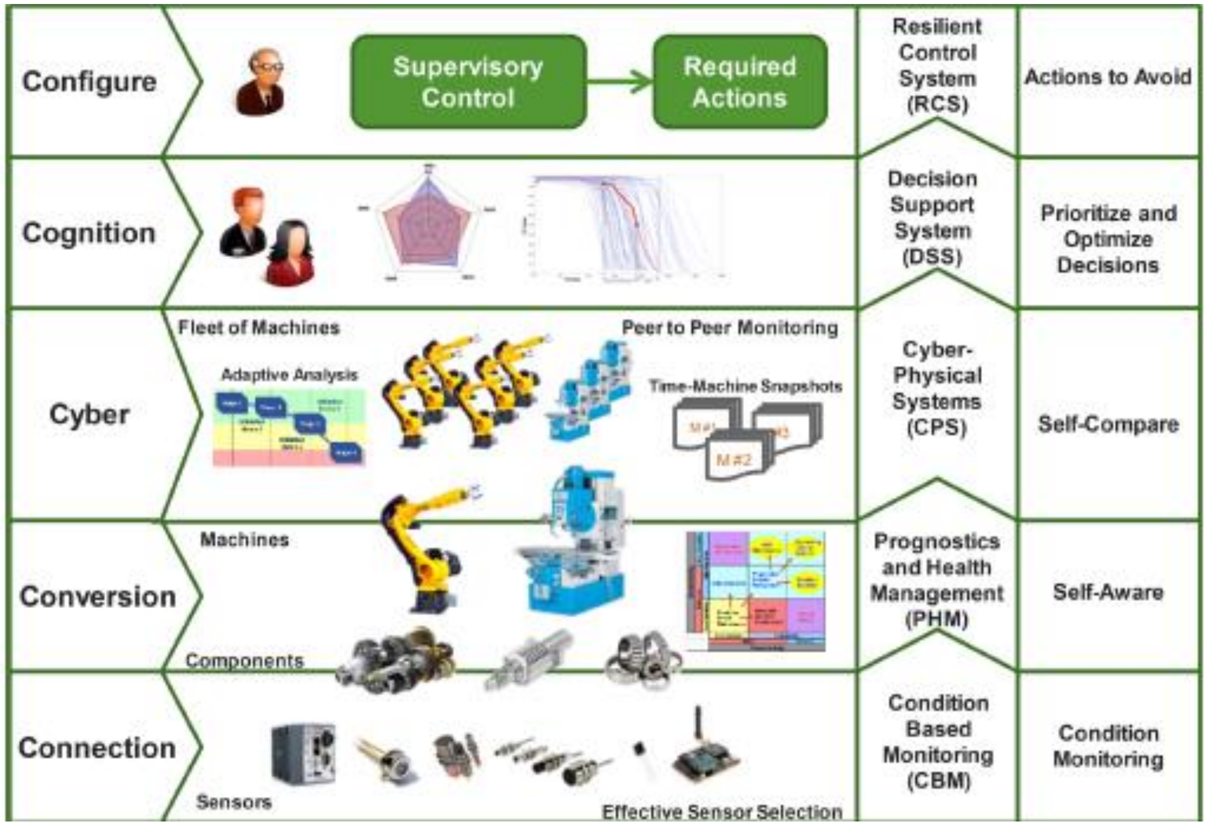
- ❑ Remote Monitoring of Production
- ❑ Remote Operation of Production
- ❑ Working Place Adaptation
- ❑ Augmented and Virtual Reality for Product development
- ❑ Augmented Reality for Maintenance
- ❑ Virtual reality for Workers Training
- ❑ Collaborative Robots



SM – Horizontal and Vertical Integration

SM – Smart Production Arch





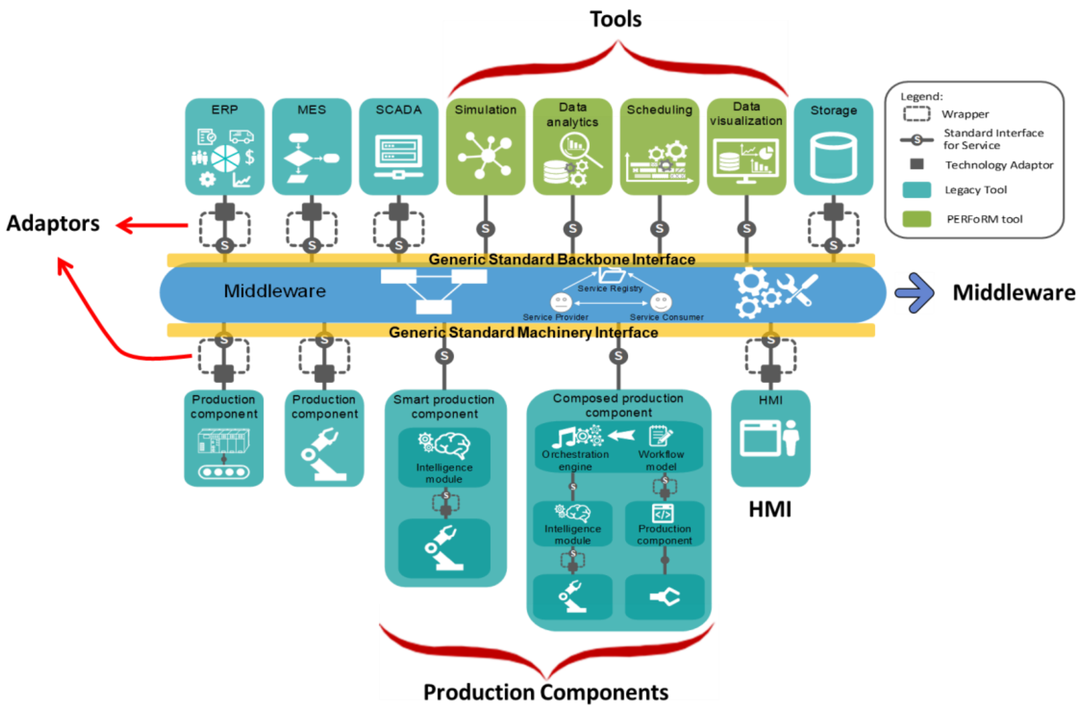
5C Architecture and Applications and Techniques. From (Lee, 2015)

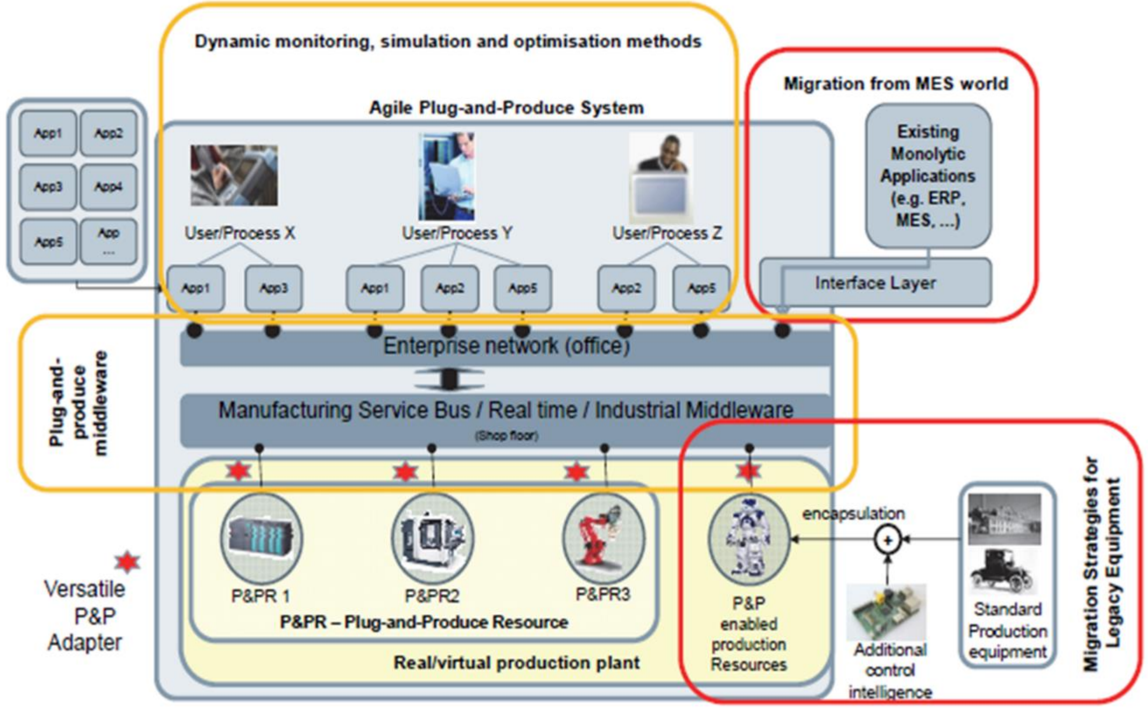
PERFoRM

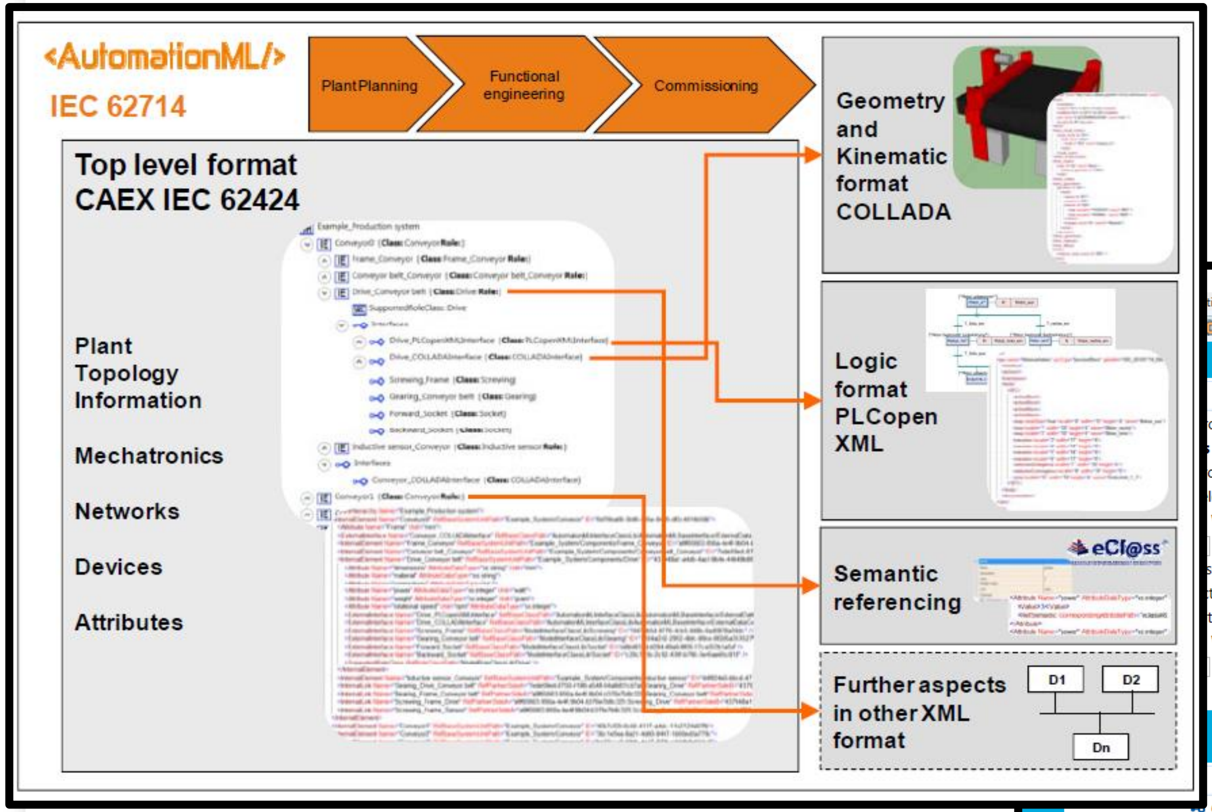
http://horizon2020-perform.eu

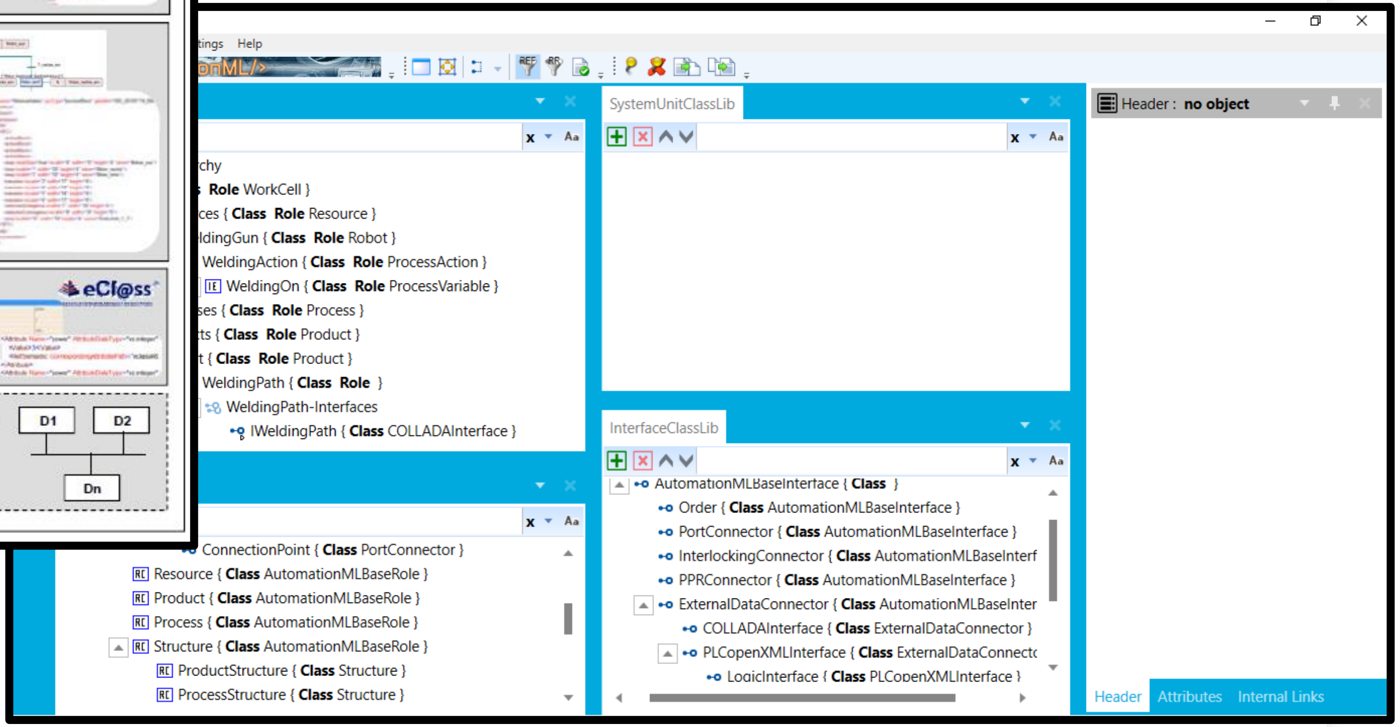
- Develop an integration layer “Middleware” to integrate the existent technology:
  - Shop floor devices;
  - Tools and functionalities.
- Possibility to develop new functionalities and add them into the existent systems:
  - Scheduler;
  - Simulation;
  - Reconfiguration.

SM – Smart Production Arch









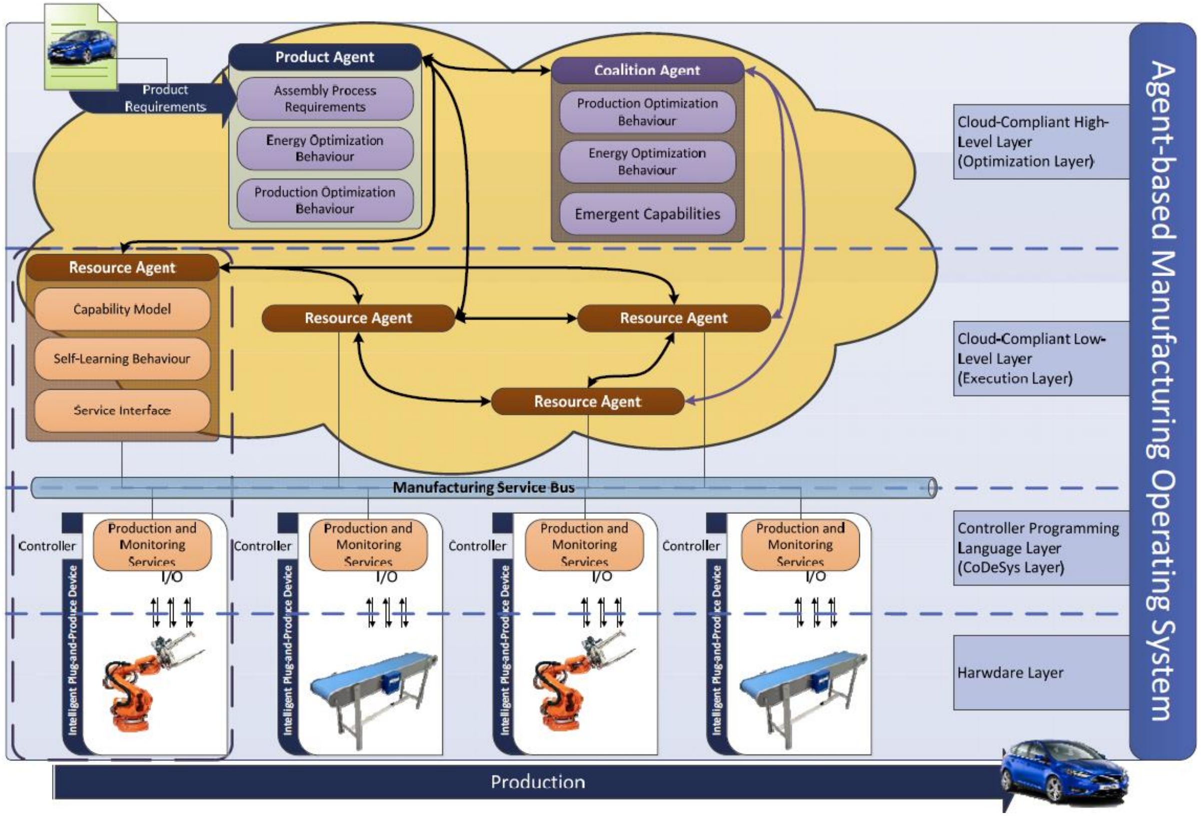
<AutomationML/>

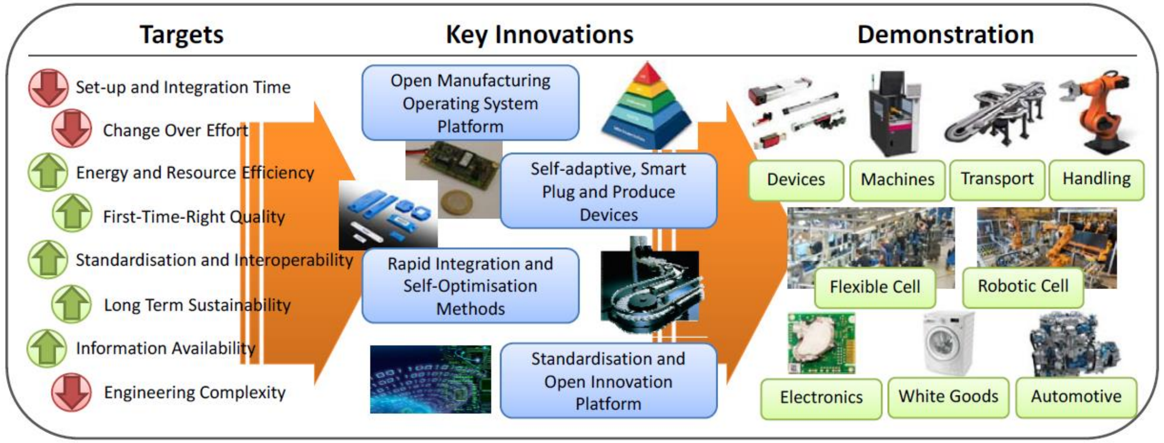
PERFoRM – Data Model

http://openmos.eu

- Development of a CPPS to optimize:
  - Energy consumption;
  - Production planning;
  - Raw material and products' handling.
- Cyber entities at the cloud and device level:
  - Cloud: Powerful processing capability
  - Device: Real-Time behaviour

SM – Smart Production Arch





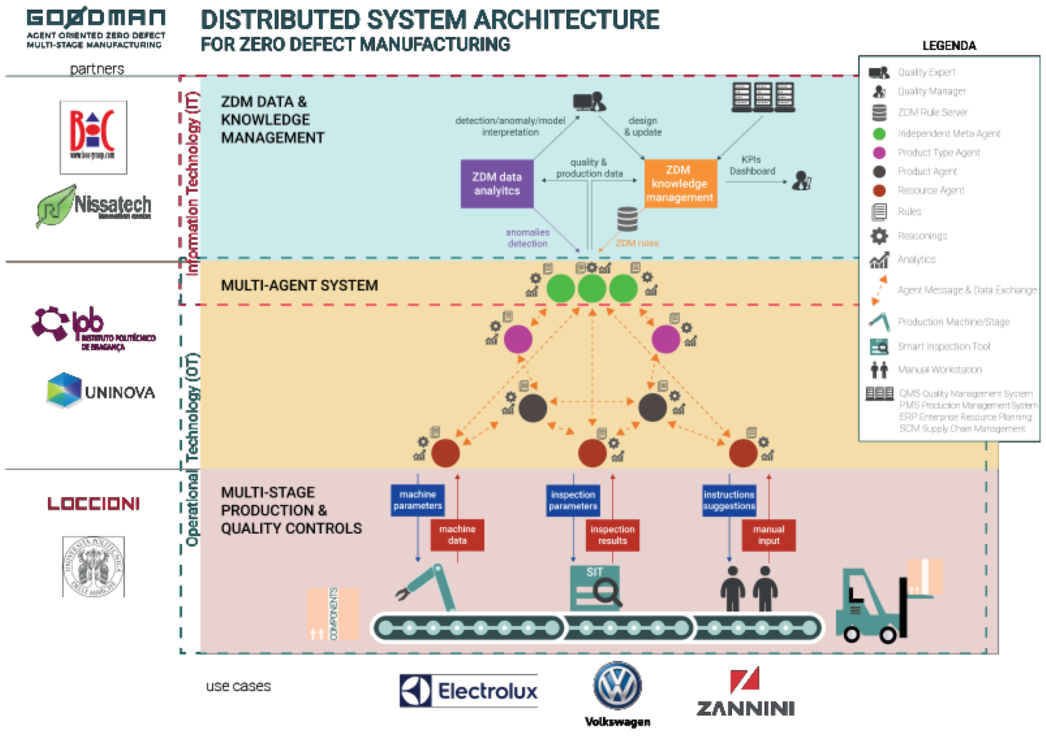
GO0DMAN
AGENT ORIENTED ZERO DEFECT
MULTI-STAGE MANUFACTURING

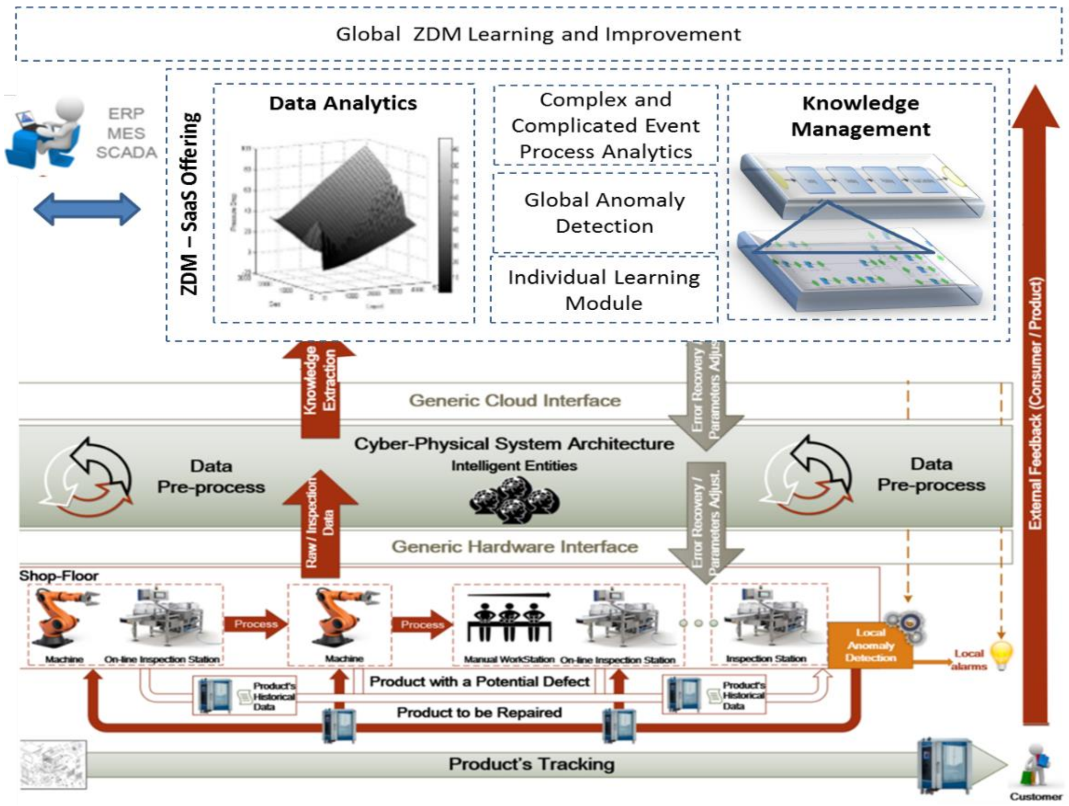
http://go0dman-project.eu

- Development of a CPPS to achieve zero defect:
  - CPPS at the device level;
  - Quality inspection tools;
  - Cloud functionalities to correlate the extracted data and generate knowledge.
- Maintenance strategies:
  - Proactive maintenance;
  - Predictive maintenance.
- Wastes and costs’ reduction.

SM – Smart Production Arch

GOØDMAN
AGENT ORIENTED ZERO DEFECT
MULTI-STAGE MANUFACTURING



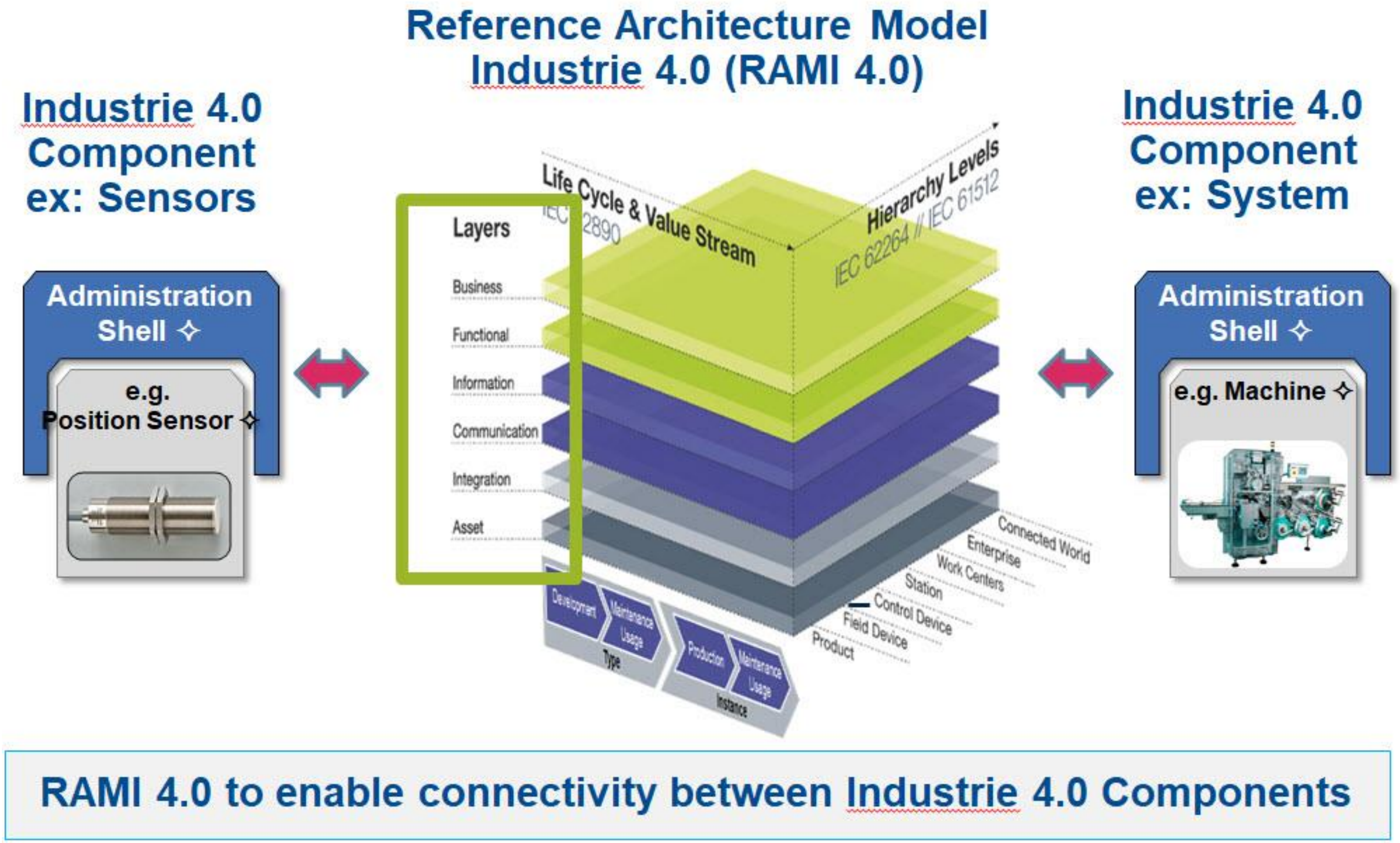


New Models Are Needed

- For the high-level topics of flexibility, efficiency, competitiveness, and sustainability **new successor models to ISA-95** are needed.
- Even small changes to ISA-95-based production automation systems are very costly and thus new models and architectures for dynamic and digitized production are needed.
- Proposed models that are gaining popularity include **RAMI 4.0** and the Industrial IoT (**IIoT**) .
- Current hierarchical implementations of ISA-95 automation systems are not sufficient to address the dynamics encountered in a flexible, multistakeholder SMART MANUFACTURING production environment.

From J. Delsing, "Local Cloud Internet of Things Automation: Technology and Business Model Features of Distributed Internet of Things Automation Solutions," in IEEE Industrial Electronics Magazine, vol. 11, no. 4, pp. 8-21, Dec. 2017. doi: 10.1109/MIE.2017.2759342

SM – RAMI 4.0



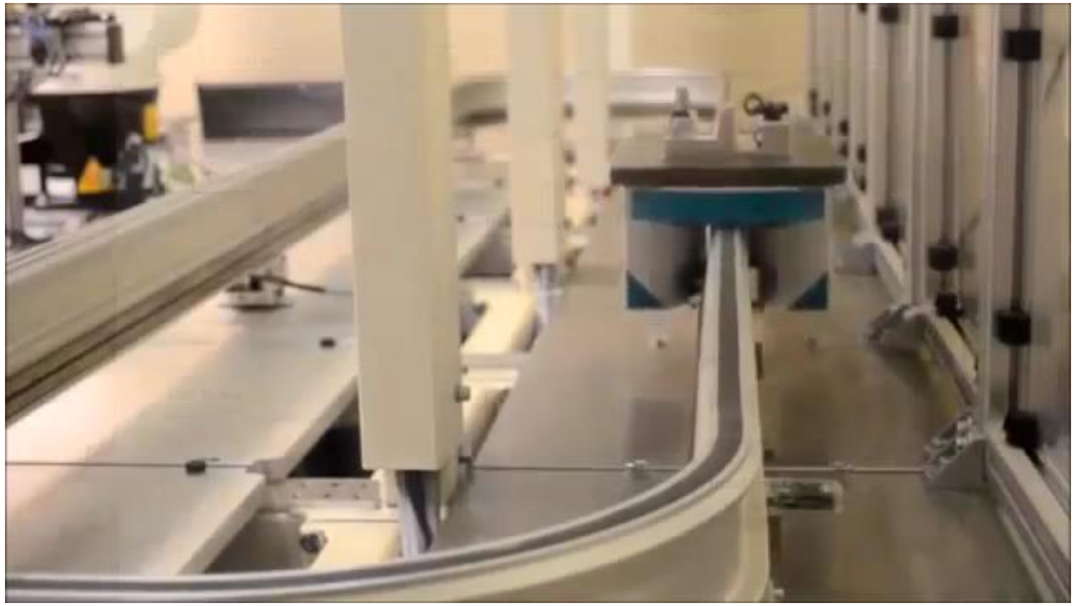
Reference Architecture Model Industrie 4.0 (RAMI 4.0)
Industrie 4.0 Component ex: Sensors
Administration Shell
e.g. Position Sensor
Industrie 4.0 Component ex: System
Administration Shell
e.g. Machine
Layers
Business
Functional
Information
Communication
Integration
Asset
Life Cycle & Value Stream
Hierarchy Levels
IEC 62264 // IEC 61512
Connected World
Enterprise
Work Centers
Station
Control Device
Field Device
Product
Type
Instance
RAMI 4.0 to enable connectivity between Industrie 4.0 Components

RICS's Current Work

RICS – Intelligent Industrial Manufacturing Systems

- 4th Industrial Revolution has brought new challenges and paradigms to the manufacturing industry:
  - More complex and highly customizable manufacturing environments and products are required.
  - Sustainable and Resilient Collaborative Manufacturing

- RICS - I2MS aims to advance the state of the art of these industrial-oriented emerging technologies:
  - Industrial IoT
  - Industrial Cyber-Physical Systems
  - Interoperability
  - Digital Twins
  - …

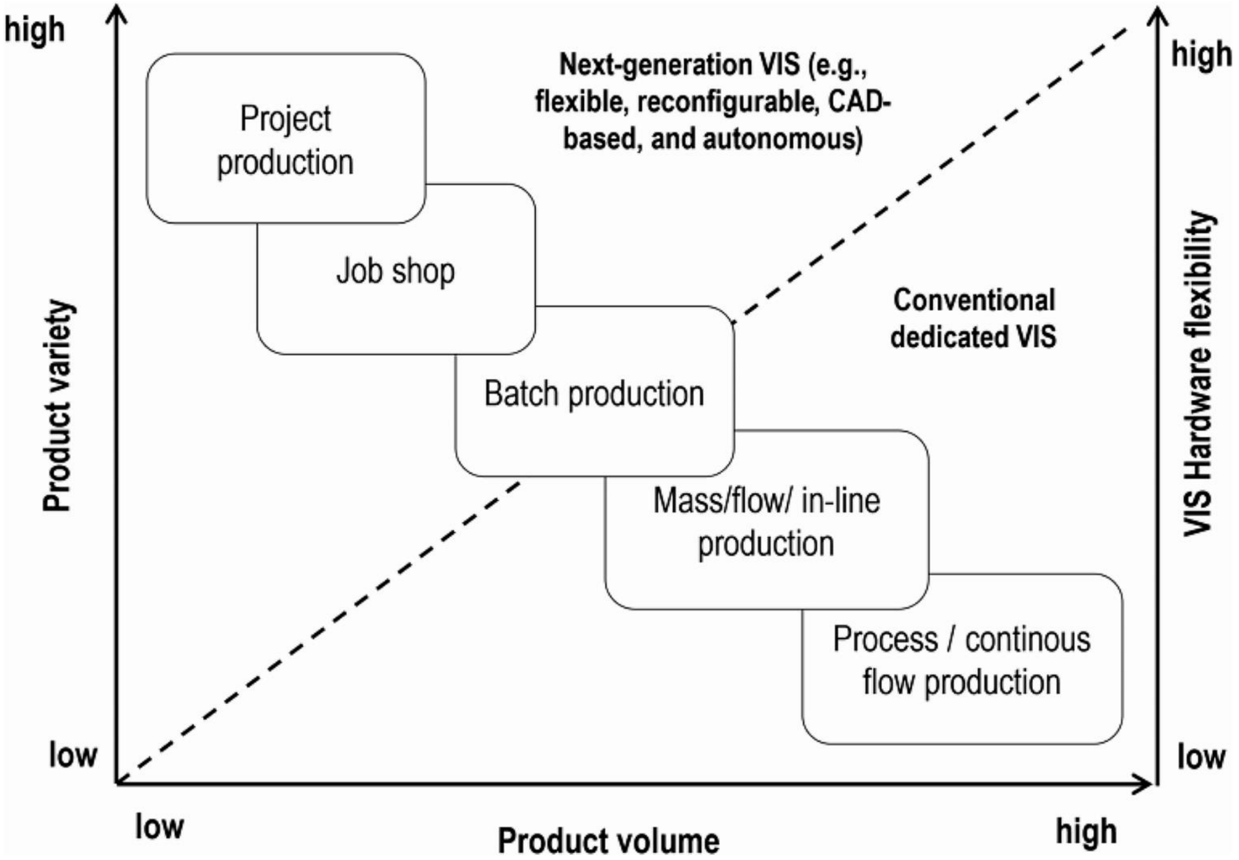


Next-Generation Visual Inspection Systems

- The <u>highly reconfigurable</u> and designed to deliver <u>customizable products</u> manufacturing systems are creating <u>problems</u> with <u>existing quality inspection</u> solutions.
- A Flexible, Reconfigurable, CAD-based, and Autonomous Visual Inspection System was developed in partnership with:

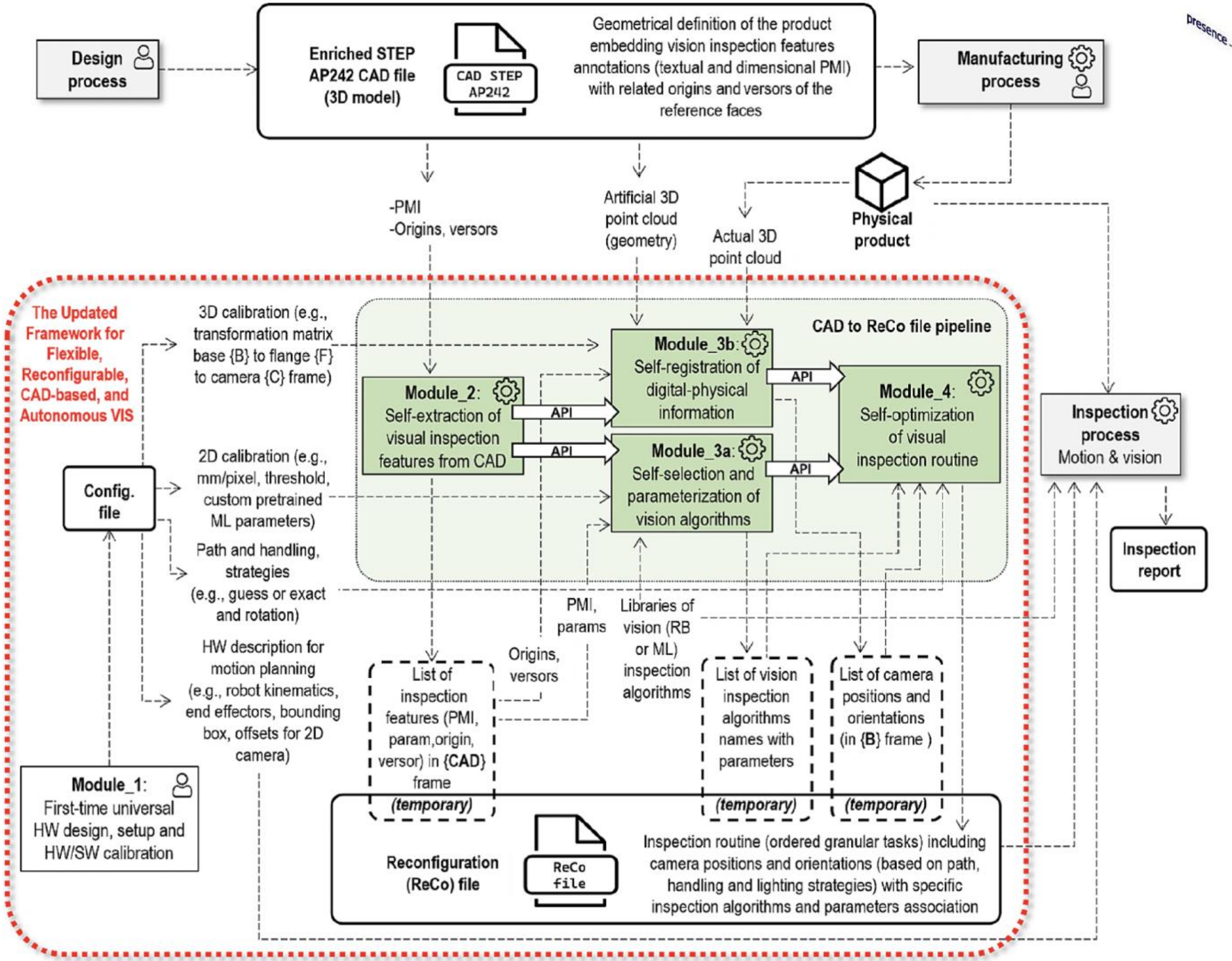
UNIVERSITY OF PISA

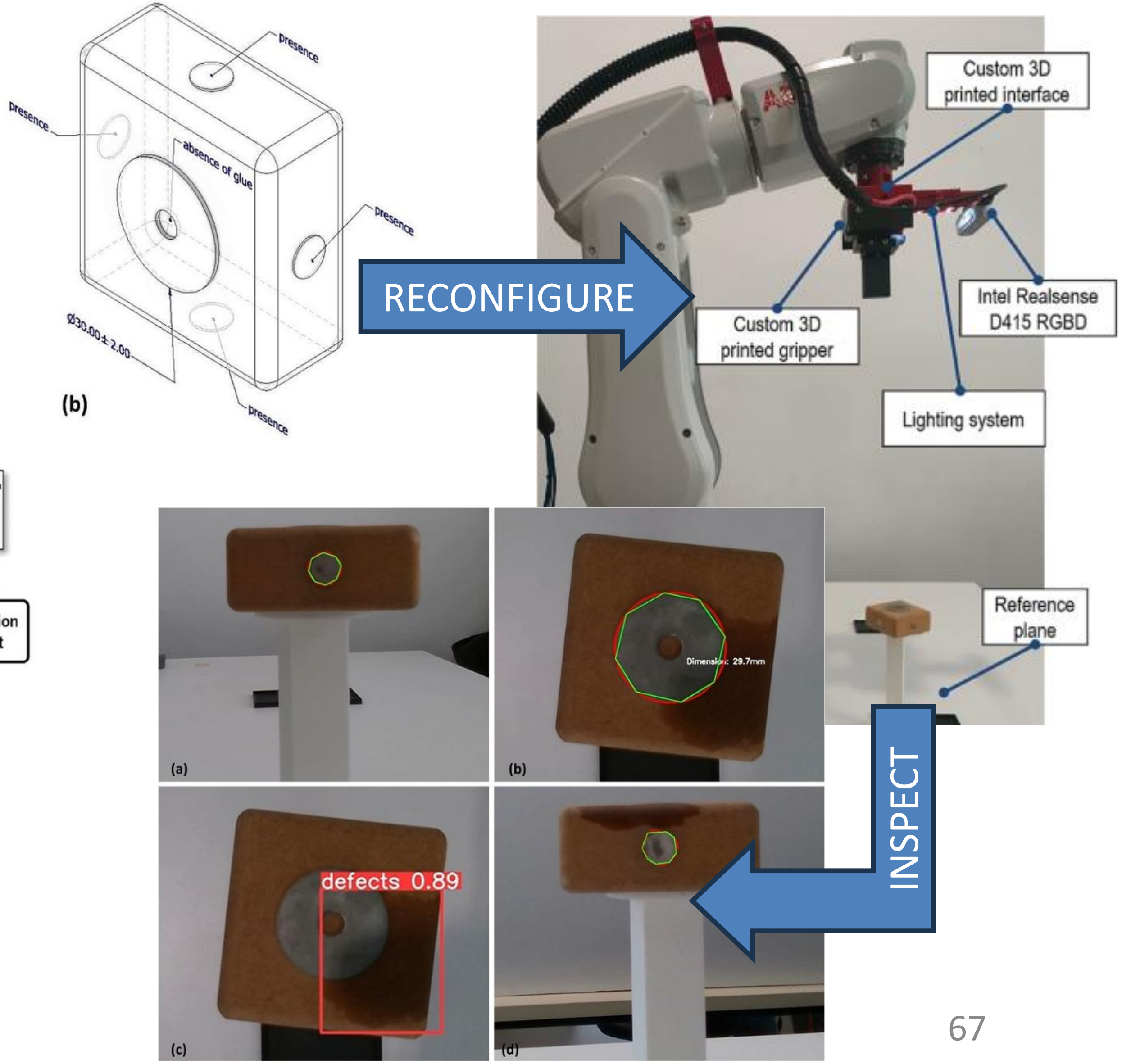
KUNGL TEKNISKA HÖGSKOLAN



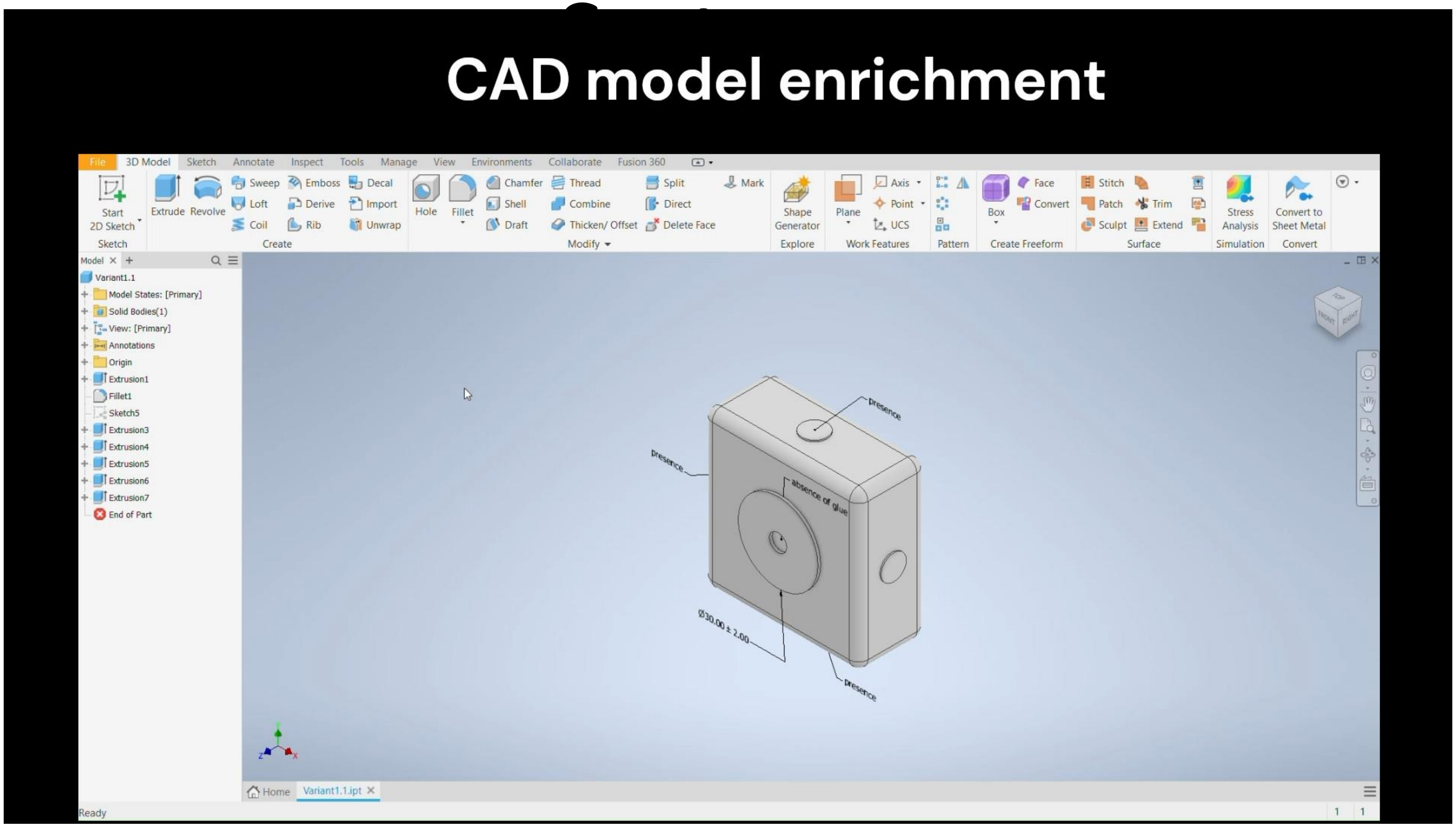
Next-Generation Visual Inspection Systems

Proposed Framework





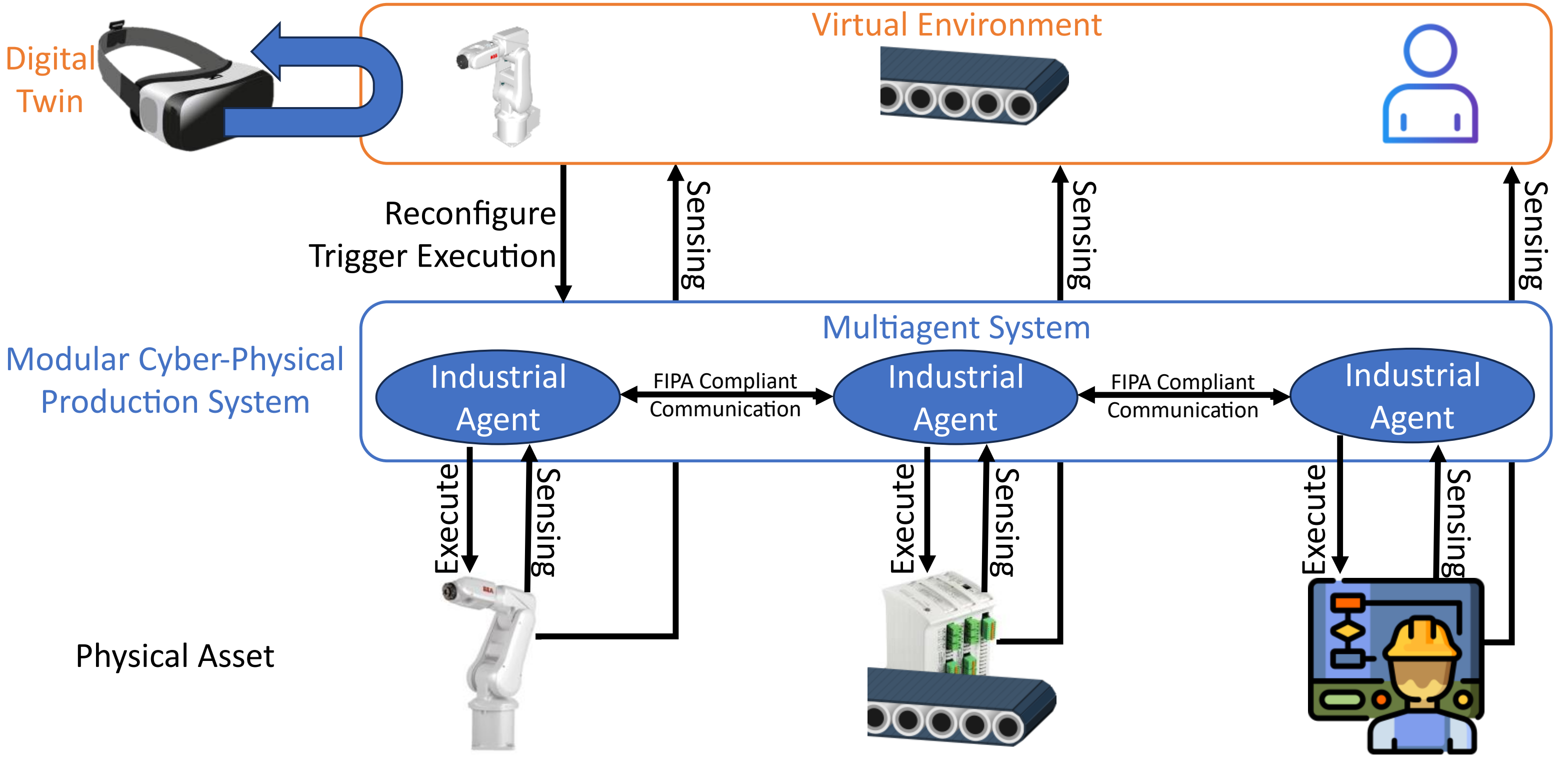
Next-Generation Visual Inspection



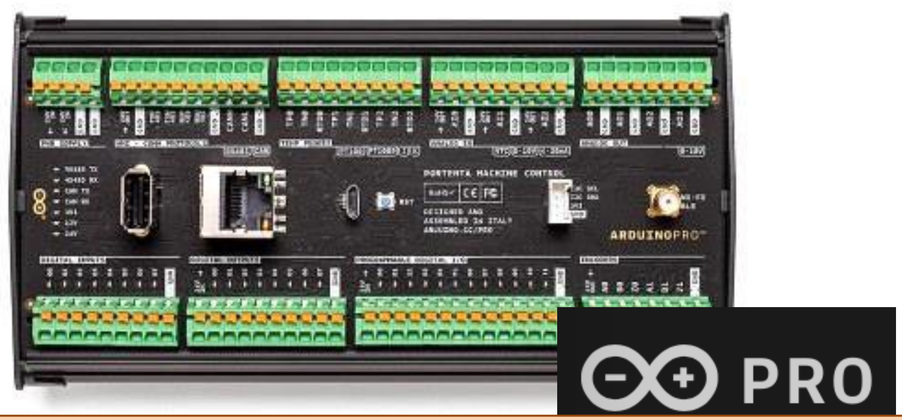
Digital Twin for Modular Cyber-Physical Production Systems

- Pluggable Modular Agent-based methods have been particularly promising for implementing distributed Cyber-Physical Production Systems.
- There has been a surge in research and practical applications of agent technology in various industrial settings, including numerous factories and demonstration projects.

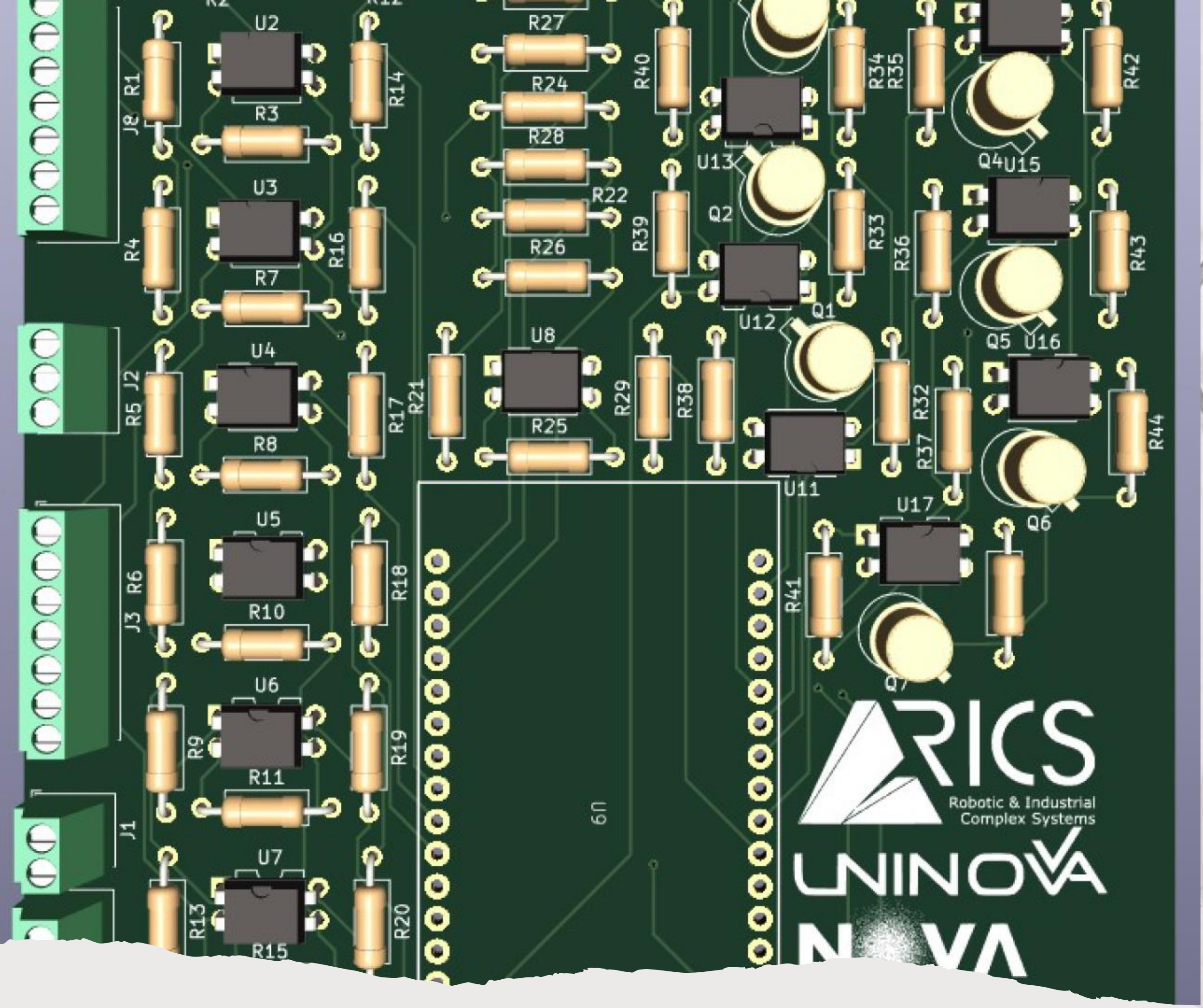
One of the barriers of these systems is the inability for the humans to understand what the system is performing, and which criteria is being used.

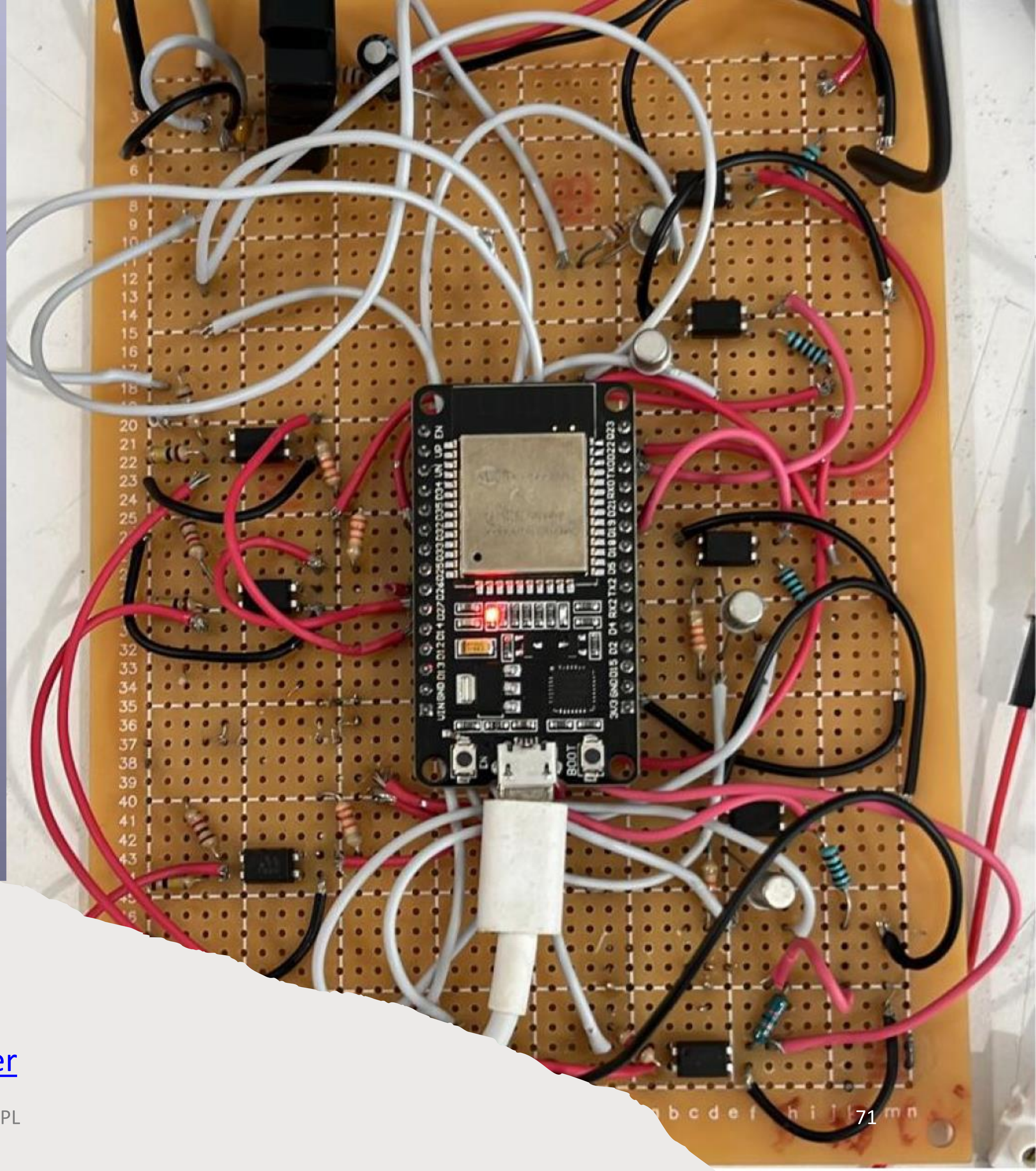


Next-Generation IIoT and ICPS oriented



The new generation of industrial controllers are Industrial IoT and CPS oriented



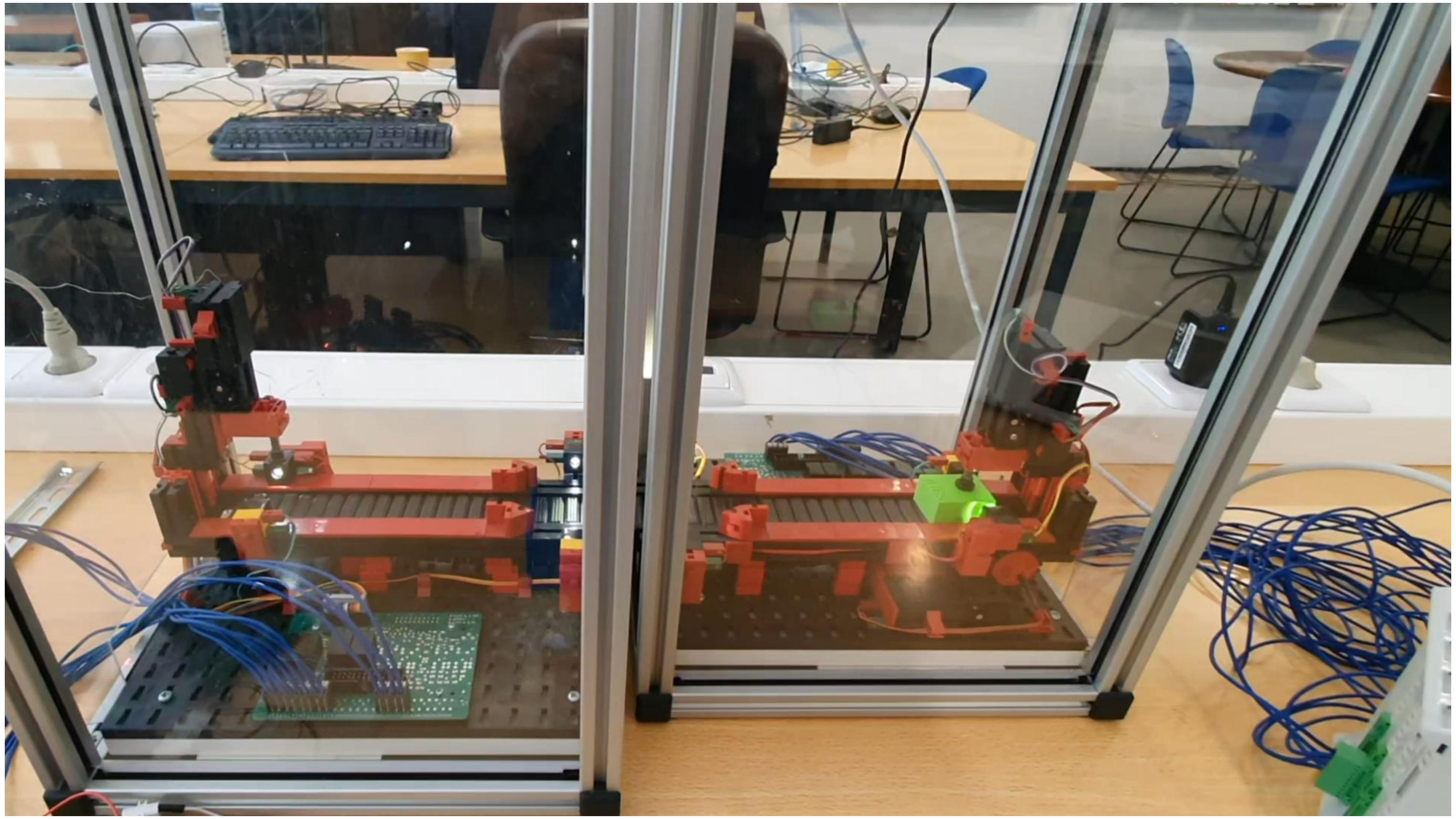


Developed Open Controller

https://github.com/NOVA-RICS-Open-Lab/open-modular-controller

Developed Open Controller

https://github.com/NOVA-RICS-Open-Lab/open-modular-controller



Dynamic Re/configuration of IIoT Nodes using AAS

Repository (Module marketplace)

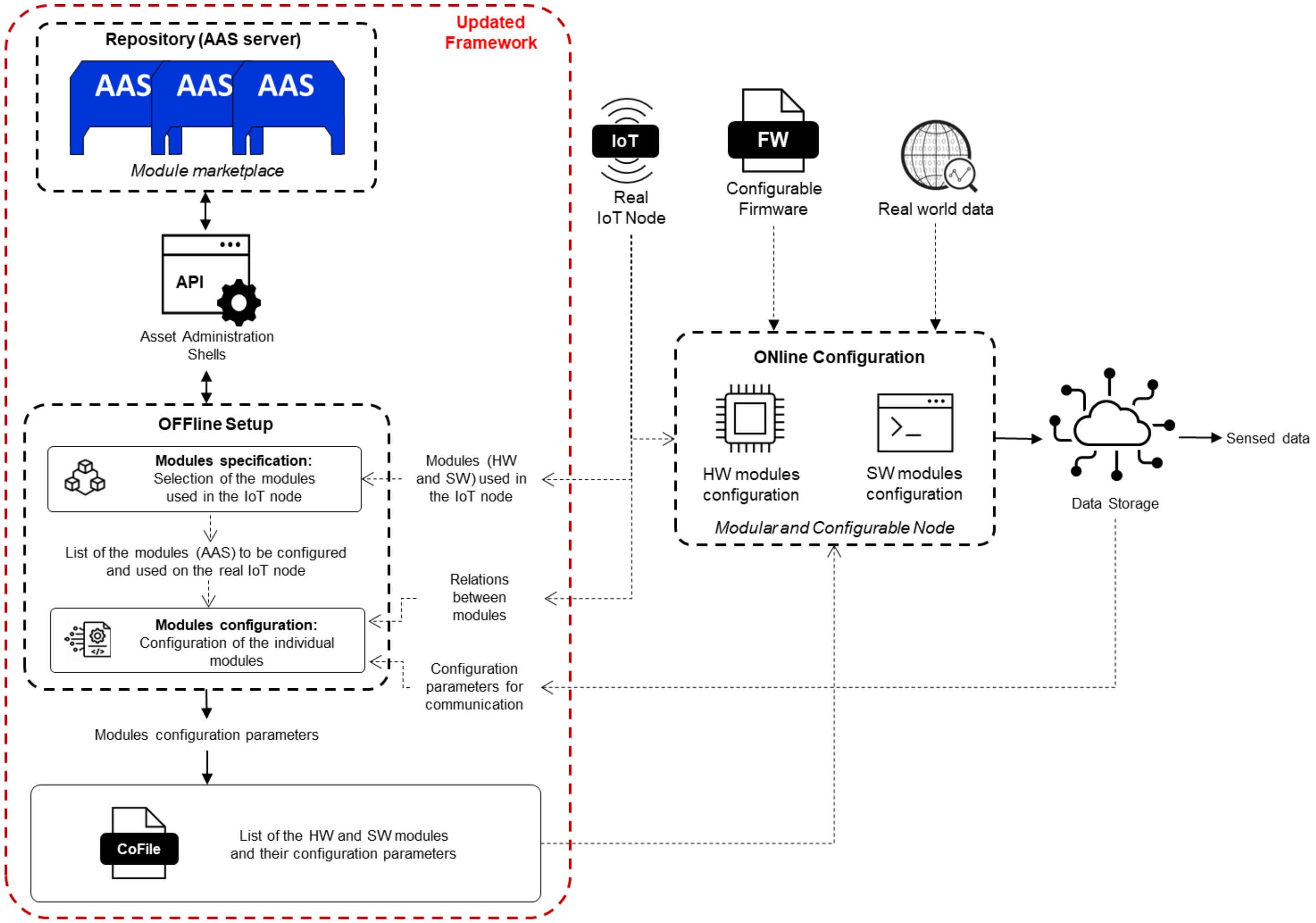
Contains the modules digital descriptions, characteristics and functionalities that will be used to build the physical nodes.

OFFline Setup

Allows the selection and offline configuration of the modules

Online configuration

Configurable Firmware: Allow node to be configured.
CoFile : holds the modules configurations
Physical IoT node



Some of our Industrial AI Applications

Our goal is to develop human-centric AI solutions at the intersection of **robotics**, **machine learning** and **cyber-physical systems** that facilitate the digital transformation across different industrial sectors.

1. Predictive Maintenance

2. Energy Optimization

3. Quality Control

4. Cybersecurity

5. Healthcare

6. Smart Farming

7. Art

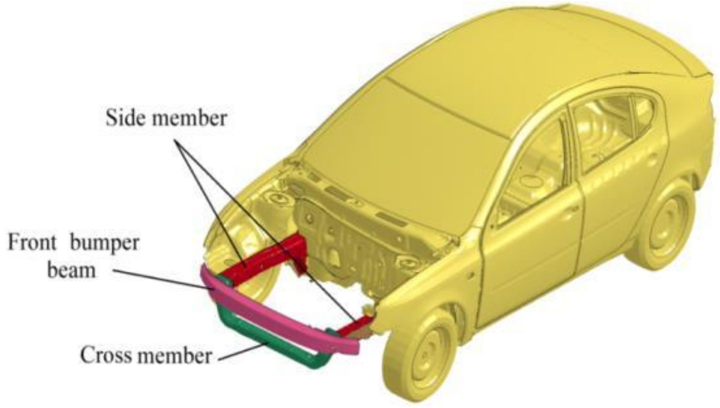
SIEMENS · NTROSYS Global Control System Designers · Electrolux · Ford

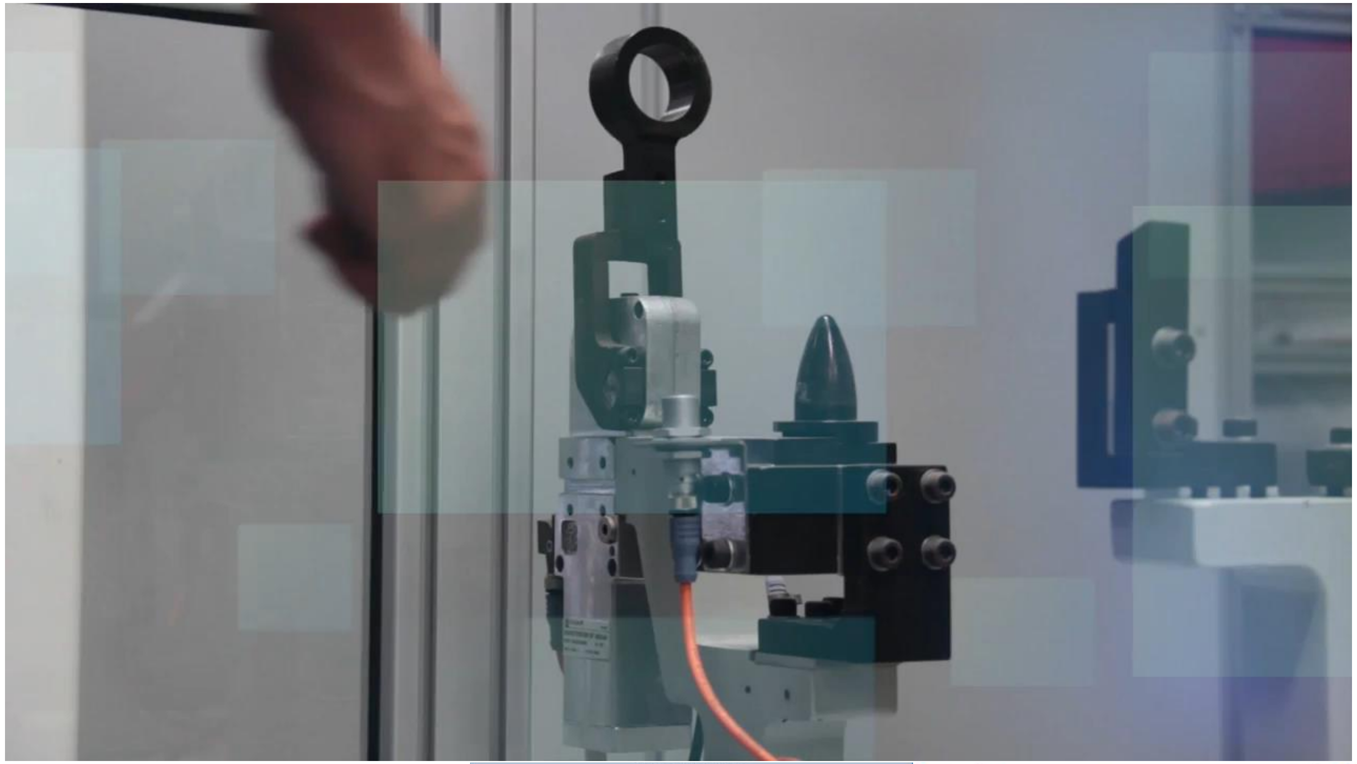
Centro Hospitalar de Lisboa Ocidental, E.P.E. · Whirlpool · FESTO · Volkswagen Autoeuropa

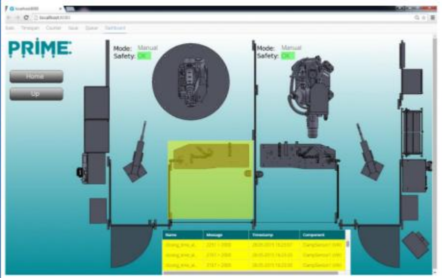
RICS · UNINOVA · NOVA School of Science & Technology

Predictive Maintenance

AI/ML models were used to **forecast the performance degradation** of industrial clamps holding an automotive side member for welding







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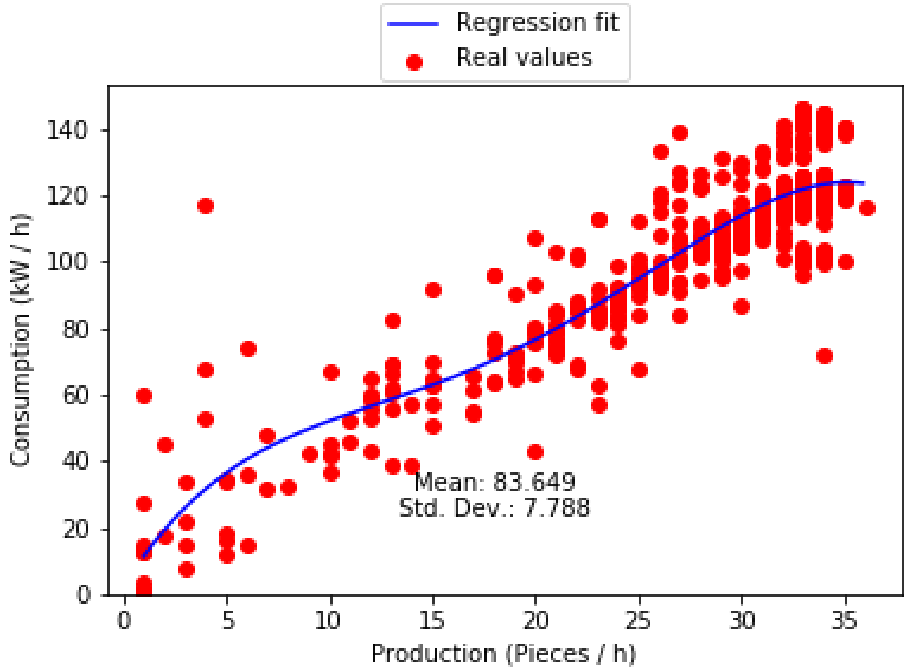
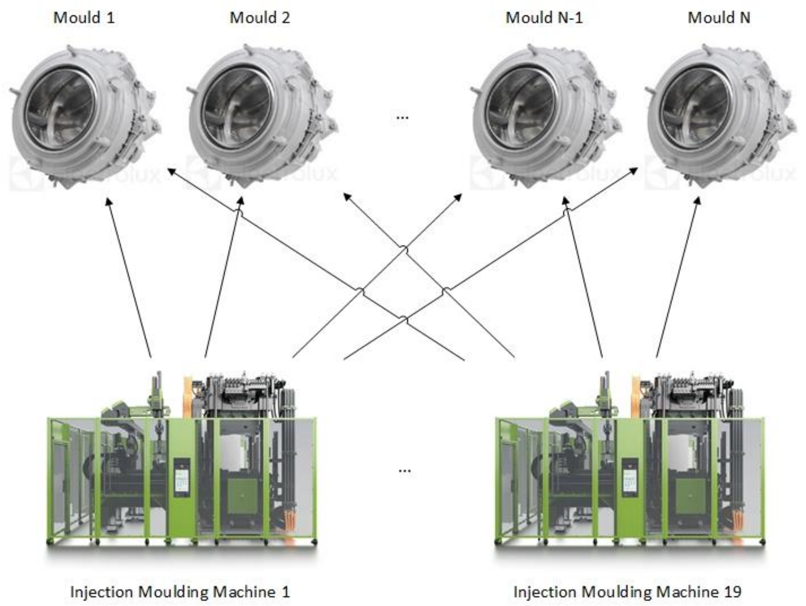
Electrolux Energy Optimization



(Values were redacted)

The analysis of different moulds for each machine enabled the selection of the machine to use based on the **predicted energy consumption** for a particular number of pieces per hour.



Source:
Electrolux Italia, H2020 OpenMOS Project

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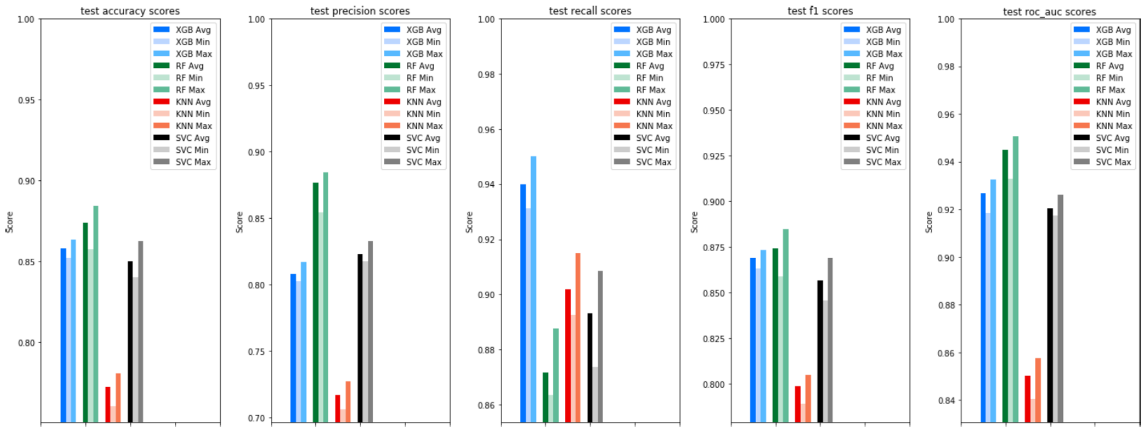
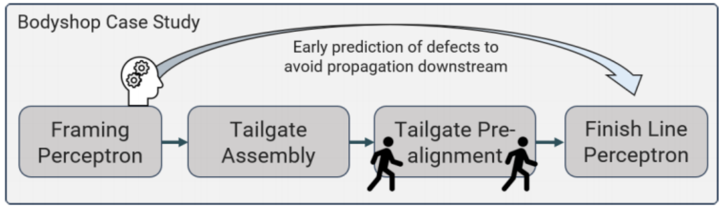
VWAE Quality Inspection

AI/ML was used to enable an **early detection of product dimensional defects** (OK & NOK) at a Volkswagen's multistage production line.



Models were trained on measurements from over 18000 cars




IEEE Access
Multistage Quality Control Using Machine Learning in the Automotive Industry

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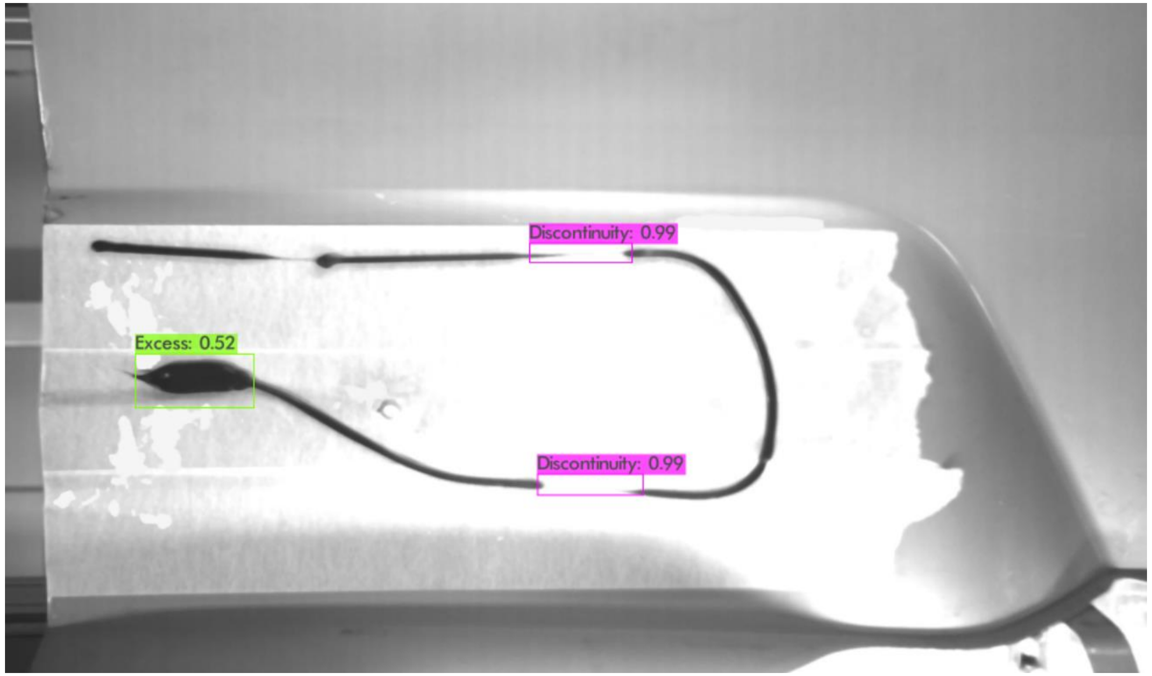
Industrial Quality Inspection

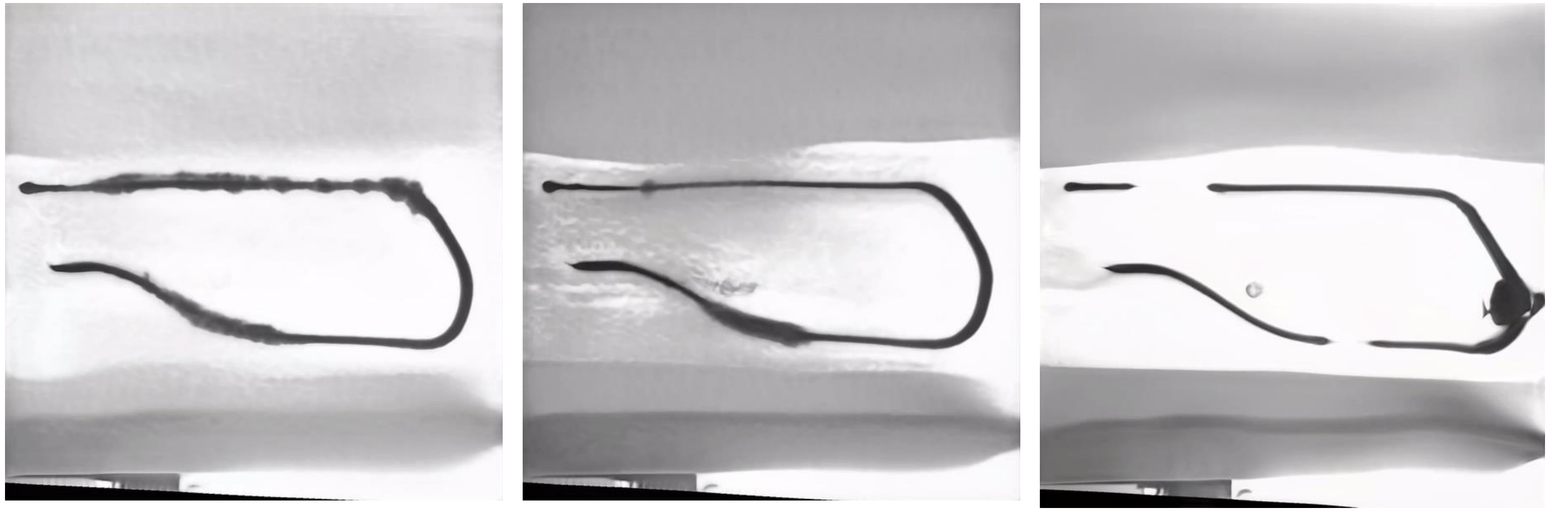


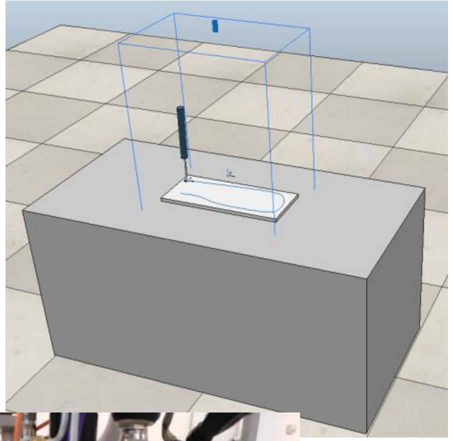
Real-time **object detection model** for online quality inspection.

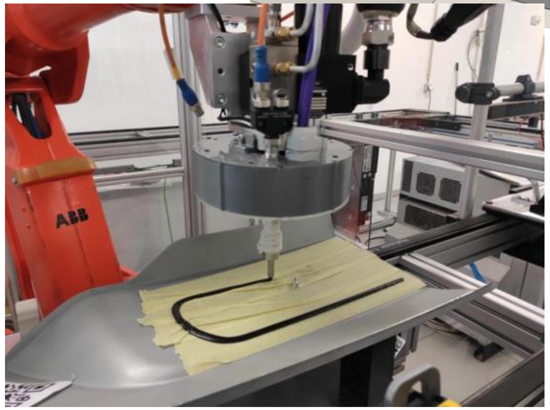
Model is able to detect and locate different types of defects in a structural adhesive application for the automotive industry

Synthetic Data & Sim2Real

None of these images are real







They were all **synthetically** created by a Generative Adversarial Network (GAN) to improve **Data Availability** in industrial applications

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ICT Cybersec & Trust

A prototype demonstrator of the BIECO concept for **runtime monitoring of a Cyber-Physical System**, showcasing a sorting line with vision-based control and automatic inspection with AI embedded in a microcontroller running at the edge.

BIECO is a large EU-funded project coordinated by UNINOVA that aims improve **cybersecurity**, **safety** and **trust** across the entire lifecycle of ICT ecosystems.

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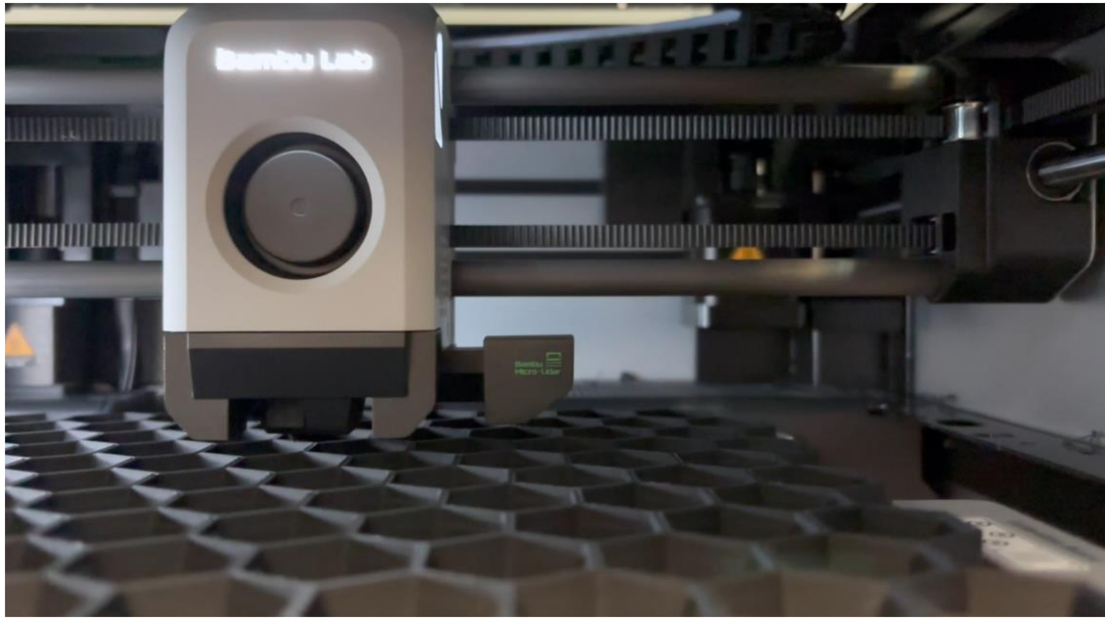
Robotics in **Education**

NOVAMOB is an affordable, open-source, 3D-printed mobile robot designed to **democratize access to hands-on robotics education worldwide**. Initiated at UNINOVA and NOVA University, it offers a hands-on learning experience using low-cost, modular components and a community-driven platform with instructional resources. NOVAMOB aims to reduce hardware costs by up to 80%, making robotics education more accessible and engaging, especially in resource-constrained environments.



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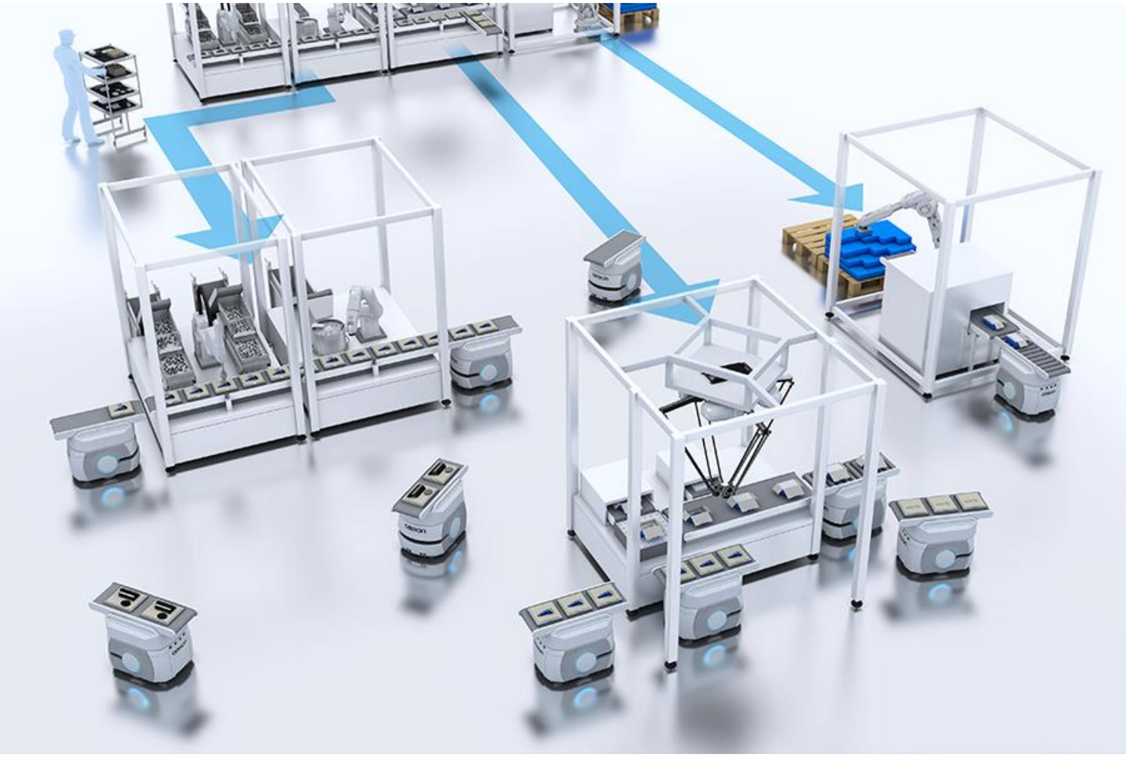
Bio-Inspiration

Smart manufacturing



Self-maintenance, healing, and continuous operations of processes.

Facts:

- **In automotive industries, unplanned downtime** represents one of the costliest events (**more than $2B**) in 2022
- Average manufacturer confronts **800 hours** of equipment **downtime per year** ($50 billion a year)

However, there are some challenges:

- Complex engineering design.
- Systems that collaborate and **self-organize**

Opportunities:

- Biologicalisation of smart manufacturing

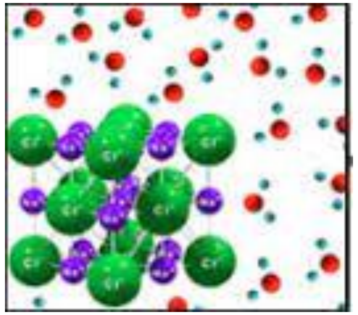
Introduction: Context and Motivation

Biologicalisation: Biological transformation in manufacturing

(Byrne et al, 2018)"bio-inspired principles in intelligent manufacturing applications to fulfill their full potential"

Composability of modules

Chemical Machine
Frei et al, 2011



2011

Control

Stigmergy
Pannequin et al, 2012

2012

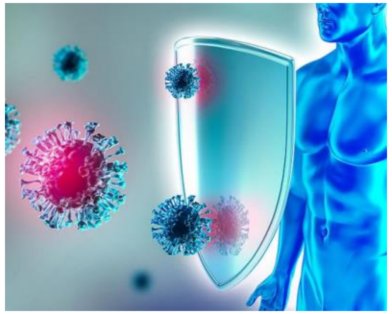
Control and navigation

Firefly algorithm
Dias-F. et al, 2018

2018

Diagnosis

Immune System
Rocha et al, 2019



2019

<u>Self-organized collaborative healing</u>

<u>Self-organized collaborative healing</u>:

*"Capacity of a manufacturing system to **cure itself** based on the assumption that the **constituent elements can provide "cures"**, or have the **capacity to help each other** in a **faulty situation**."*

Altruism in in Vampire Bats: A Biologicalisation concept

Vampire Bats:

- Colonies (Society)
- Hematophagy
- **Die after 48-72 hours without a meal**
- **Practice Altruism**

Engage in reciprocal altruism ***by regurgitating blood meals to share with unrelated individuals who were unsuccessful in finding food****. (Gerald Wilkinson, 1984)*

Altruismin Vampire Bats: A Biologicalisation concept

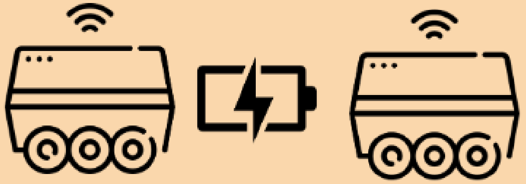
Biological Domain	Manufacturing automation Domain	Technological enablers

Biological Domain

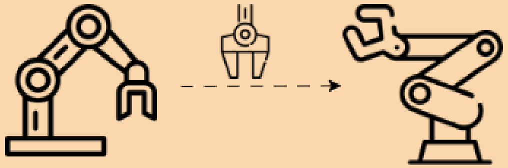
Reciprocal Altruism

Manufacturing automation Domain

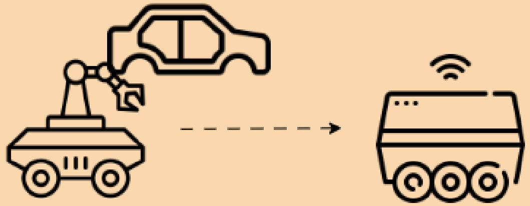
Sharing energy



Sharing resources/spare parts



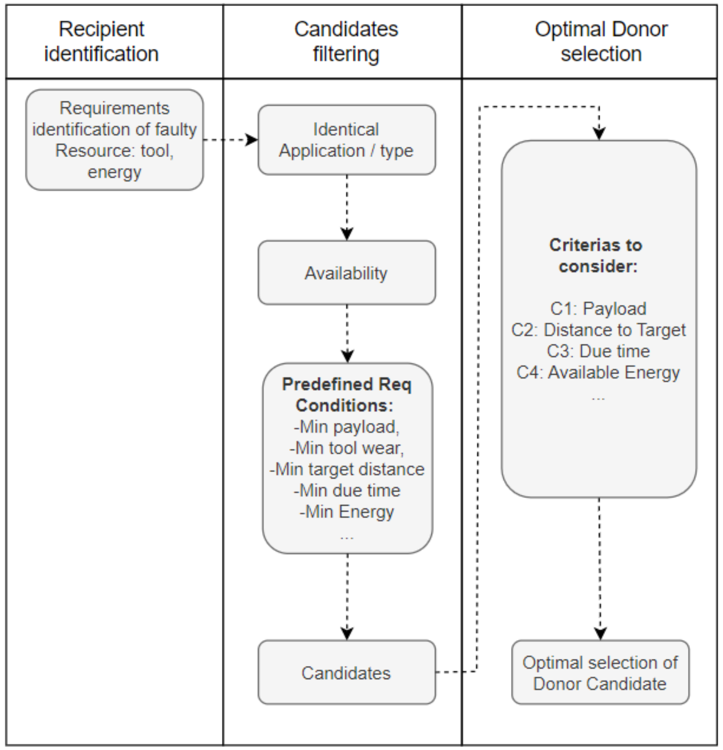
Sharing loads

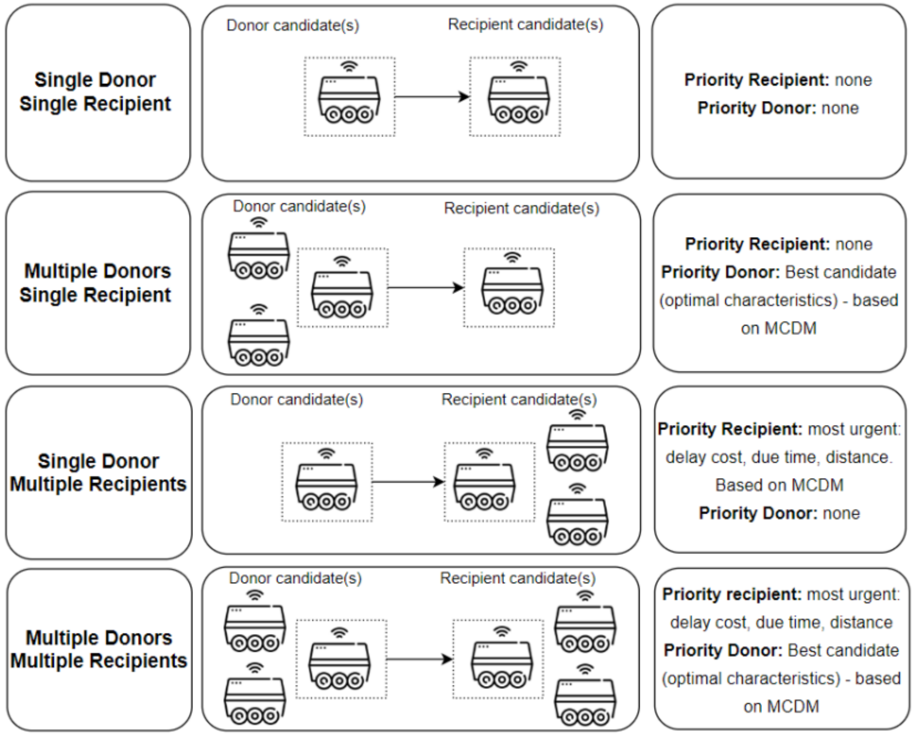


Technological enablers

- Intelligent Agents.
- Modular manufacturing equipment.
- Smart perception systems.
- Wireless energy chargers.
- ...

Vision: Logic and Scenarios





Future Prospects

- **Special attention to new ways: Biologicalisation, Complexity Theory: Self-Organisation, Emergence**.
- **Green and Sustainable Manufacturing**:
  - Transition to carbon-neutral factories by 2050 in line with the EU Green Deal.
  - Adoption of **circular economy** models to minimize waste and improve resource efficiency.
- **Digital Transformation**:
  - Integration of advanced digital technologies like **AI, IoT, and Big Data** to drive the EU's Digital Strategy.
  - Widespread use of **Digital Twins**.
  - AI-Powered Systems: **Advanced AI and machine learning** driving real-time optimization, predictive maintenance, and autonomous operations.
- **Resilient and Secure Supply Chains**:
  - Building resilient supply chains using **blockchain** and real-time data analytics.
  - Promoting reshoring and nearshoring to reduce dependencies on external suppliers.
- **Human-Centric Industry 5.0**:
  - Prioritizing collaboration between humans and AI to enhance creativity and innovation.
  - Ensuring job creation through upskilling programs and digital literacy initiatives.
  - Emphasis on **collaborative robotics** and human-centric design.

Future Prospects

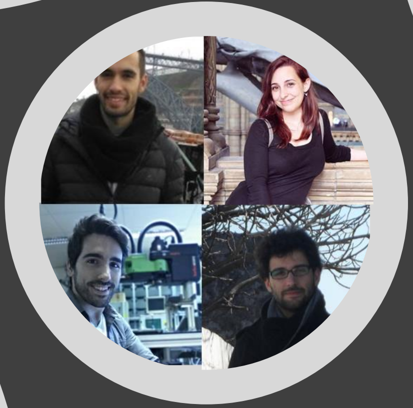
- **Manufacturing as a Service**:
  - On-demand, decentralized production leveraging shared resources and distributed networks.
- **Sustainable Energy Integration**:
  - Increasing reliance on renewable energy (solar, wind, hydrogen) to power factories.
  - Developing energy-efficient production processes to meet stricter emissions targets.
- **Ethical AI and Data Usage**:
  - Ensuring ethical deployment of AI and data-driven technologies in manufacturing.
  - Strengthening regulations for data privacy and cybersecurity in industrial environments.
- **Standardization and Interoperability**:
  - Promoting global competitiveness through unified frameworks like the Asset Administration Shell (**AAS**).
- **AI and Autonomous Systems**:
  - Real-time optimization and decision-making powered by AI and machine learning.
- **Increasing Adoption of Autonomous Mobile Robots (AMRs)**

Conclusions

- **Systems are Complex so we need complex approaches**
- **Manufacturing Evolution**:
  - From the Industrial Revolution to Industry 5.0, manufacturing has transformed through technological and societal advancements.
  - The shift from rigid systems to adaptive, modular, and intelligent manufacturing reflects the increasing complexity of demands.

- **What was in the genesis**

- **We Analysed some of the Contributions and what is still needed to be done**:



THANK YOU

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