CPS Engineering Process

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INSIDE Industry Association

CPS Summer School 2024

Inside
Industry Association

Summary

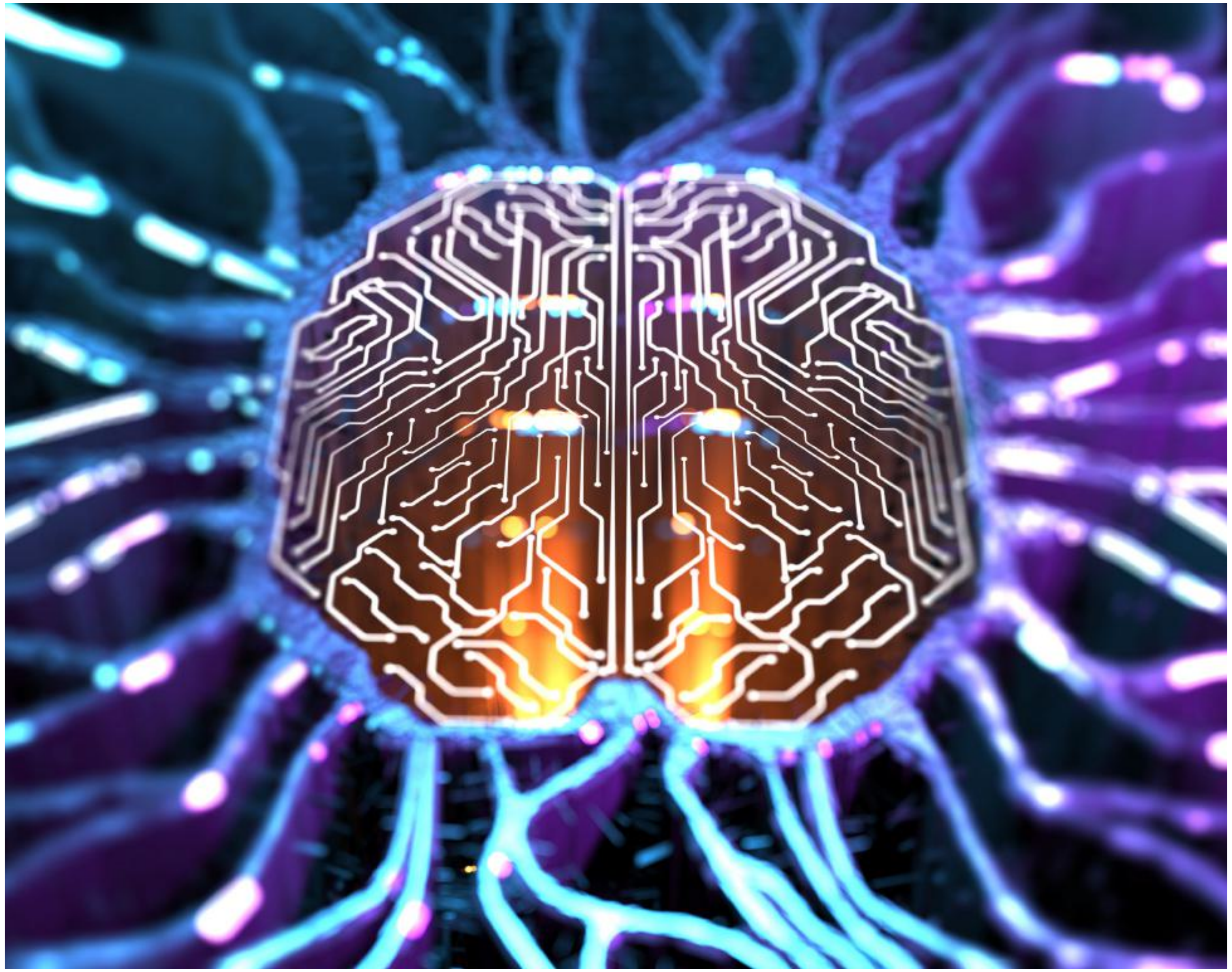
- INSIDE Industry Association
- Introduction to the Engineering Process
- The ECS/CPS value chain
- Engineering Process models
- A new model for the Engineering process
- A model for the Value Chain

INSIDE Industry Association

The Association

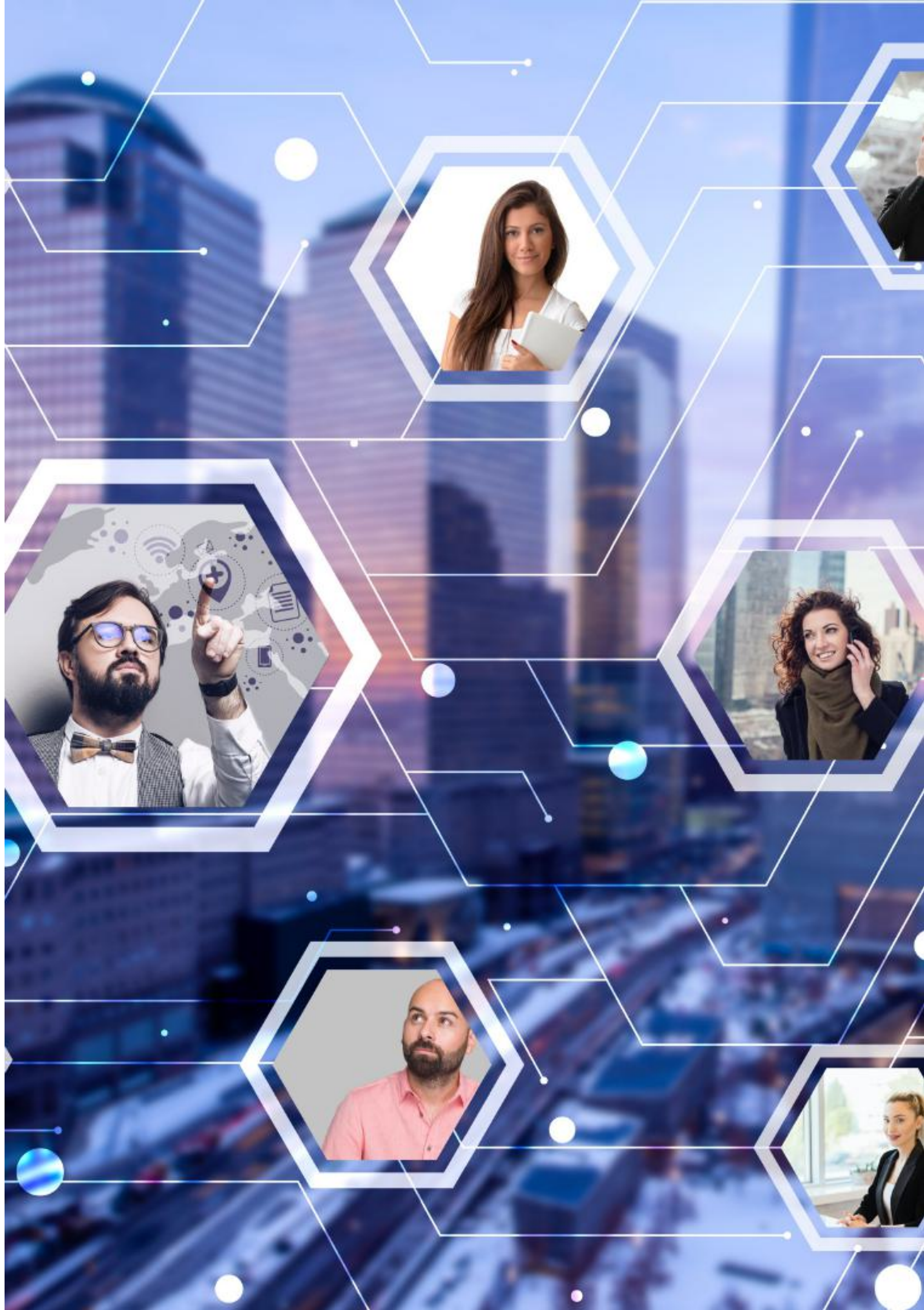
INSIDE Industry Association is the European Technology Platform for research, design and innovation on Intelligent Digital Systems and their applications.

We are one of the three private partners of the Chips JU, a Joint Undertaking based on a tripartite governing model between the Participating States, the European Commission and the private sector as represented by three Industry Associations.



Your interest, our goal!

We strive that the industrial world and academic community are supported and get funds contributing to create innovative, competitive, trustworthy, and sustainable solutions for the European industry and for European key application domains, in respect of European values.



Our growing network

A grasp of our current members

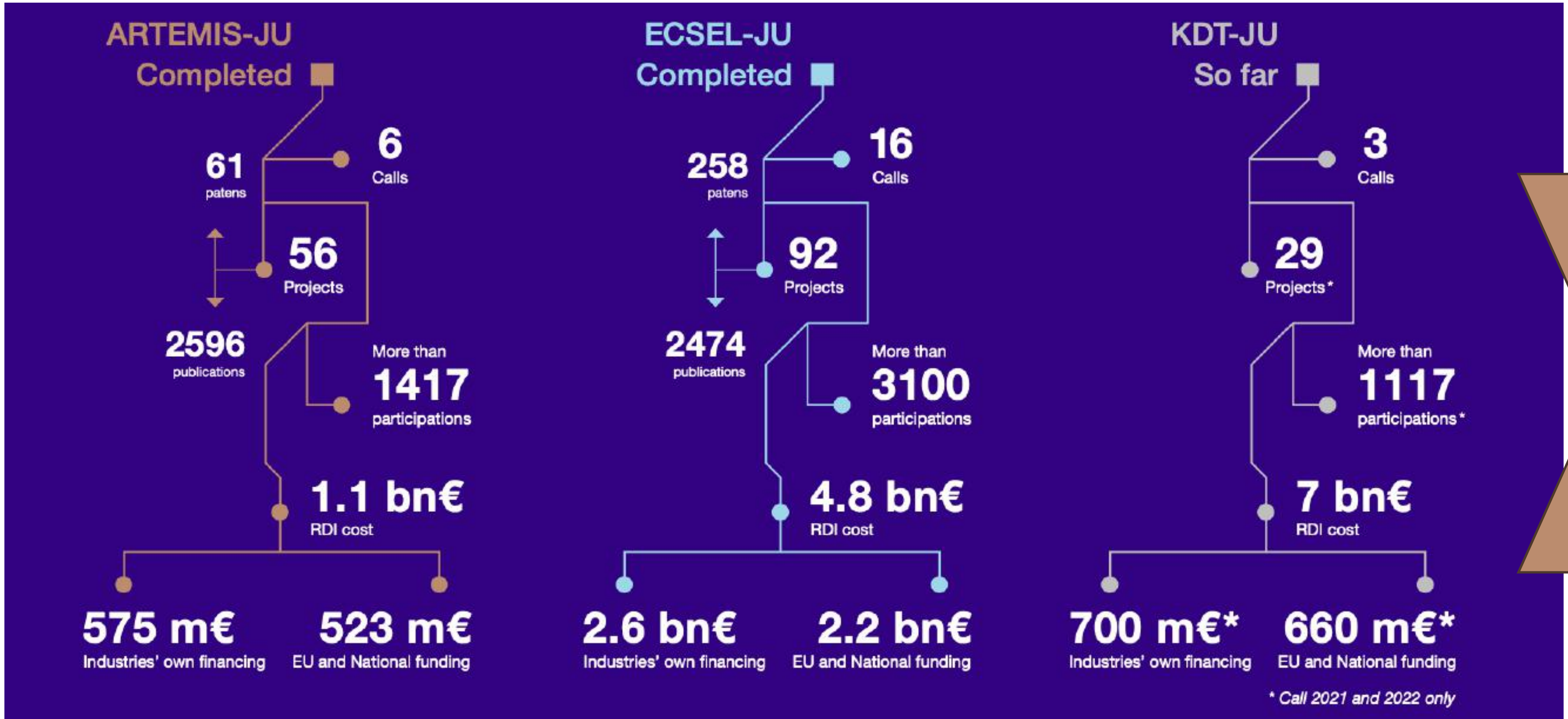
- Together we have one strong voice
- Co-define the European R&I strategy on Intelligent Digital Systems
- Align with industry, research & university

A successful story

INSIDE Industry Association was formerly known as **ARTEMIS** Industry Association:

- INSIDE started as ARTEMIS Joint Undertaking in 2006.
- It was member of ECSEL JU, of its successor KDT JU, and currently a member of the most recent Chips JU.

A story made of successful projects with a significant industrial impact.

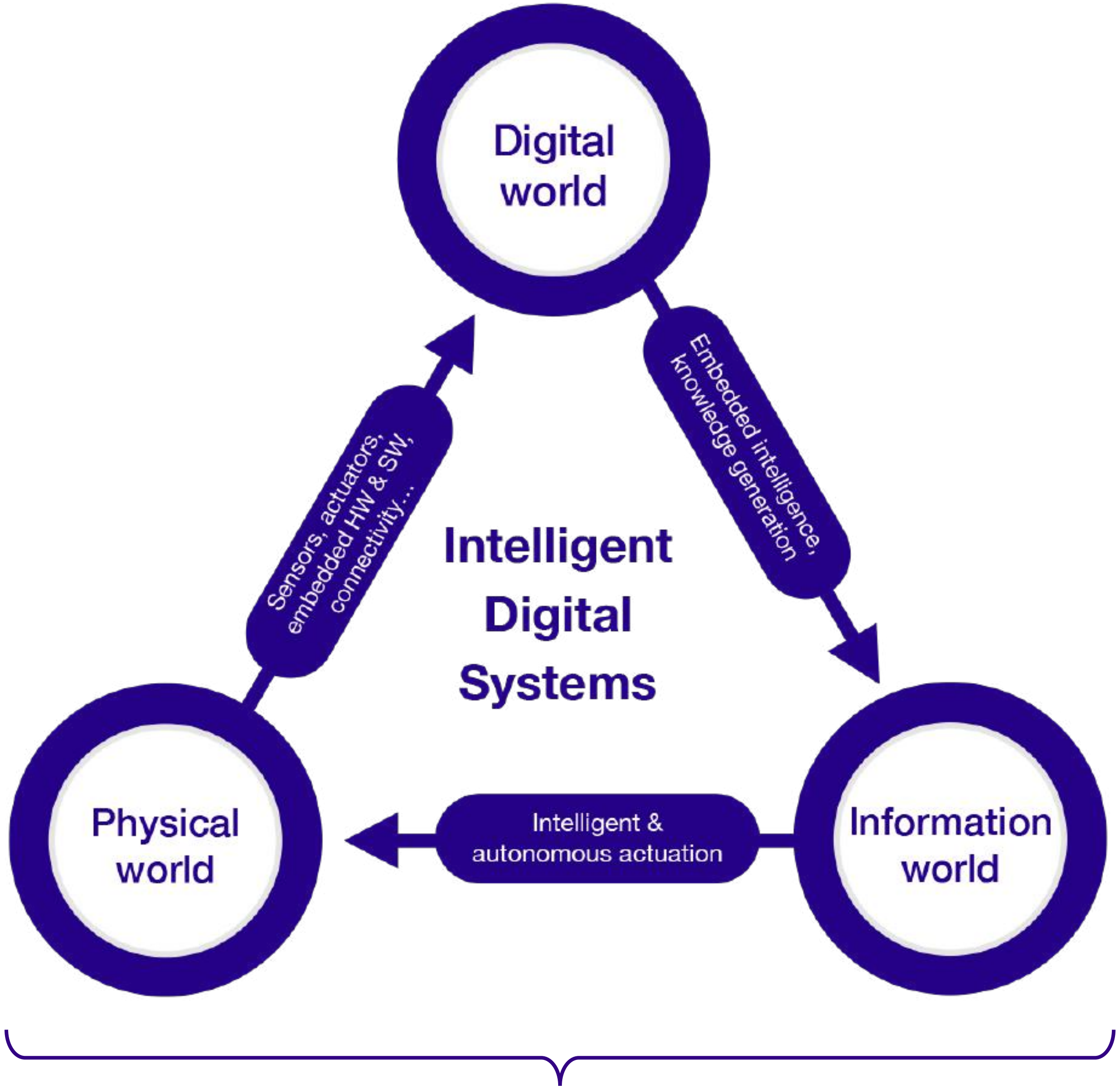


Chips JU

Focus Areas

- Embedded & Cyber-Physical Systems: Hardware, Software and Connectivity
- Edge Computing & Embedded Artificial Intelligence
- Hyper-connected & High-Performance Embedded Systems
- Dependable & Trustworthy ECS(security, safety, reliability, explainability, ...)
- IoT & SoS Integration, Monitoring and Management
- Autonomous, Adaptative, Intelligent and Evolutionary Technologies
- Engineering Methods and Tools, Engineering Automation and ECS Lifecycle Management*
- Education & Professional Training *

* Cross focus areas



Strong dependence on the engineering process.

Industry representative in Chips-JU

Chips JU is a tri-partite initiative (PPP composed of the European Commission, participant state and private entities) mobilizing more than 11 billion euro to safeguard, consolidate, and strengthen the Electronic Components and Systems value chain and its applications in Europe.

Inside is a proud member of

INSIDE together with AENEAS and EPoSS, shape the **ECS Strategic Research Agenda** which drives the Chips-JU Calls

https://ecssria.eu/2024

[Chapter 2.3 focuses on engineering support.]

Engineering process: intro

Towards the 5ft Industry revolution

Digitalization and **ubiquitous/hyper connectivity** are already shaping and will sh
and our society in an unprecedented way.

Summer school 2018

The advances in technologies such as the **Internet of Things (IoT)**, **Cyber Physic**
embedded systems, **M2M communication**, **cloud computing**, **artificial intelligence** (AI provi e all the enabling elements for the starting point of the **fourth industrial revolution**.

INDUSTRY 1.0

INTRODUCTION OF MECHANICAL PRODUCTION FACILITIES BASED ON WATER AND STEAM POWER.

MECHANICS, WATER, STEAM POWER

1784

INDUSTRY 2.0

MASS PRODUCTION BASED ON THE DIVISON OF LABOR AND THE HELP OF ELECTRICAL ENERGY

ASSEMBLY LINES, ELECTRICITY

1870

INDUSTRY 3.0

INCREASED PRODUCTION AUTOMATION WITH ELECTRONICS AND IT

PROGRAMMABLE LOGIC CONTORLLER

1969

INDUSTRY 4.0

FULL PROCESS AND VALUE CHAIN AUTOMATION THROUGH DIGITALIZATION AND HYPER-CONNECTIVITY

CPS, IOT, CLOUD COMPUTING, AI, CONNECTIVITY, …

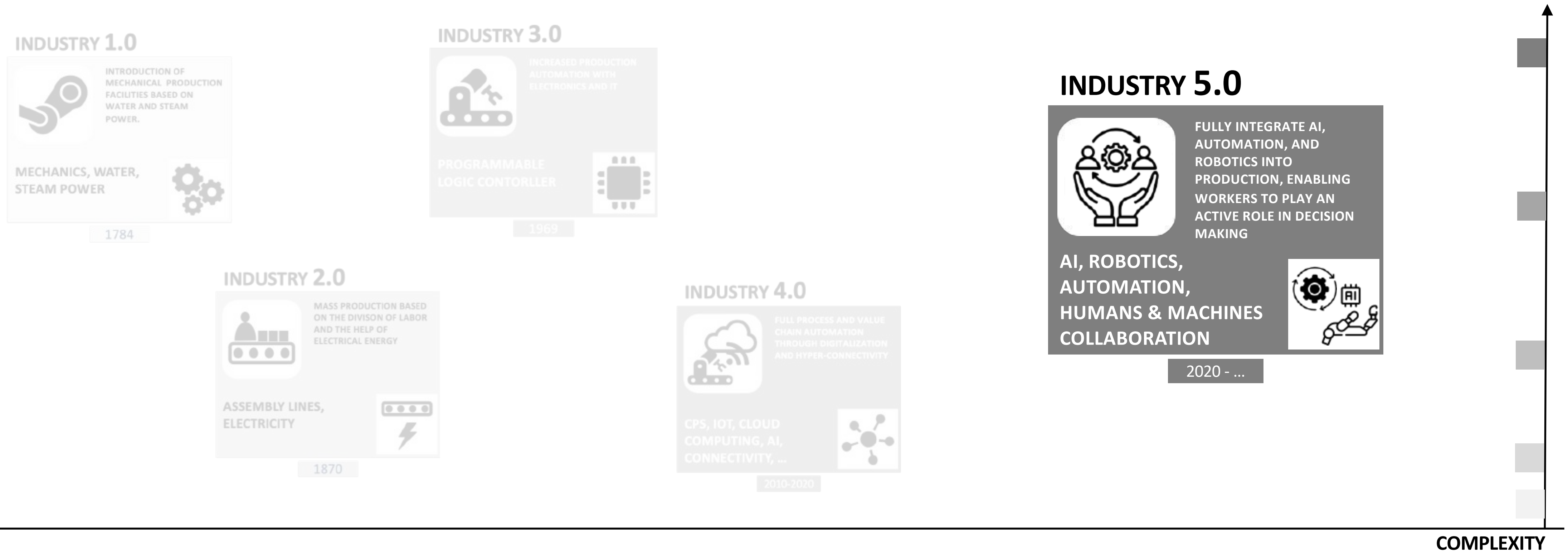
TODAY

Implementing Industry 4.0 remains a challenge

Inside Industry Association

Towards the 5ft Industry revolution (2)

The FIFTH industry revolution (Industry 5.0) aims to radically change how companies work, automating and optimizing processes, with a human-centric approach that will make their lives easier, more productive, and more meaningful.



Key challenges of the 4th and 5ft Industry revolution are COMPLEXITY, COMPETITIVNESS, SUSTAINABILITY, AUTOMATION, PRODUCTIVITY, etc.

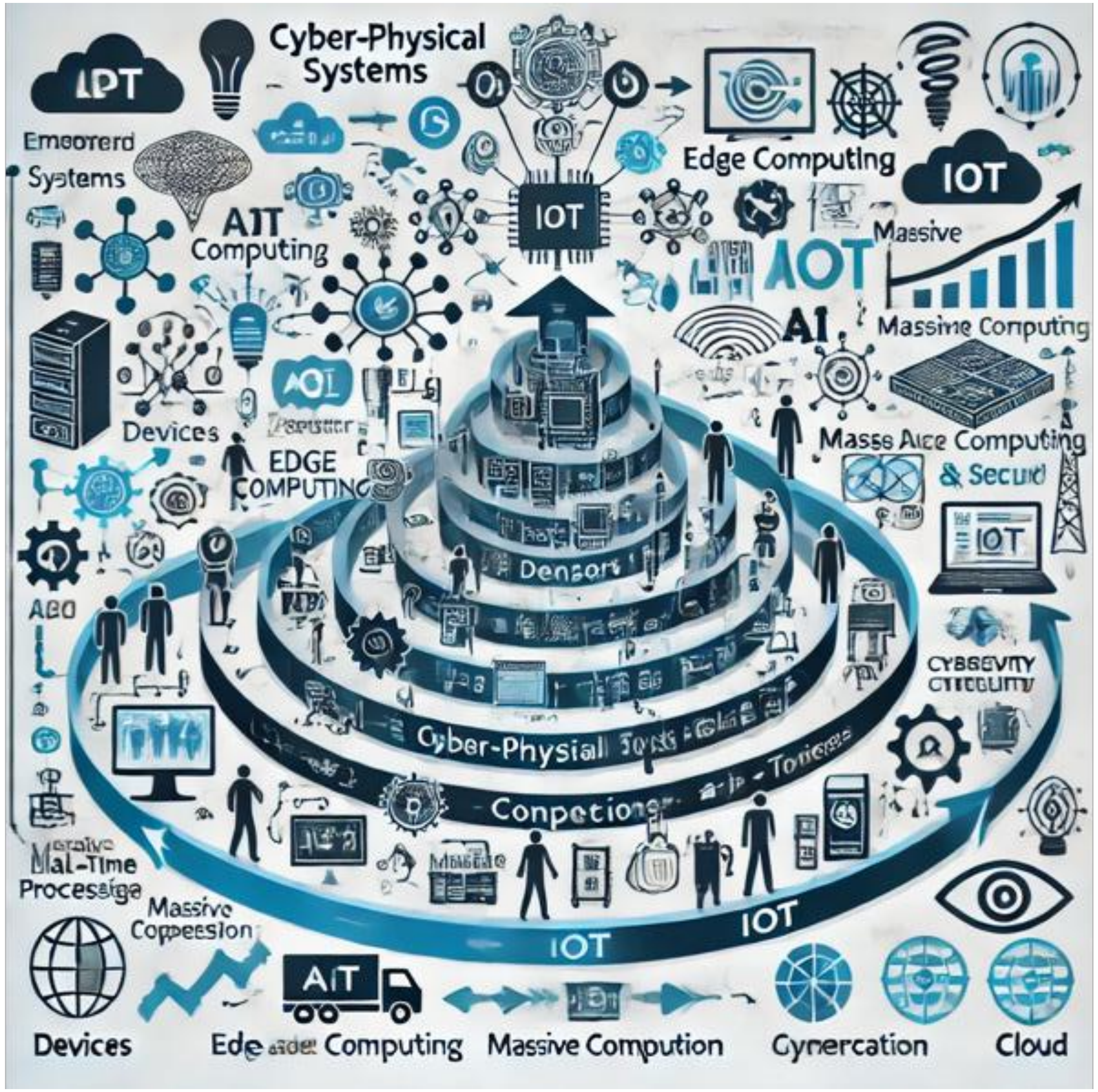
Why the Engineering Process (EP)?

The EP plays a key role to tackle these challenges, and it is fundamental to:

- Efficiently manage CPS complexity (see e.g. EDA).
- Provide support along the entire CPS lifecycle.
- Tackle the lack of skills and of human resources.
- Increase safety, security (e.g. e2e security still a mirage), quality of the final product/service.
- Contain engineering costs.
- Ensure competitive time-to-market and costs.

1 - The issue of CPS complexity

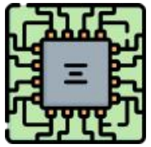
I asked Chat GPT (DALL-E) to visualize complexity …



… it reminds the middle ages representations of the hell, from Dante’s Divine Comedy.

The issue of CPS complexity (2)

CPS complexity is rapidly evolving due to increasing demand for intelligence, connectivity, real-time processing, data-driven decision making, etc.



Modern CPUs have billions of transistors.
Snapdragon X plus 8: 10 B
Jetson TX2: 15.3 B
A18 (iPhone) > 19 B
Nvidia Blackwell ~ 200 B

1000+ chips trad. car
2000+ chips elec. car
3000+ chips aut. car
Lines of code: 100 M
(F35 Fighter 2013: 24 M)
1TB/h of generated data

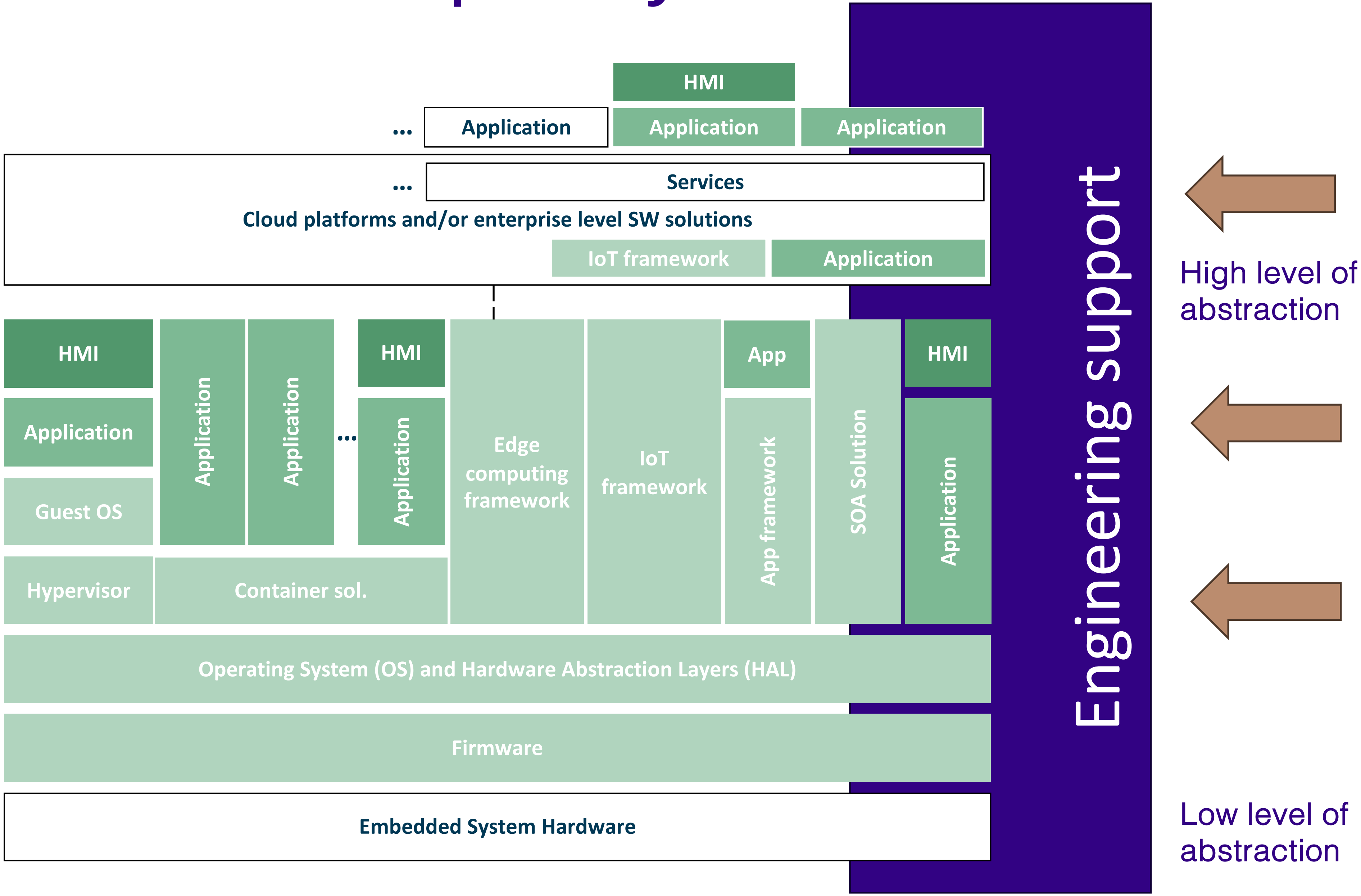
IoT connected devices
15B in 2023
20B in 2030
generating by 2025
80 ZB of data

Towards sustainable computing: in 2023 10-100Wh/Gb is not exactly green …

Complexity is worsened by the lack of skill and human resources!

Software stack complexity

Example of a typical CPS/IoT SW stack



2 - Need for lifecycle support

CPS engineering doesn't limit to design, development and test phases!

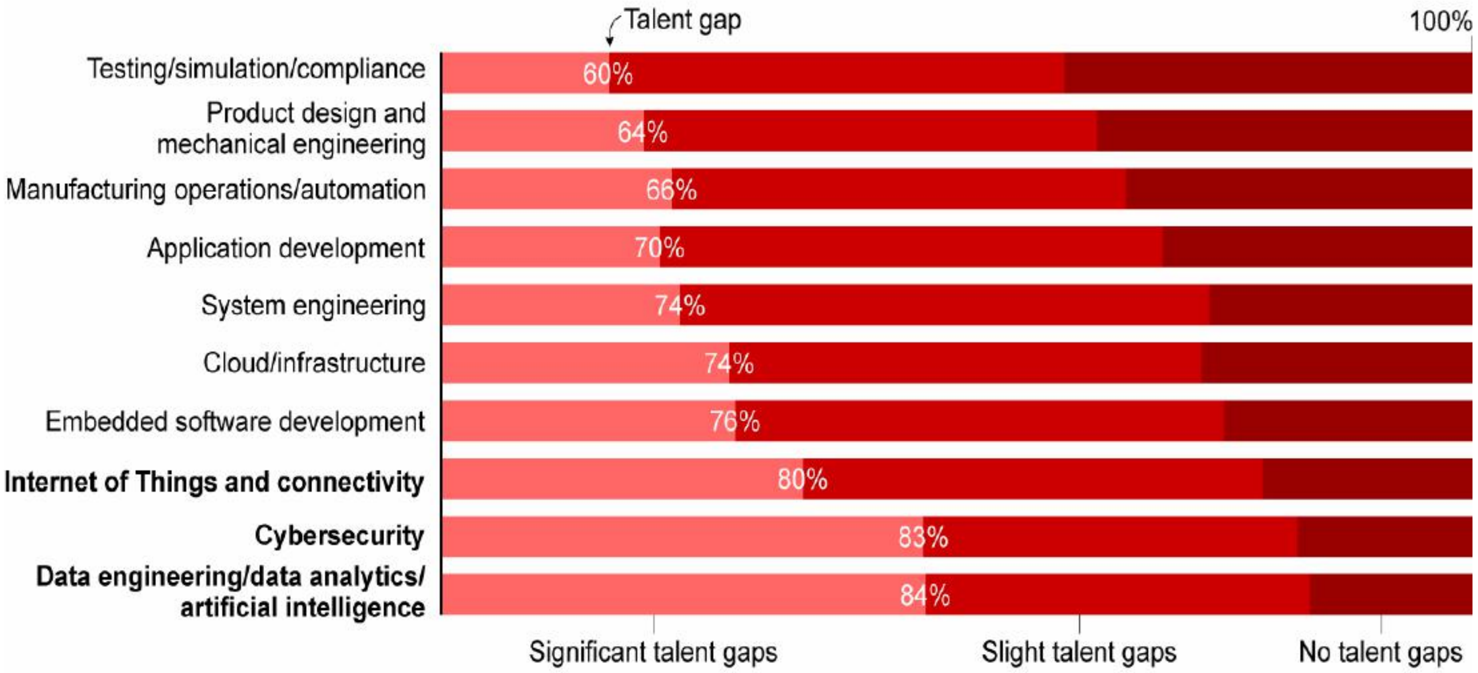
- The nature and complexity of CPS require to consider also deployment, operation, maintenance.
- CPS engineering must be continuous (e.g. dev/ops).
- CPS have an environmental impact (Reuse? Recycle?).
- Technology evolve quickly: how to address CPS evolution?
- Lifecycle support is required by the digitisation process.
- Support the edge to cloud continuum.
- Support the concept of "everything as a service".

3 - The lack of skill & human resources

Education and professional training struggle to keep up with tech evolution, especially with the complexity of digitisation.

73% of engineering and R&D-focused companies report talent gaps*:

- with the inability to keep up in replacing people retiring (↑ 6,2%) with new graduates (↑ 1,8%),
- and midcareer engineers transitioning to non-engineering roles (17% increase in the last 2 years),
- equally affecting all geographies, likely throughout the coming decade.



Notes: Decision makers were asked, "Do you expect talent gaps in the below capabilities over the next three years? (single choice by capability)"; results filtered for aerospace and defense; the formula for calculating talent gap percentage is first adding number of slight talent gaps together with the number of significant talent gaps and then dividing the sum by the total number of responses
Source: Bain Engineering and R&D survey 2022 (n=505)

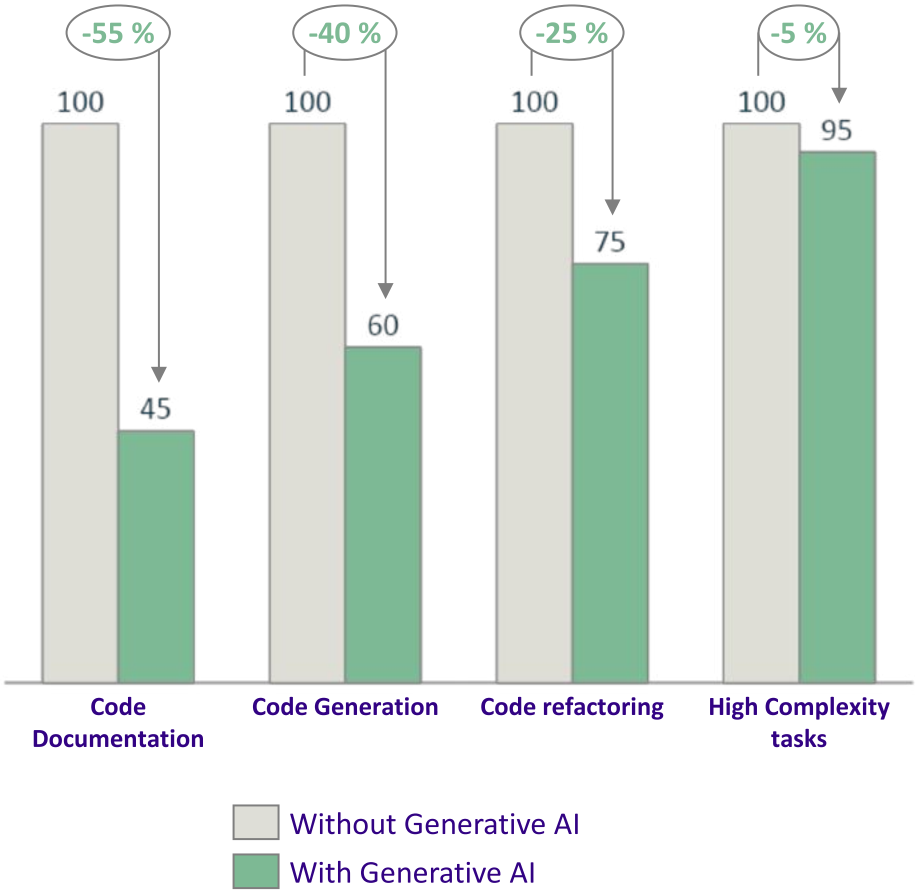
*Bain & Company, Bridging the Talent Gap in Engineering and R&D

The lack of skill & human resources (3)

Potential solutions:

- ENGINEERING AUTOMATION to improve efficiency and relieve engineers from tedious, low-level, routine tasks (40% of employee time today).
- Investing in employee growth: reskill, upskill, high-level competency development (e.g. 500M € program at Audi).
- Companies need to transform the value proposition they offer to potential employees.
- Pay for skill, not for tenure.

SOFTWARE DEVELOPMENT – TASK COMPLETION TIME WITH OR WITHOUT GENERATIVE AI | %, Benchmark



Source: McKinsey, Bain, Microsoft, Strat Anticipation analysis

What is the engineering process?

The EP is a comprehensive, multidisciplinary approach for the creation and management of complex digital systems.

- It spans the entire lifecycle of the system, from concept to decommissioning, and involves rigorous coordination between various engineering disciplines and stakeholders.
- It is a workflow composed of:
  - sequential and concurrent phases and activities,
  - interacting through the exchange of raw data, meta data, aggregated information, documents, and tasks,
  - according to a set of procedural standardised rules.

The EP is strongly linked to the CPS supply/value chain because its stakeholders EXECUTE the EP!!!

The ECS/CPS value chain

The supply and value chain concepts

Value chain simplified example Source: Oracle 2023

The Supply Chain represents all the steps required to get the product to the customer, starting from raw materials.

The phases of the chain are connected by a producer/consumer (supplier/customer) relation.

Companies depend on cost-effective, fast, reliable, resilient supply chains to manufacture quality products and keep them flowing to customers (e.g. chips shortage caused by the pandemics).

This is the mandatory baseline of any business.

The supply and value chain concepts (2)

The Value Chain builds on the Supply Chain and focuses on how value is created, enhanced and delivered, as the product moves along the supply chain emphasizing efficiency, optimization, and the role of different stakeholders in enhancing the overall value: "value only happens when the goods or services are in customers' hands".

Value chain simplified example

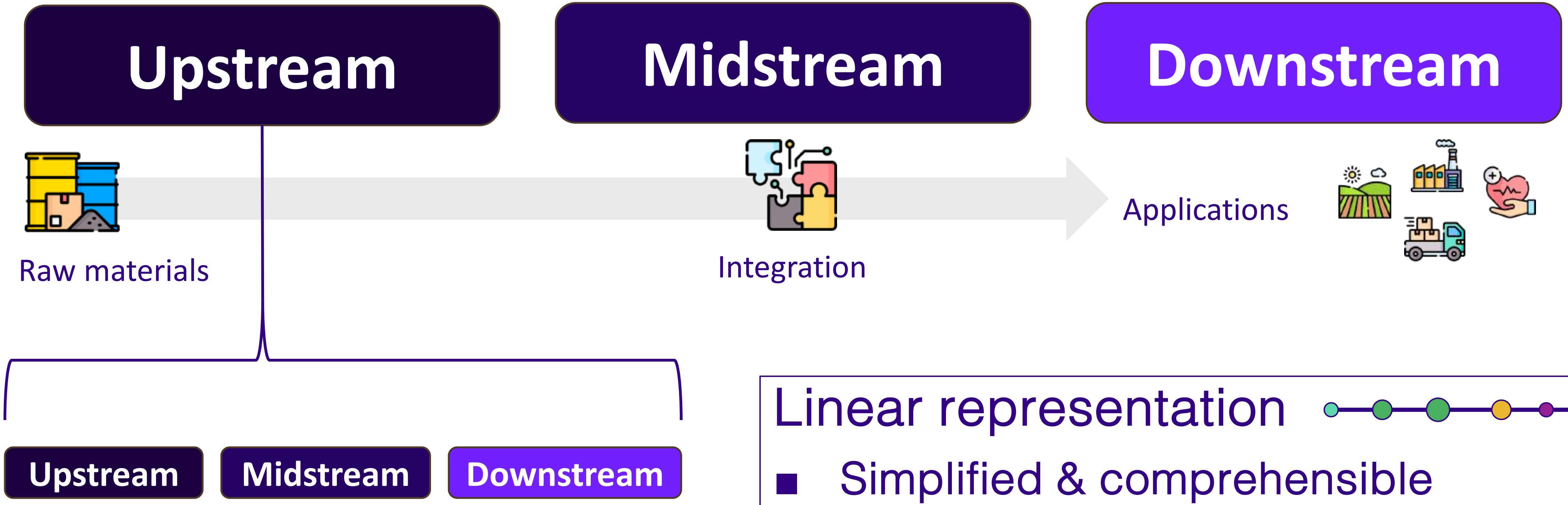
Source: Oracle 2023

And business performance depends just as much on the value that products and services generate in the customers' hands.

In essence, a value chain outlines how businesses create, capture, and deliver value to gain a competitive advantage.

The Value Chain concept

- Typically composed of three segments
  - From raw materials down to the final application
  - With a recursive structure



Linear representation

- Simplified & comprehensible
- Unrealistic

Example of linear representation

Smart Module
- SIM Card
- Sensors
- Embedded Chips
- Aggregator
- Transporter

Smart Object
- Vending Machine
- Appliances
- Meters
- Car
- Camera
- Meters

Connectivity
- Network
- Connectivity
- Availability
- Quality

Platform
- IoT Enabling Capabilities
- Billing
- Integration with 3rd party applications
- Analytics

Software Customization
- Interfaces
- Solution Build-up
- Hardware
- Back-end
- Data Management

Applications
- Vertical solutions
- Bundling of service
- CRM & Billing
- Customer Care

Customer
- Buys Services
- Sells Services

The concept of Value Network

CPS/IoT/SoS are complex entities, adopted in complex and cross domain vertical applications:

- Their lifecycle is rarely managed by a single company.
- They require an appropriate ecosystem of companies with complementary competences and businesses.
- Their EP reflects this nature!

A non-linear model is required: the Value Network

- More complex to represent and manage.
- Reflects the real EP, market dynamics and synergies.

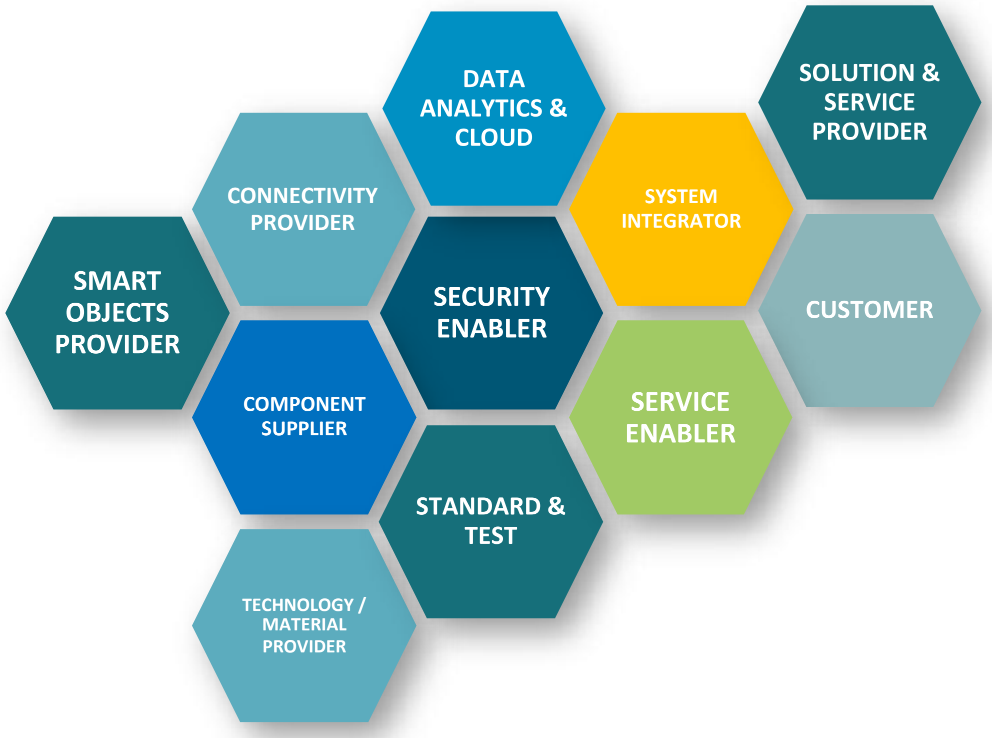
The concept of Value Network (2)

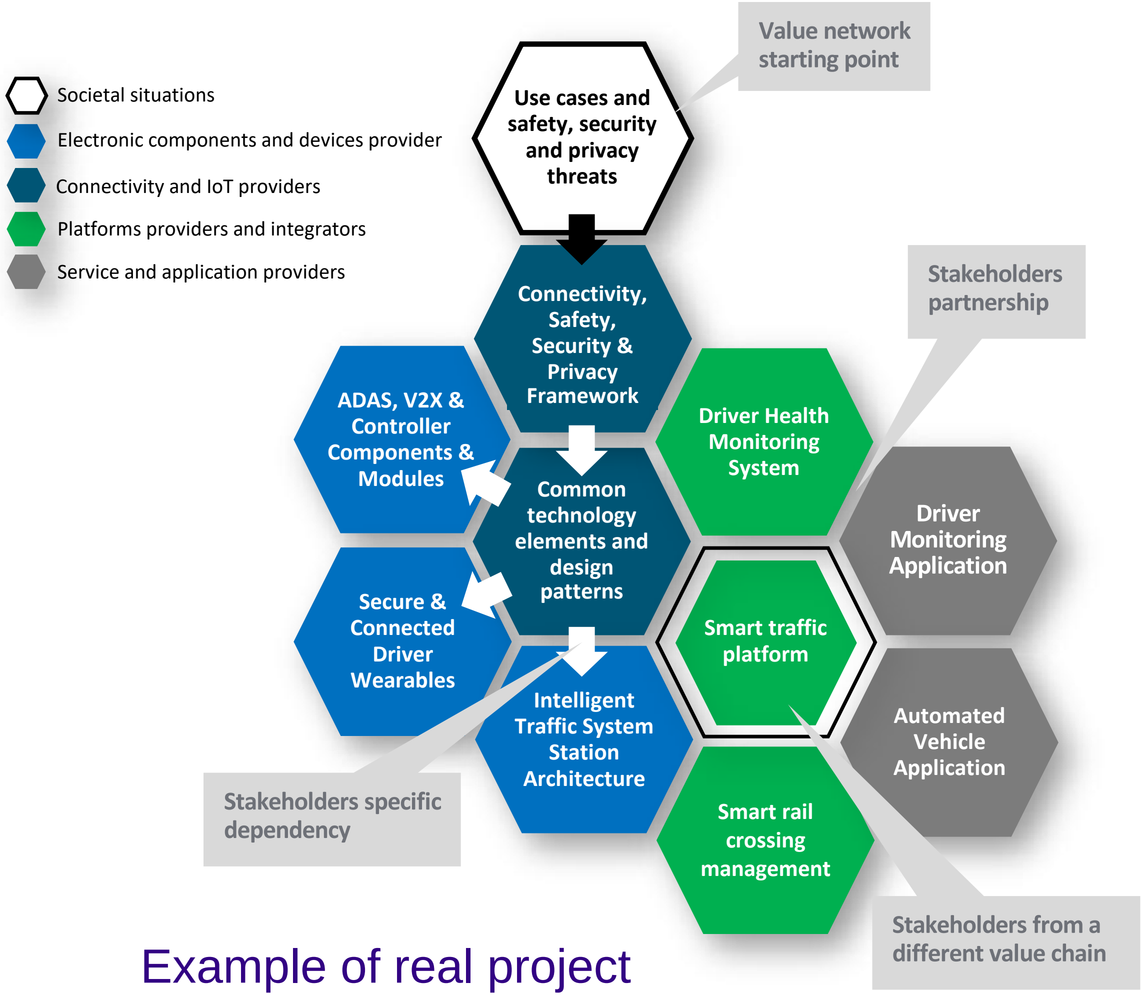
- In a VN, new and existing actors can integrate both vertically and horizontally encompassing all stages of production.
- Hardware manufacturers, software providers, service providers, system integrators, application developers and end-users may collaborate in a flexible manner for the creation of a product.
- The conventional boundaries between industries, technologies and vertical domains fade away in VN.
- In a VN, new business model combinations and new revenues stream could be generated from potentially any connection between stakeholders.
- The VN pushes companies to exit from their comfort zone.

The concept of Value Network (3)

- Value network has an impact on competitivity. The complexity of CPS/IoT pushes companies to bring all competencies under a single umbrella.
- In the value network, a multitude of actors, with their own peculiarities, could forge alliances and partnerships, which in turn will compete against each other.
- In a value network the traditional roles and responsibility can mix, shift and change:
  - customers can act as designers for their products;
  - machine manufacturers can become service providers, selling both machine and aftersales;
  - new service providers will emerge;
  - …

Example of VN representation

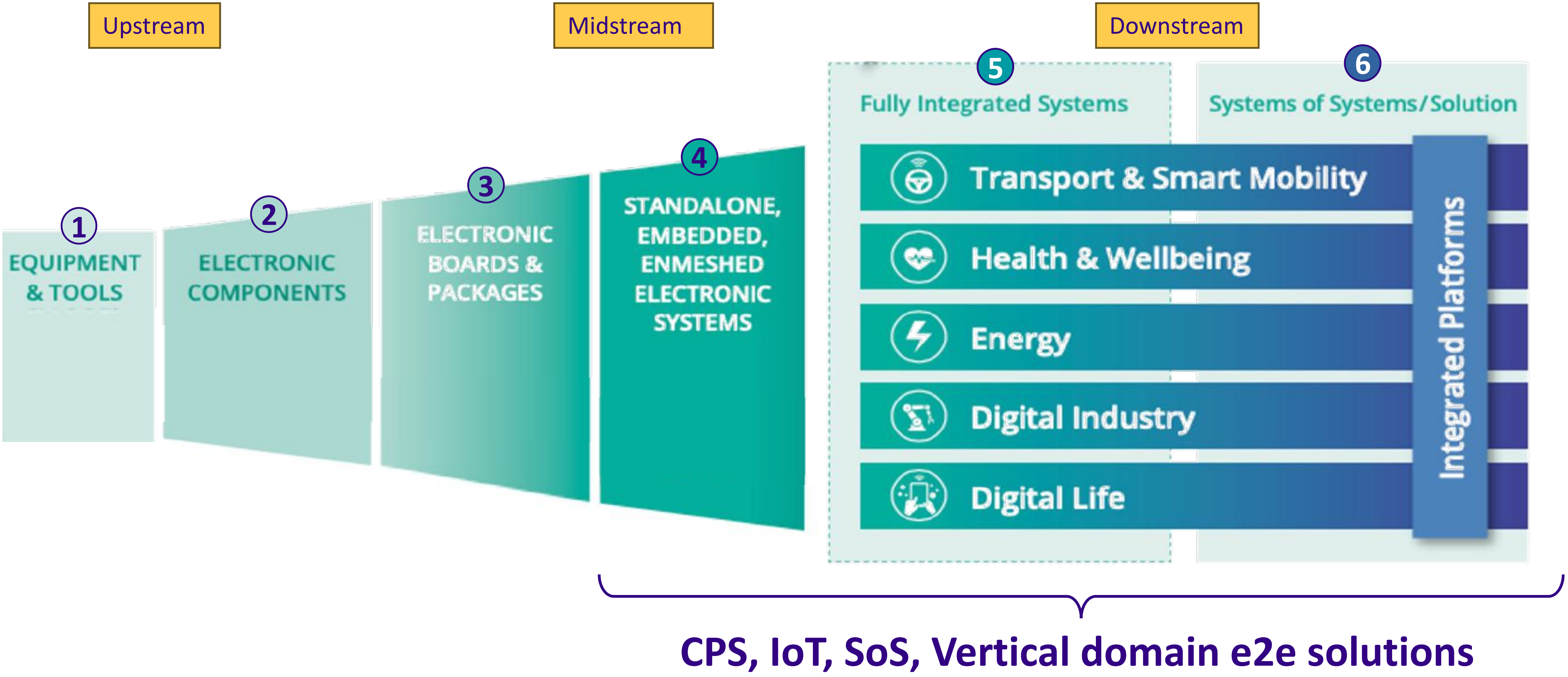




This representation has many limits, especially considering the EP.

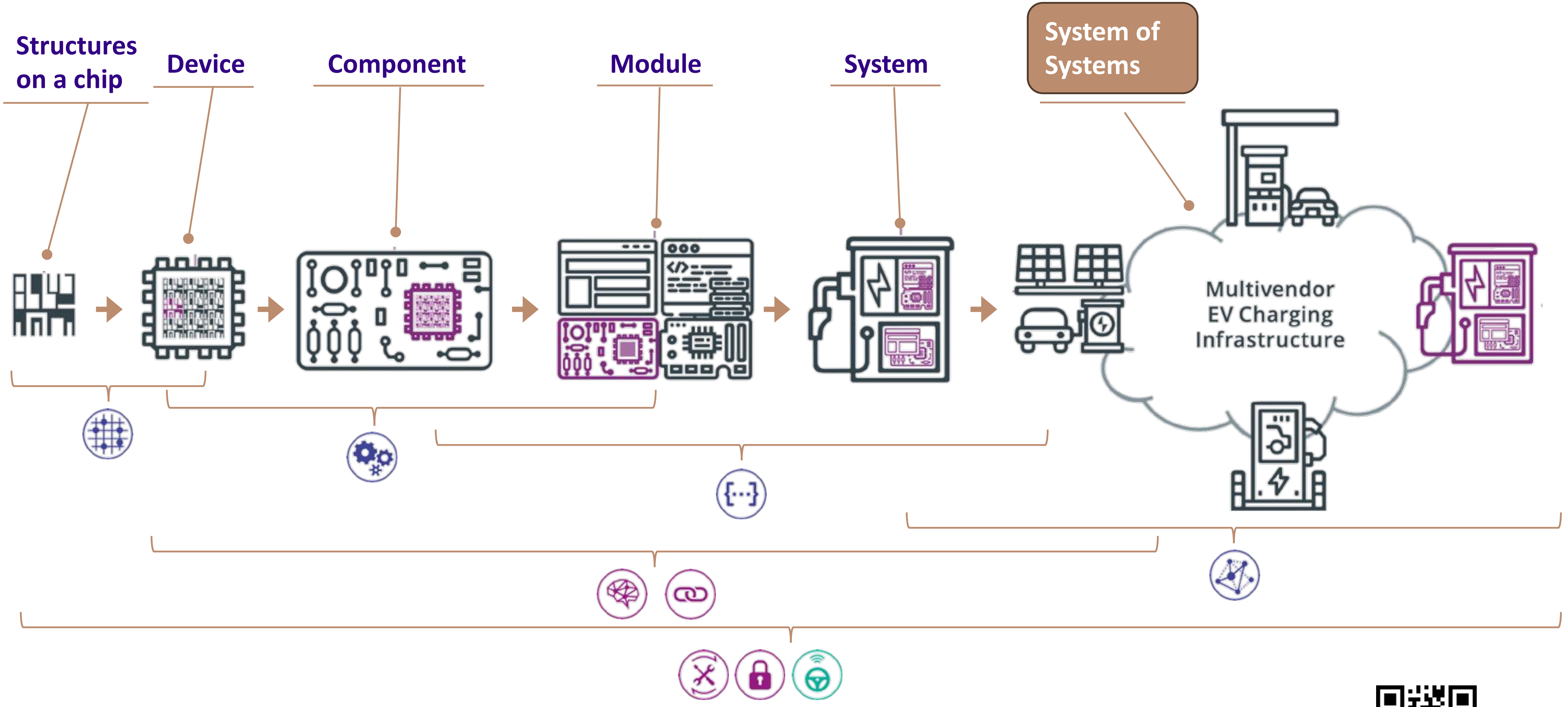
Example of real project in the mobility sector

The ECS/CPS Value Chain (linear)



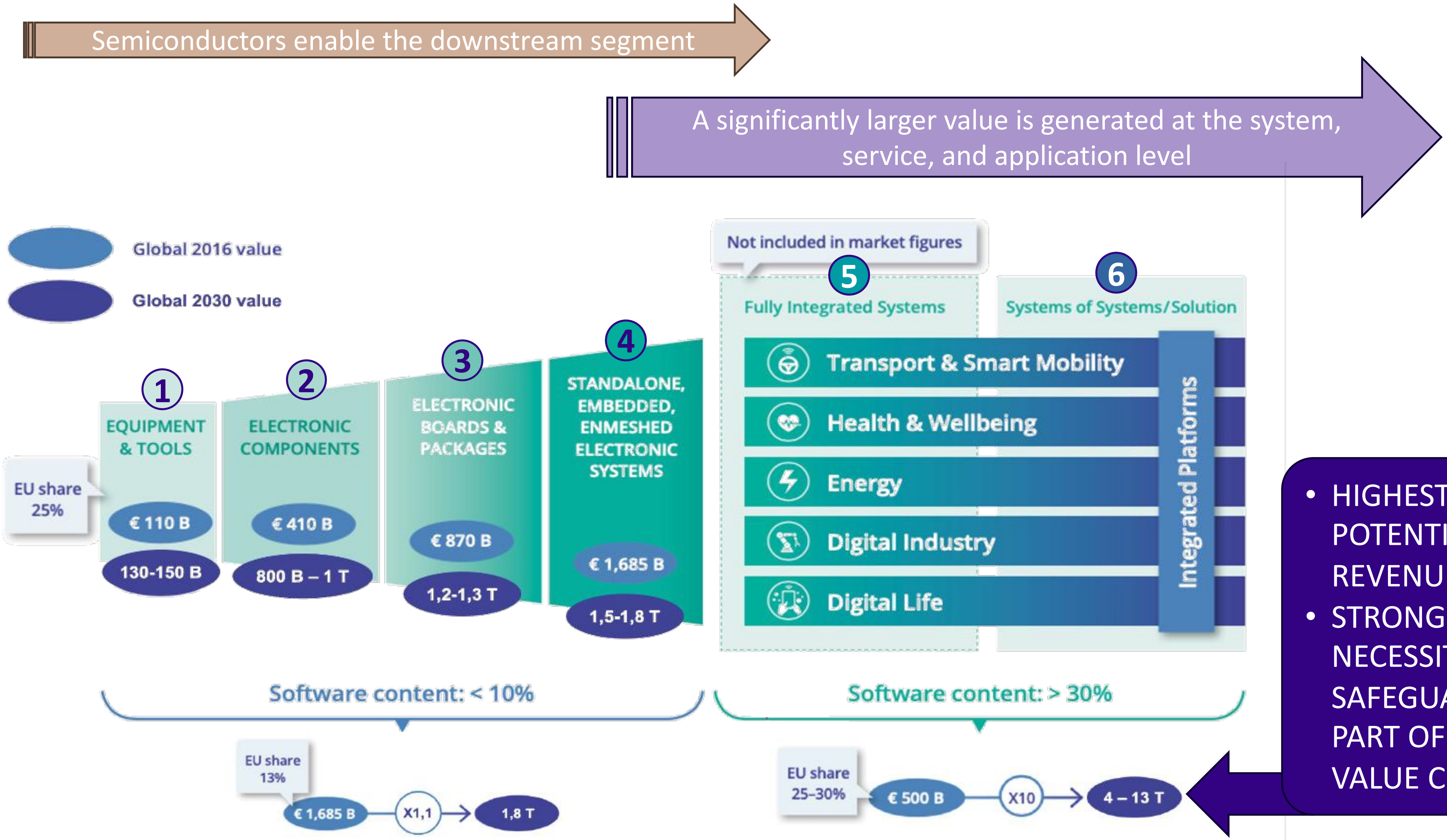
Globally integrated value chains where **geopolitical issues impact all stages (monopolised segments, shortages, single techs dependencies, …).**

The technology perspective (ECS-SRIA)



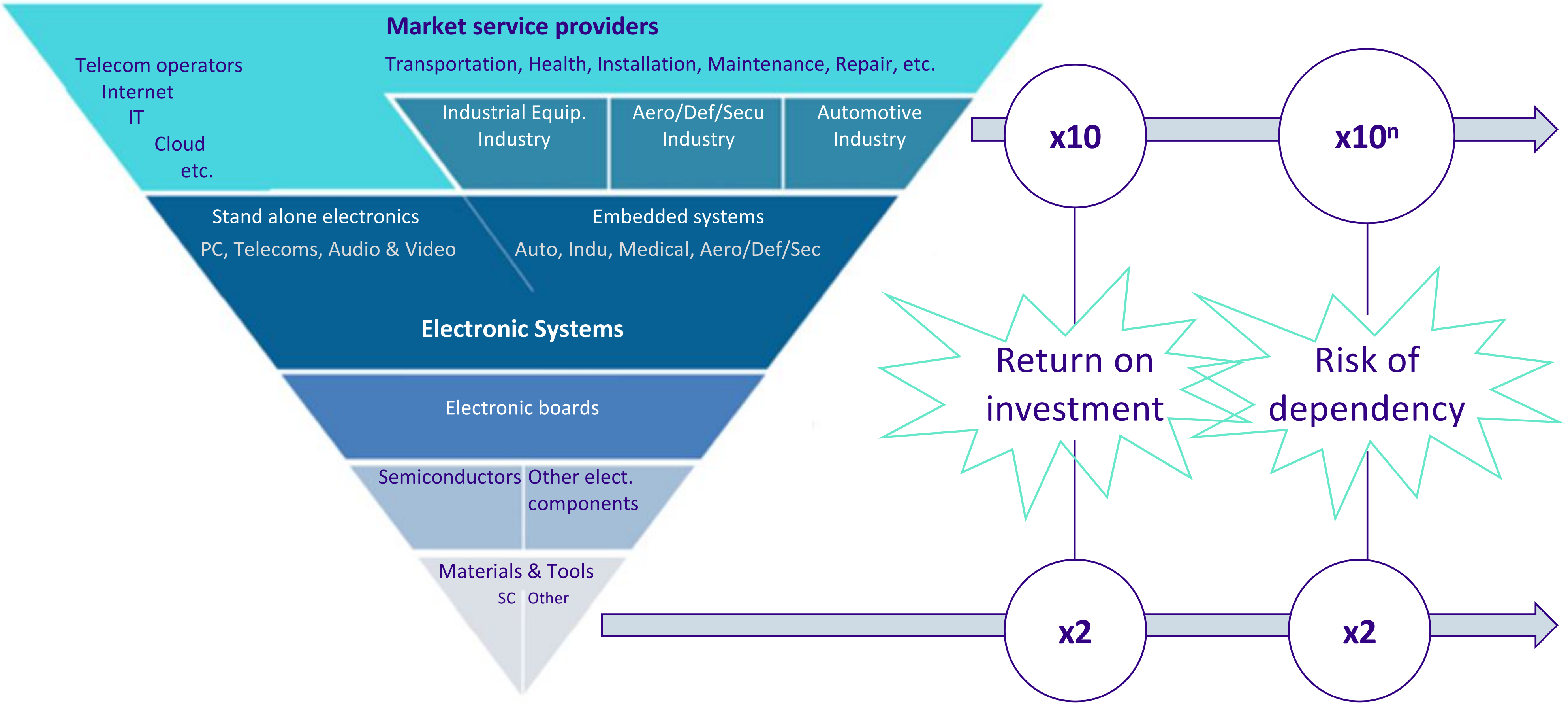
Electronic Components and Systems Strategic Research and Innovation Agenda (https://ecssria.eu/)

The ECS/CPS Value Chain (2)



- HIGHEST POTENTIAL REVENUES
- STRONG NECESSITY TO SAFEGUARD THIS PART OF THE ECS VALUE CHAIN

The ECS/CPS Value Chain risks



Investing in the upstream part is necessary, but **not sufficient**!
It would only **shift the dependencies downstream**, leading to greater issues.

The CPS technology stack

There is no digital and CPS without chips!!!

While securing chip production is vital, safeguarding the entire HW/SW stack is even more critical: the EP has a crucial role!

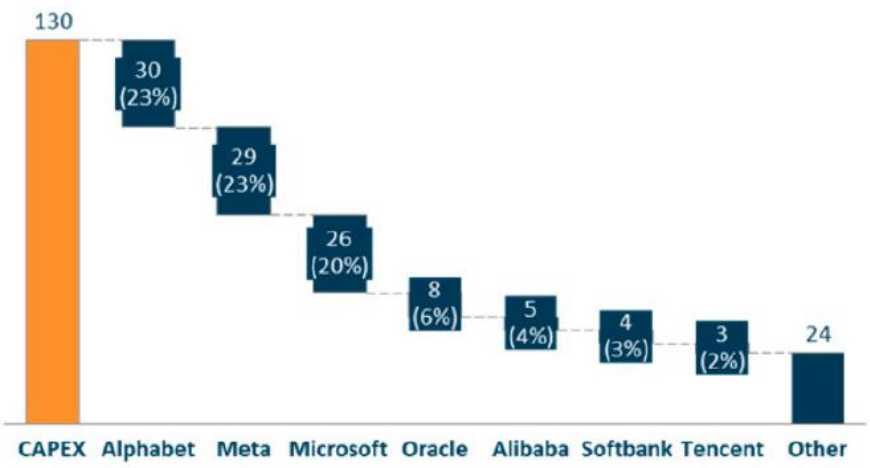
- The continuity of the HW/SW technology stack is not guaranteed
  - Modern applications reach millions of lines of code.
  - Critical levels of software complexity, uncontrollability, and unpredictability.
  - Security concerns (e.g. Open-source software lacks rigorous testing).
- Affected stack layers: firmware, drivers, OS/virtualisation, but also the higher layers of the stack, SoS integration, application, cloud, etc.

Global software investments

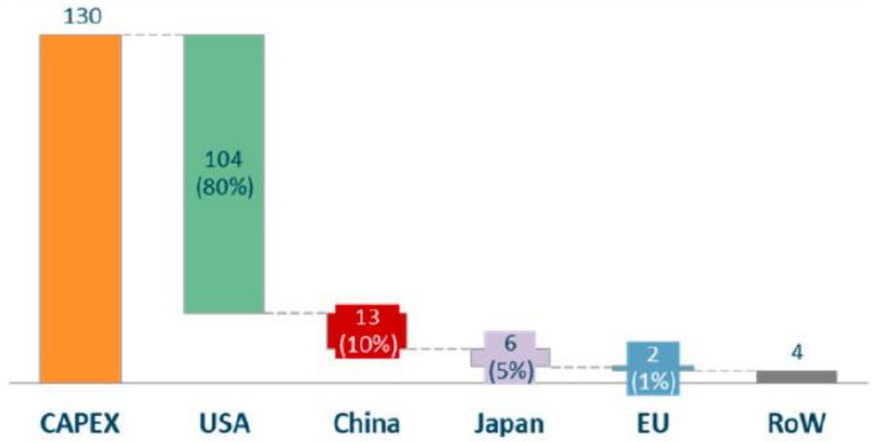
- 2022 Global Software CAPEX: $130 billion
  - US: 80% ($103 billion)
  - Europe: 1%

- R&D Spending
  - Global Software R&D (2022): $240 billion
  - US: 74%
  - Europe: 6%

SOFTWARE MAIN CAPEX INVESTORS | *B$, Worldwide, 2022*



SOFTWARE CAPEX BY REGION | *B$, Worldwide, 2022*



SOFTWARE MAIN CAPEX INVESTORS | *B$, Worldwide, 2022*

EU semiconductor strategy: a SW blind spot?

- Europe's Semiconductor Strategy.
  - Focus on safeguarding semiconductors strategic autonomy.
  - Emphasis on upstream production (chips).
  - Fundamental for a profitable value chain & EU key applications.
- The software stack presents a critical blind spot potentially:
  - Limiting the impact of the investments in semiconductors.
  - Creating technological dependencies from US and China.
  - Damaging the downstream part of the value chain where the revenues largely exceed the upstream (chips).

The investments level on software should be comparable or higher than the one in hardware!!

Securing the Software Stack

A more holistic strategy is required to maximise European investment in semiconductors and put in place the condition of success of big software leaders that Europe is missing.

- Increased investments in EU software stack development.
- Establishment of dedicated software research programs.
- CREATION OF THE EU SOFTWARE ACT!
- Increase the investments in the Chips JU:
  - SW design and development alongside new chip generations.
  - Ensuring a solid hardware/software ecosystem.

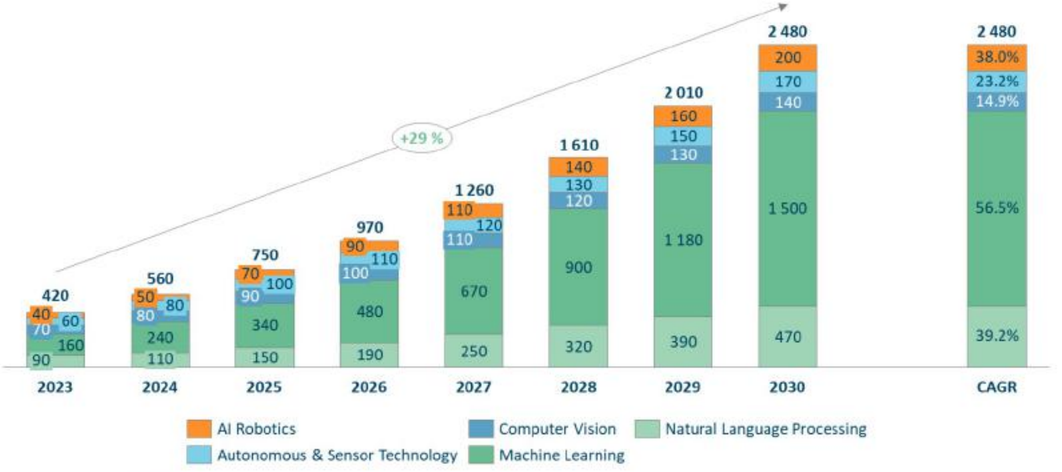
Investments in ENGINEERING AUTOMATION:

➡ To address the challenges generated by complexity
➡ To address the lack of skill and human resources
➡ Support competitiveness and sustainability

The rise of AI

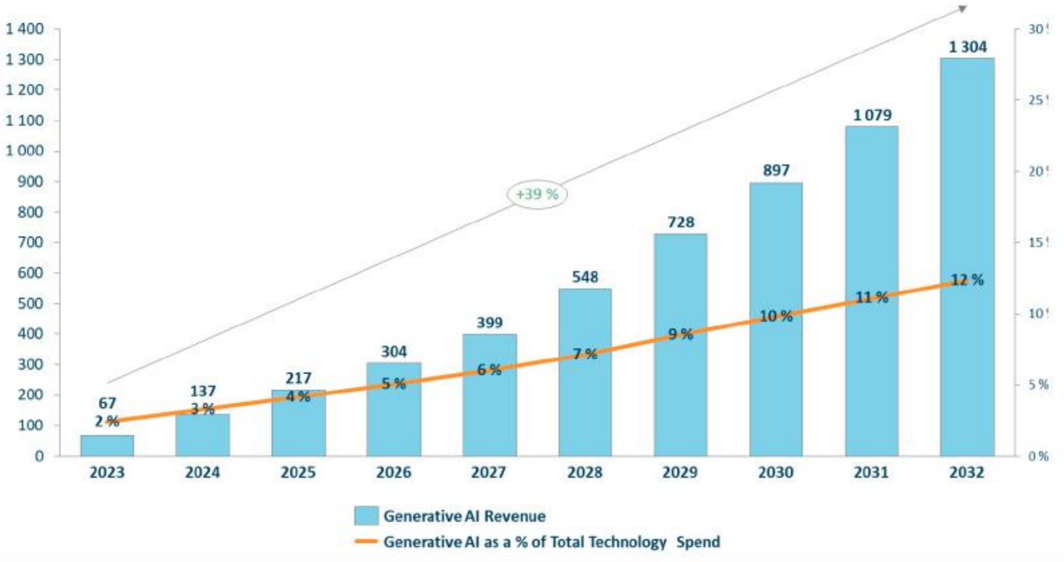
The need to invest massively in software has become even more critical with the rise of AI!

- AI Market Growth
  - 2023 Valuation: $420 billion
  - Projected 2030 valuation: $2480 billion
  - CAGR: 29%
- Generative AI
  - Projected revenue by 2030: $900 billion
  - CAGR: 39%
- AI chips will constitute 45% of global chips demand by 2027



Source: Statista, March 2024, Strat Anticipation research and analysis

ARTIFICIAL INTELLIGENCE – GENERATIVE AI REVENUE AND GENERATIVE AI AS A % OF TOTAL TECHNOLOGY SPEND | B$, 2024-2028



Source: Bloomberg, June 2023, Strat Anticipation research and analysis

AI and HW/SW symbiosis

- AI is a good example of the business convergence towards the full (HW/SW) technology stack:
  - From HW to SW, the traditional chip maker business model is integrating software development.
  - From SW to HW, the traditional software providers have entered the fabless design hardware market.

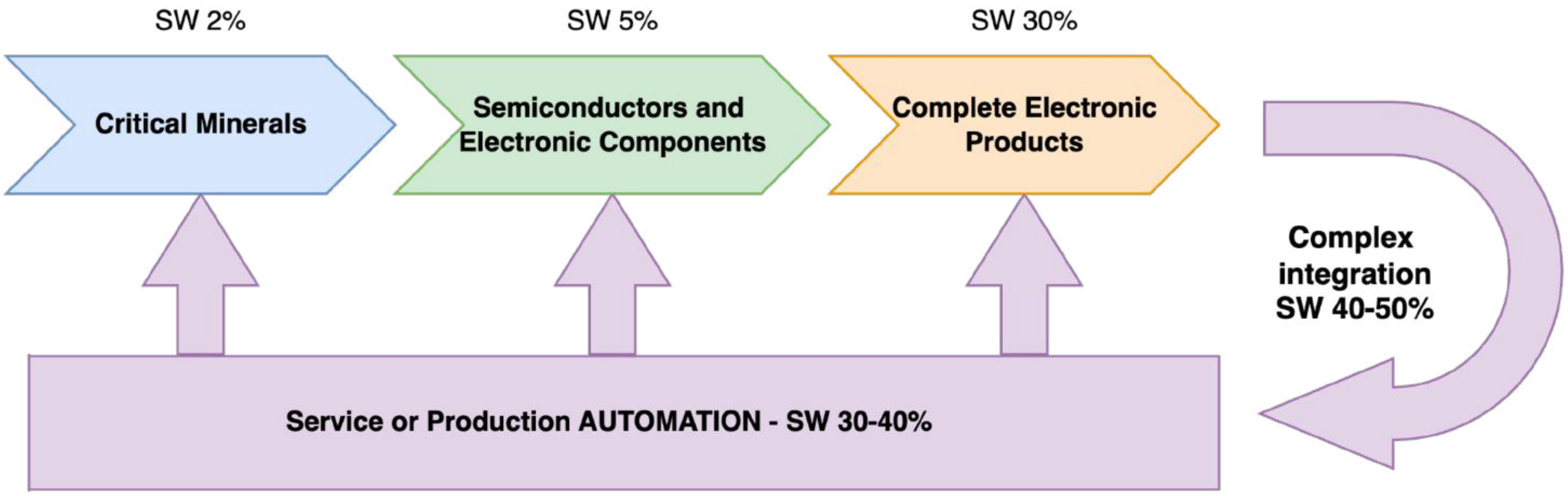
COMPANY	SOFTWARE DEVELOPMENT PROJECTS
NVIDIA	NVIDIA has now new proposals in terms of software for companies and private person, such as NVIDIA AI Enterprise, to use generative AI in companies but also development software
AMD	AMD has less software product but sells development tools and graphics tools
intel	Intel is developing a wide spectrum of software in cybersecurity, AI, performance management and cloud infrastructures
ST life.augmented	STMicroelectronics has several technical software that are made for their product (including electro-thermal simulations) but also embedded software for their products or development tools
infineon	As STMicroelectronics, Infineon has several technical software, simulation and development of their product and embedded software
NXP	NXP has developed more than 2 500 software : there are mainly embedded software and development tools for several industries including automotive and telecoms
arm	Arm built tools for developers so they can optimize their code on Arm's chips. They have also a range a software for the automotive industry and functions.

Source : Intel, NVIDIA, ARM, AMD, Infinineon, NXP, Strat Anticipation research and analysis

This convergence is strongly dependent on ENGENEERING AUTOMATION and on an appropriate ENGINEERING PROCESS … that is SW

Software in the value network

No chips without minerals!
No electronic products without chips!
No product functionality without software!

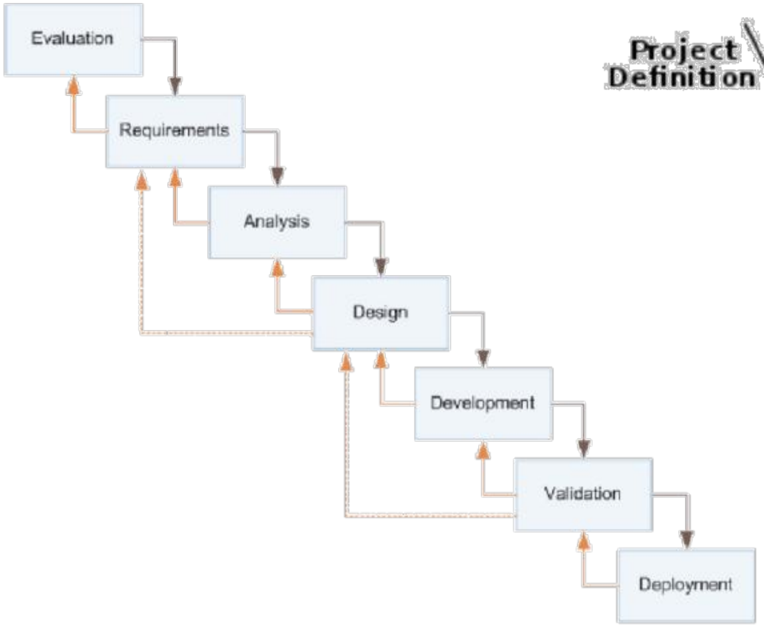


Software is everywhere!
Software is the AUTOMATION enabler!

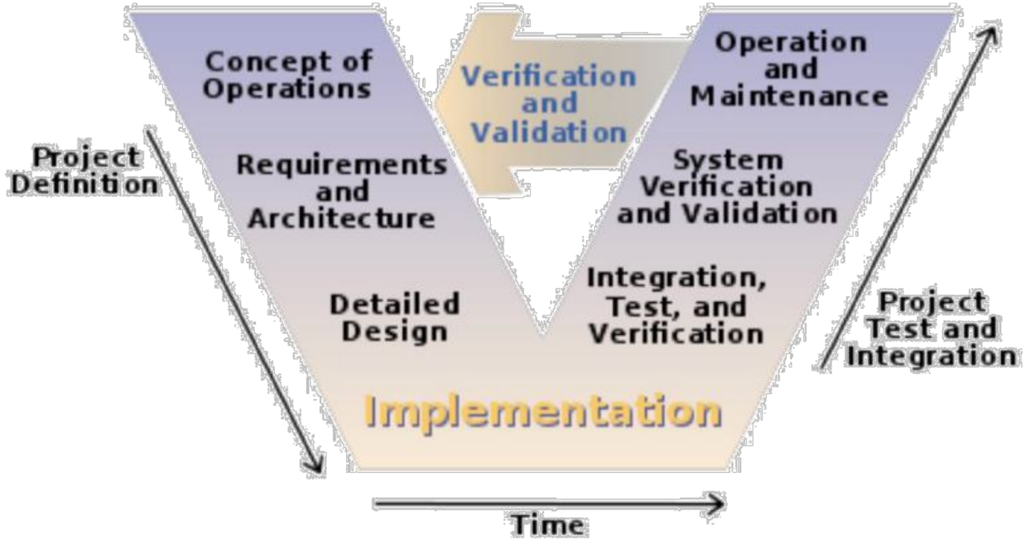
Engineering Process models

Existing EP models

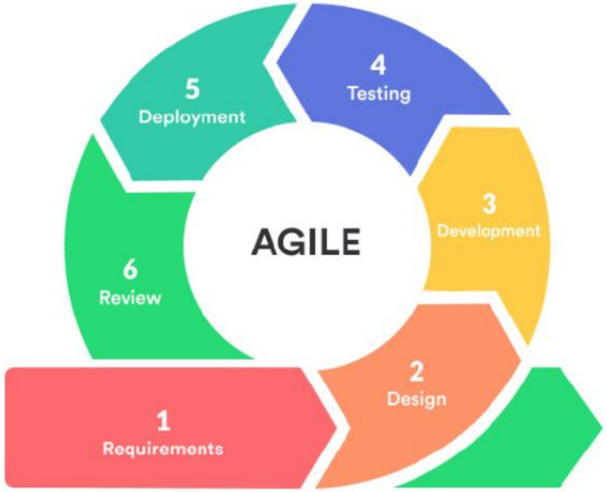
Mainly used in SW domain



Waterfall Model ('70)



V Model

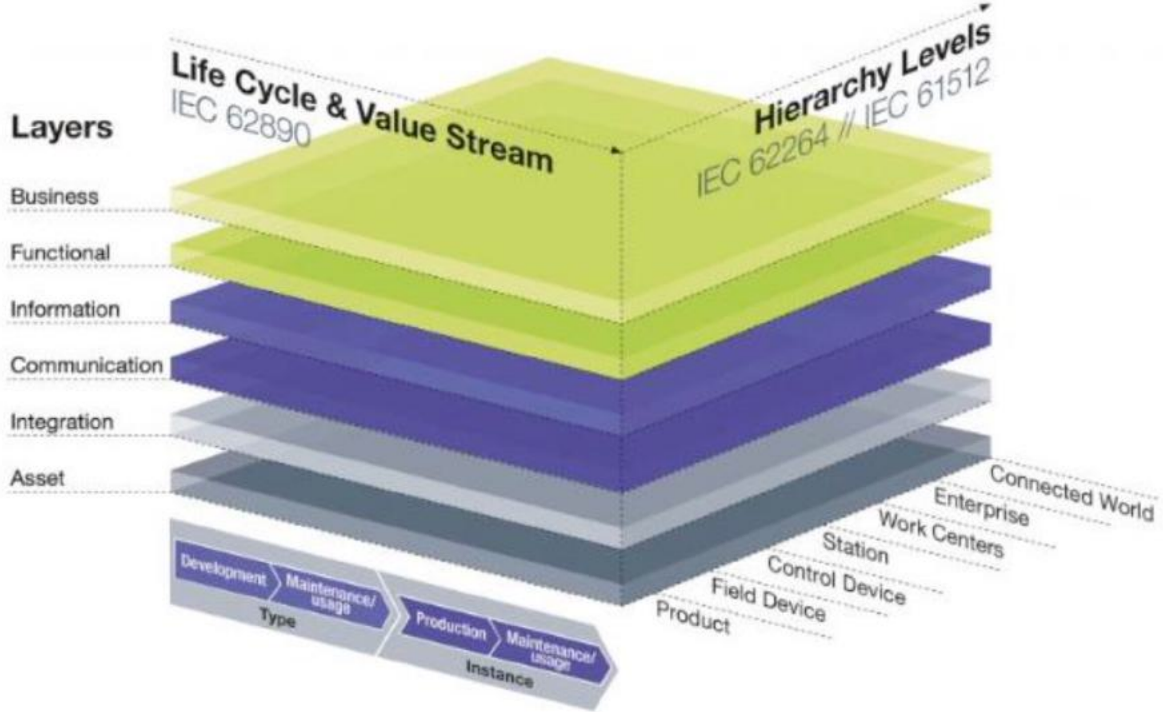


AGILE Model

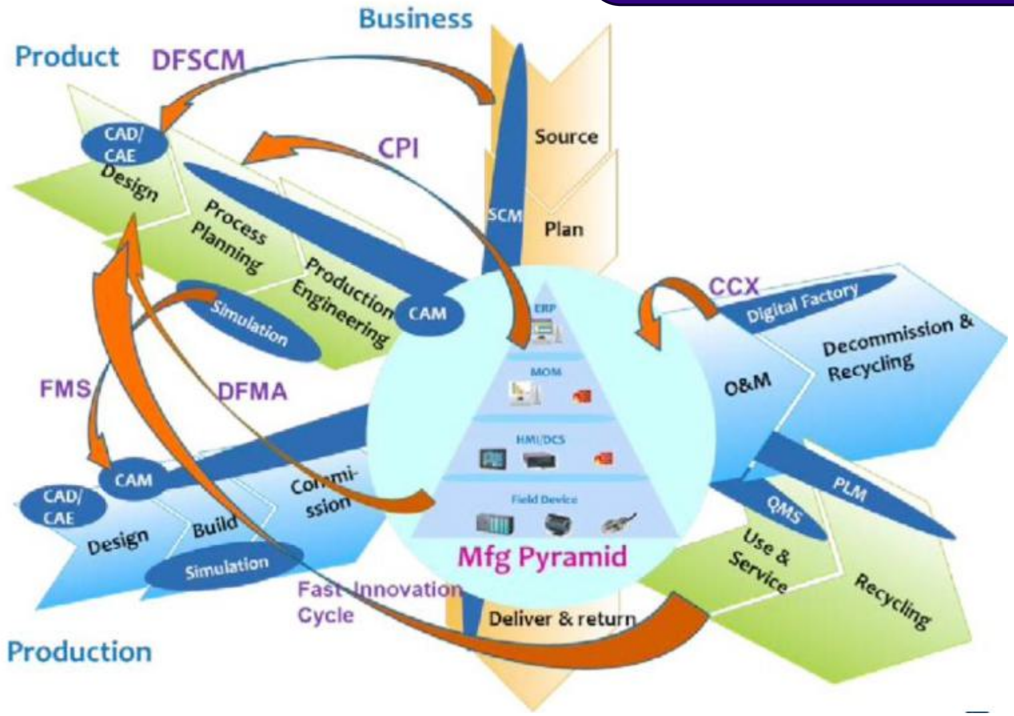
Linear models with branches in the execution of parallel tasks and decision-making steps allowing many alternative execution paths.

Existing EP models (2)

Mainly used in industry



RAMI 4.0

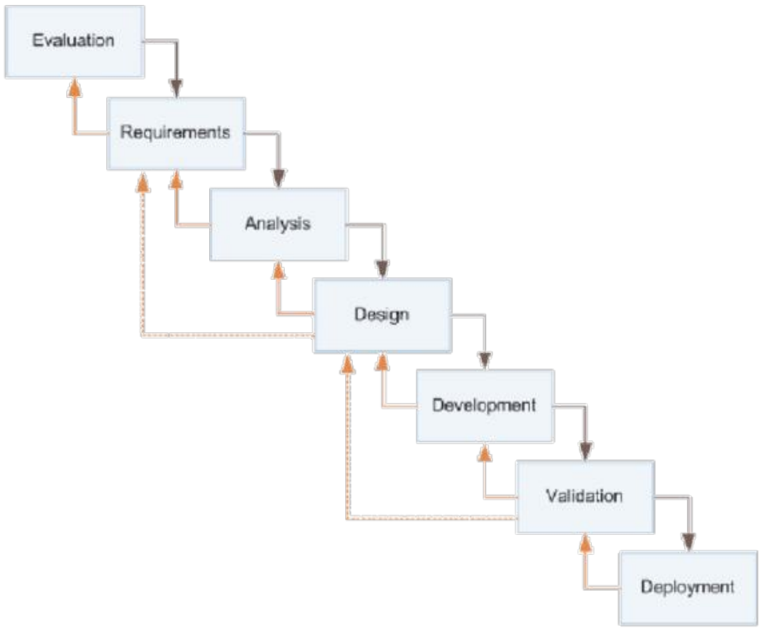


Smart Manufacturing Ecosystem Model

The trend is to define 3D models, integrating also the factory layers and business aspects layers, covering the whole life-cycle.

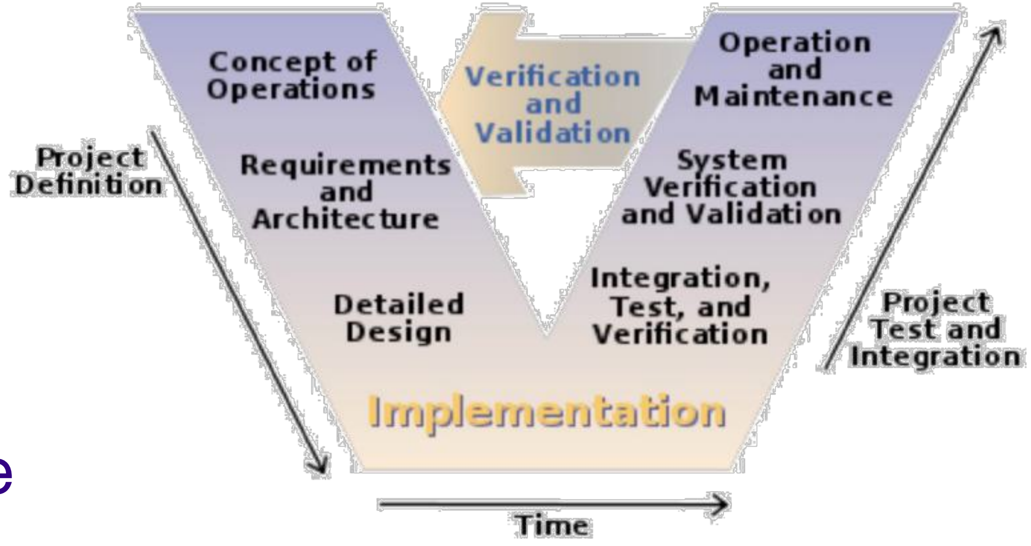
Waterfall Model

- Defined in ’70, describes the steps to be implemented in a sorted list of consequential phases, without any overlap.
- The result each phase must be passed to the next one in the complete form, tested, and well documented after a predefined time allocated for its development.



- Pros: simple, structured, clear documentation, easy to manage, works well for small projects with stable requirements, early identification of goals.
- Cons: inflexible, assumes perfect requirements, late testing, no overlap or parallel work, high risk of misaligned outcomes, unsuitable for long/complex projects, poor customer involvement.

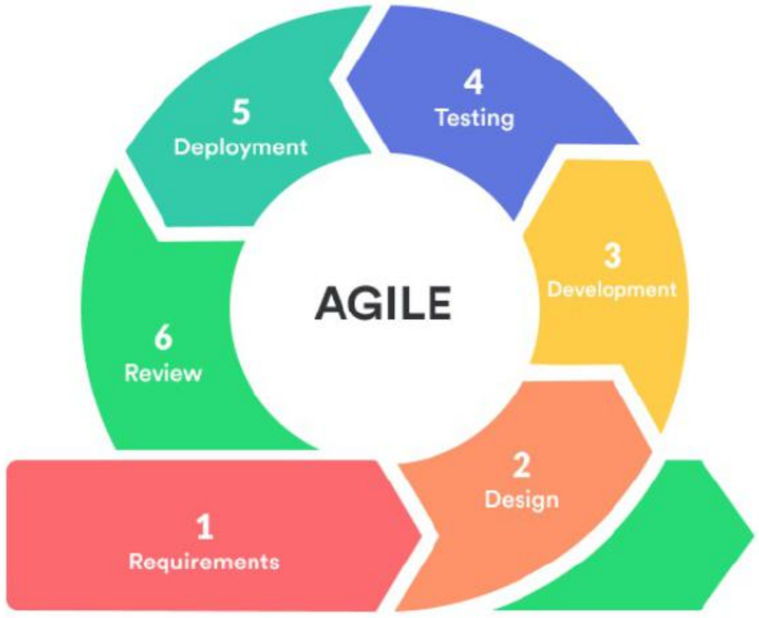
V-Model



- Introduced to overcome the limitations of the Waterfall model.
- Development and test proceed strictly in parallel with benefits in terms of time and cost.
- The result of each phase is properly checked and approved before moving to the next phase.
- Pros: clear structure, defect detection at each phase, good requirements clarity, disciplined process, ideal for small/medium projects, strong documentation.
- Cons: inflexibility, poor adaptability to changes, impossibility to address early-stage issues until the end of the process, high dependency on detailed requirements, unsuitable for large or agile projects, late testing risks.

AGILE model

- Widely used in SW development due to its flexibility and iterative nature.
- Pros: flexibility, adaptability, customer collaboration, faster delivery, potential improved quality, motivated teams, reduced risk.
- Cons: scope creep, lack of documentation, high customer involvement, uncertain end dates, team expertise influence quality and productivity, and less predictability.

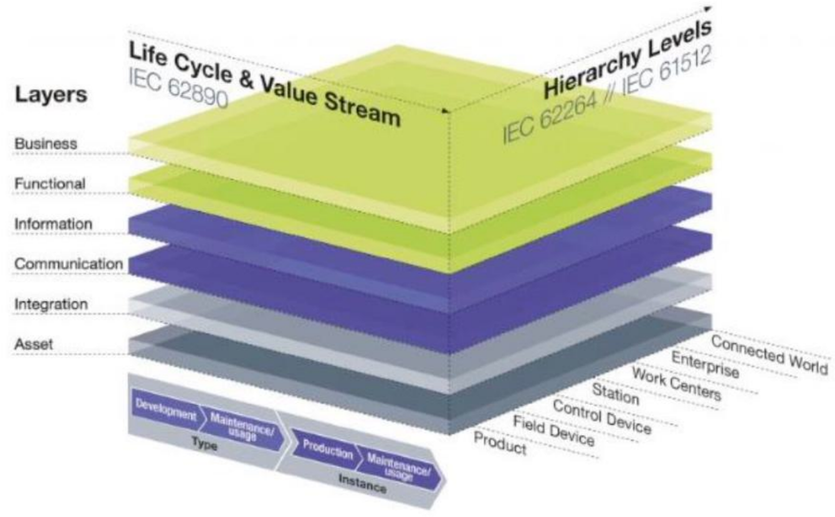


Industry oriented models

- The current SOTA for the EP is based on ISA 95 architecture and engineering standards like, e.g., IEC 81346, CAEX, ISO 15926 and IEC 62424 ... But there are many models:
  - Smart Manufacturing ecosystem developed by NIST
  - Industrial Internet Reference Architecture (IIRA).
  - IBM Industry 4.0 Architecture.
  - Reference Architecture Model Industrie 4.0 (RAMI 4.0).
- Models require the inclusion of stakeholders in ecosystems.
- This inclusion requires data sharing among different local automation systems owned by different legal bodies, which are possibly located in different countries under their legal systems.
- Sharing data enables the optimisation of productivity,which is the basic motivation for automation.

Rami 4.0

- 3D map covering the most important aspects of manufacturing in Industry 4.0:
  - Hierarchy Levels: axis based on the IEC 62264 Enterprise control system integration.
  - Life-Cycle and Value Stream: axis representing the life-cycle of product/solution, which is based on IEC 62890 Life-Cycle Management.
  - Layers: vertical axis describing the decomposition of product/solution in a way to enable its virtual mapping (Business, Functional, Information, Communication, Integration, and Asset)



- Pros: structured approach, interoperability, scalability, standardization, end-to-end integration, life cycle management, supports smart manufacturing.
- Cons: complexity in implementation, high initial costs, requires skilled workforce, fragmented standards, lengthy implementation, limited adoption, maintenance complexity.

EP models analysis

- They don't follow a SOA model.
- They do not specify how EP resources, can be composed, shared, and utilized on-demand and throughout value networks of collaborating and competing stakeholders.
- Mechanisms for dynamic and decentralised mapping of EP resources are not defined.
- They don't specify how humans interact with the emerging technologies (i.e., human-machine symbiosis) and don't address training.
- No continuous engineering support.
- Except for RAMI 4.0, they don't consider the supply/value chain. Mostly focused on the business-to-business use cases.
- They were not conceived to address the complexity of CPS, IoT and SoS.
- There isn't a universal model.

A new model for the EP

The EP must ensure the same levels of flexibility and automation of the technologies engineered with itself (e.g. CPS, IoT, SoS, etc.), across all the phases of their lifecycle.

- The rigidity of today's approaches to automation, based on standards, such as the ISA-95 architecture [56], represents a substantial limiting factor.
- More recent standards, such as RAMI 4.0 and IIRA, attempt to address the issue of engineering process flexibility but do not support it when moving from pure automation to the automation of the digitalisation process.
- Stakeholders and training must be considered.

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A new model for the Engineering process

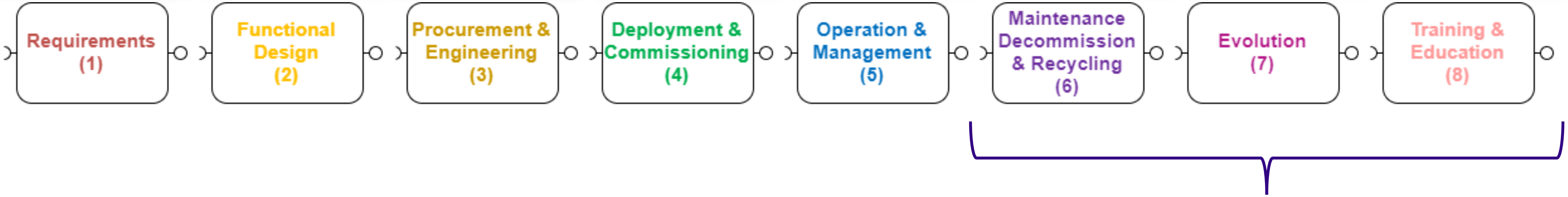
The new model objectives

1. Extend the EP from design time to run time engineering, i.e., the lifecycle continuous engineering.
2. The shift from single stakeholders to multiple stakeholders collaborative and integrated EP automation and digitalisation.
3. The capability to handle a substantially increased number of I/O due to much more fine-grained automation.
4. The inclusion of digital education and training activities as an integral part of EP.
5. The reduction of engineering costs obtained through the full digitalisation and management of the CPS life cycle.
6. The adoption of a service-oriented architecture and framework, to simplify, encourage, and promote the use of the new EP model
7. The EP must evolve dynamically to support technology evolution.

The extended EP

- Extend current automation engineering standard IEC 81346.
- Cover as much as possible the entire lifecycle with:
  - Three new phases.
  - Phase reiteration (beyond linearity) and feedback management.
- Adopt a Service Oriented Architecture (SOA) to facilitate interoperability and automation.
- Described with an ontology to facilitate the EP automation
  - Track the interactions between EP phases, toolchains, and related tools, especially in a multistakeholder value chain.
  - The model can be executed!!

The extended EP (2)



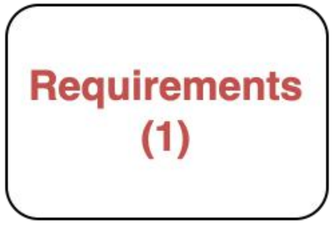
New phases

Better capture the necessities of:

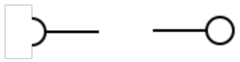
- Continuous engineering during system maintenance to guarantee future system evolution.
- Decommissioning and end of life.
- Personnel preparation.

Production, marketing, or sales, are not directly related to the EP but can be represented in the model as black boxes.

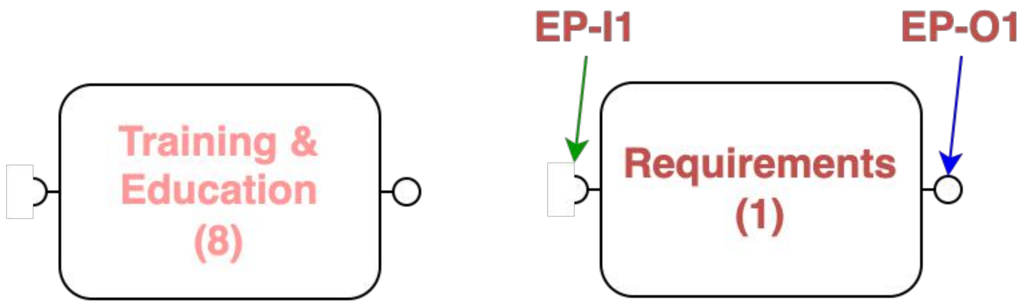
The EP model: some details



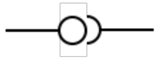
EPP (EP Phase)
Tools and toolchains are associated to EPP



EPI (EP Interfaces)
Input: EPI-I[n]
Output: EPI-O[n]



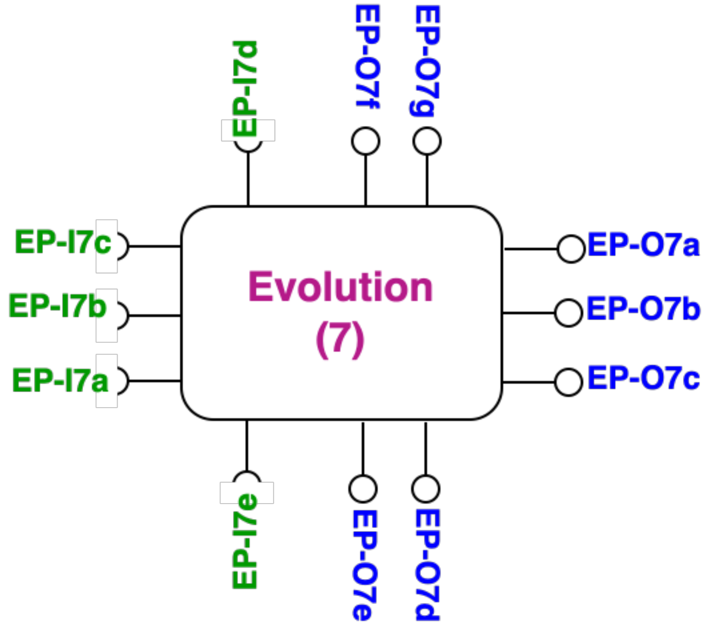
EPU (EP Unit)



EPC (EP Connection)
Enumeration system adopted to assign a unique identifier to each EPI connection (a pair of interfaces)

EPM (EP Mapping) designed to identify the links between the tools and one or more EPUs.

Example of real instance of an EPU



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New model advantages

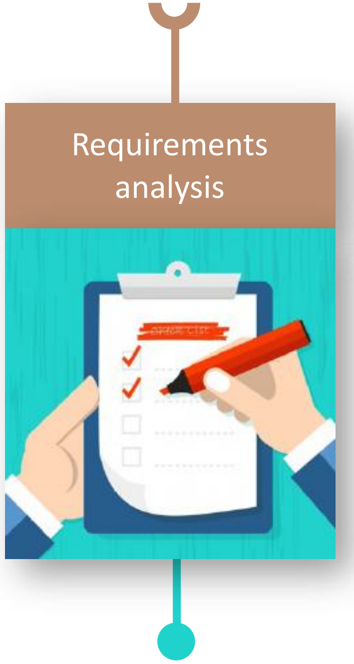
- Increased efficiency in complex multi-stakeholder cooperative EPs (typical of IoT, CPS, SoS).
- Potential reduction of costs for maintenance due to the efficiency of continuous engineering, including validation, deployment, decommissioning, and retirement.
- Potential reduction of costs for bug fixes, updates, and new releases of the system (continuous evolution).
- Increased quality and resilience.
- Increased sustainability and reduced environmental footprint.
- Faster return on investments.

Requirements

The Requirements elicitation phase consists of identifying the CPS requirements from users, customers, and other stakeholders.

- The output of this phase is typically the list of CPS requirements.
- This phase is a good example of EP circularity and non-linearity.

Interviews & input from other phases



Requirements

Functional Design

The Functional Design phase relies on functional design paradigm to simplify the system design.

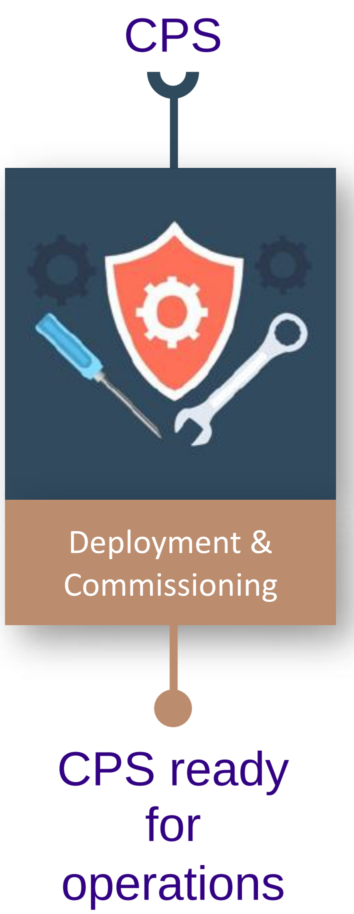
- Functional design ensures that each modular part of the CPS has a precise role and performs that role correctly together with the other parts.
- Functionally designed modules tend to have low coupling and high reuse.
- The output of this phase is typically a model of the CPS, or an architecture, and/or a computer simulation.

Procurement and Engineering

- These phases proceed in parallel and are continuously interacting.
- The Engineering phase, includes the design, development, and testing of the CPS, prototype/POC creation and, after some iterations, the complete CPS.
- The Procurement phase consists of finding and agreeing to terms and acquiring the goods, services, or works required to engineer the CPS and construct or manufacture it from an external source. This phase is used to ensure that the buyer receives goods, services, or works at the best possible price when aspects, such as quality, quantity, time, and location, are compared.
- Strongly linked to Operation/Maintenance phases (e.g. for bug fixing) and Evolution (e.g. to implement improvements, new features, etc.).

Deployment and Commissioning

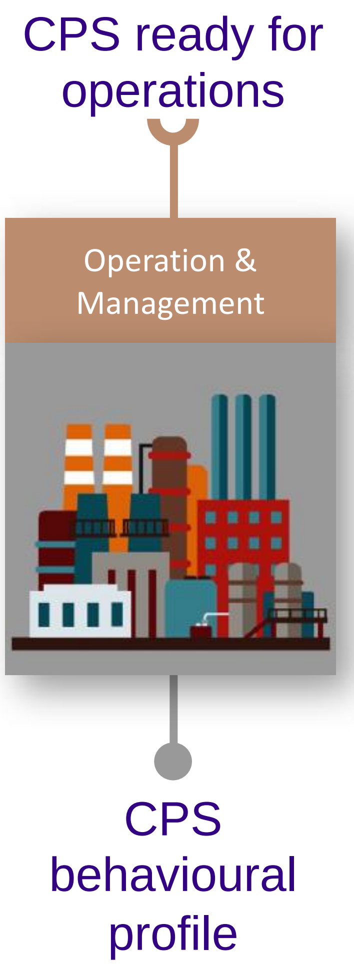
- The Deployment and Commissioning are sequential phases intended to prepare the CPS for operation.
- Deployment: installation and integration of the CPS in a controlled environment or in the final operative environment for testing and debugging purposes, including preliminary verification and validation of the CPS.
- Commissioning: process of ensuring that the CPS is designed, installed, tested, operated, and maintained according to the operational requirements of the owner or the final client.
  - Commissioning may be applied to new projects but also to existing systems subject to renovation, updates (e.g., for maintenance purposes), or expansion (see Evolution phase).



Operations and Management

Consists of operating and managing the CPS according to the operational specification and requirements of the owner or the final client.

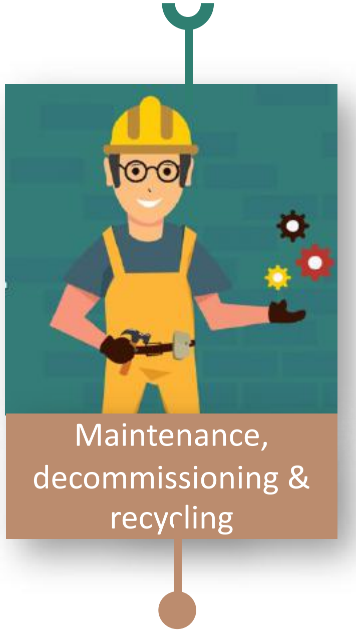
- This is generally the longest phase in the CPS lifecycle.
- The CPS is also monitored remotely to acquire information about its behaviours during operations.
- This information is aggregated and dispatched to the Maintenance and Evolution phases but, if needed, also to other stakeholders in the CPS value chain for further analysis and activities, depending on their role.



Maintenance, Decommissioning & Recycling

- Maintenance: identify and establish the requirements and tasks to be accomplished to achieve, restore, and maintain the operational capability of the CPS across the entire life cycle.
  - Executed concurrently with Operation phase.
  - Addresses bug fixes and minor enhancements, as well as minor adaptations to the standards, new features, software updates, and troubleshooting. In contrast, considerable changes in the system are identified and planned in the Evolution phase.
- Decommission & Recycle the CPS at the end of its life and its responsible recycling to reduce the impact on the environment.
  - Related concepts: second life, reuse, green ECS, material recycling, sustainability, etc.

CPS behavioural profile



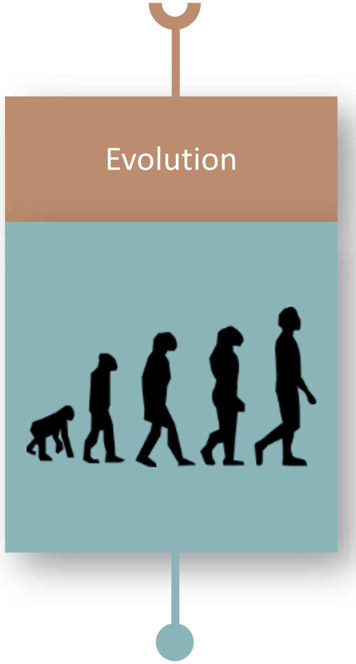
- Feedback to previous phases
- Feedback to Evolution
- Decom. & recycle plan

Evolution

The Evolution phase addresses the inability to predict a priori how user requirements, market, and technology trends will evolve.

- The role of this phase is to monitor these aspects and identify and plan <u>substantial</u> changes in the future version of the CPS, including the CPS's end-of-life.
- This phase must also ensure the <u>continuous improvement</u> of the CPS, always respecting the user requirements and the standards efficiently, reliably, and flexibly.

Feedback from maintenance and previous phases



Evolution plan

Training and Education

- Training and Education include all the educational and professional training activities required by the engineering process across the entire system's life cycle:
  - Initial training, re-skilling, up-skilling, etc.
- This phase is responsible for the development of:
  - instruction and installation manuals,
  - demonstrators,
  - formative courses,
  - and other learning material intended for a large audience that spans from engineering teams to end-users.

Necessities from the entire EP

Training activities, demonstrators and documentation

The non-linearity of the EP

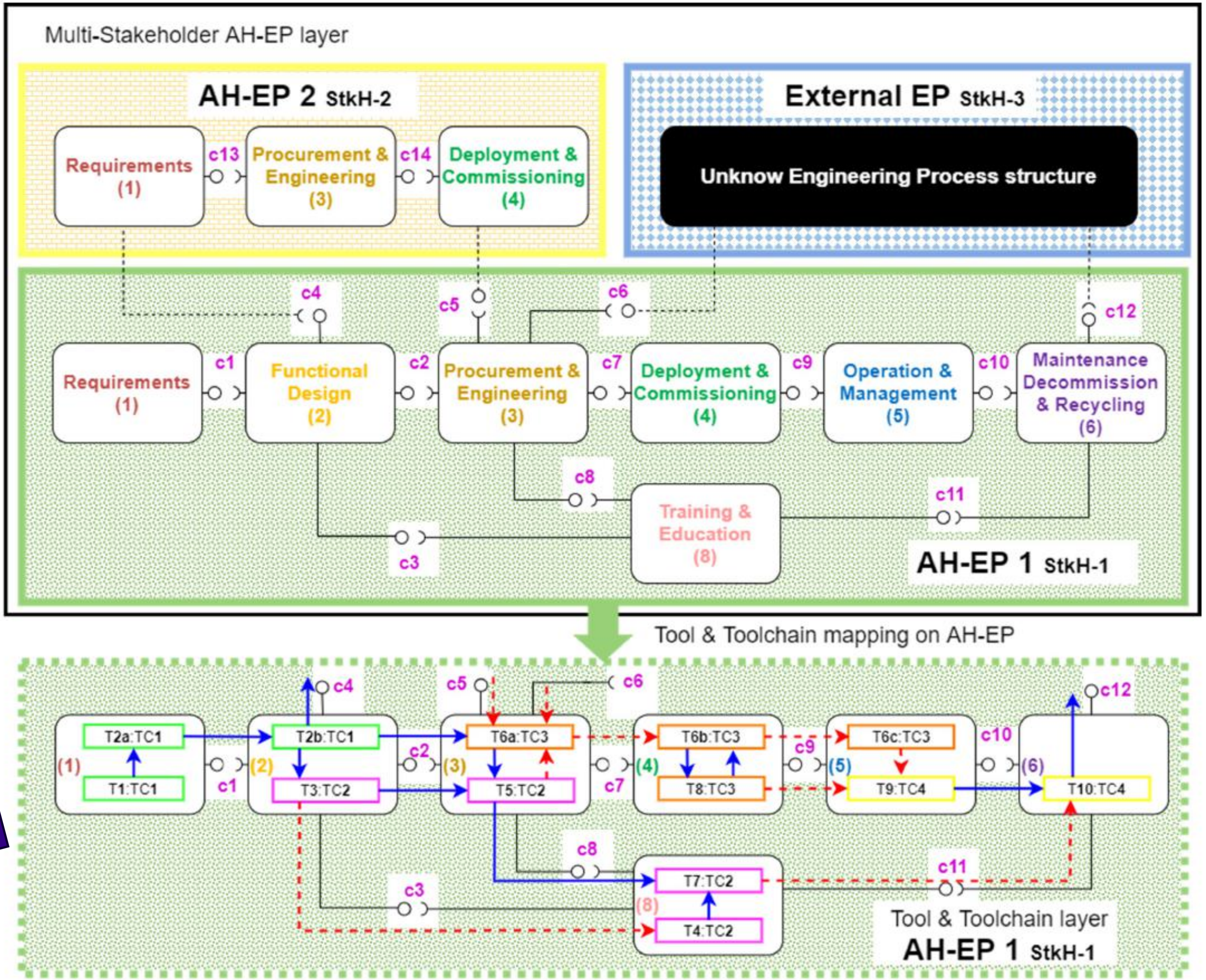
- Like for the Supply/Value chain, the linear representation of the EP is artificial, it is a simplification.
- The EP is not linear:
  - Because it reflects the structure of the value/supply chain.
  - Rarely a single company manages the entire lifecycle of a CPS.
  - CPS are based on multi stakeholder collaborative integrated EP.
  - It is iterative, potentially recursive.
  - It requires continuity, along the entire CPS lifecycle.

Example of model usage

Example of an EP directed graph and tabular notations.

It represents two EPs from two different stakeholders, connected with an unknown EP from a third stakeholder.

Detailed view of tools and tool-chain layer of the AH-EP1 adopted by SthH-1



AH-EP 1 StkH-1

EP-O	EP-I		
EPP1	EPP2		
EPP2	EPP3	EPP8	ex2-EPP1
EPP3	EPP4	EPP8	
EPP4	EPP5		
EPP5	EPP6		
EPP6	EPP3	ex3	
EPP7			
EPP8	EPP6		
ex2-EPP1	ex2-EPP3		
ex2-EPP2			
ex2-EPP3	EPP3		
ex2-EPP4			
ex2-EPP5			
ex2-EPP6			
ex2-EPP7			
ex2-EPP8			
ex3	EPP3		

Example of a real CPS: a Smart Boiler

Benefits of digital transition:

- Connectivity
- Smart functionalities
- Integrated in IoT infrastructure
- Continuous monitoring and product evolution
- Simplify services for the

manufacturer, installer, user

- Reduce management costs

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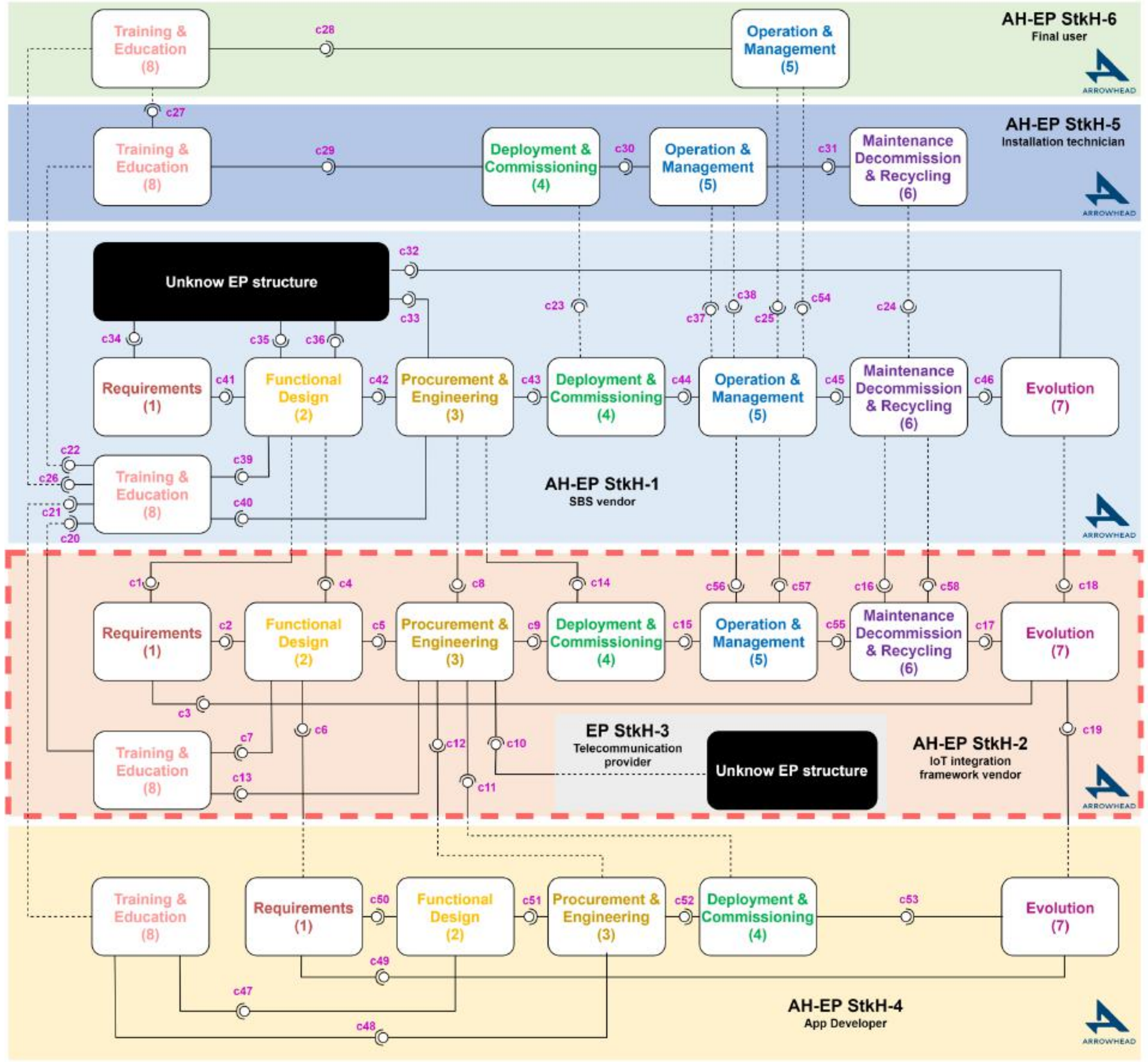
Example of a real CPS: a Smart Boiler (2)

Smart Boiler System (SBS)

- **SthkH1:**
  - Electromechanical parts of the SBS,
  - Deployment and Commissioning,
  - Operations and Management.
- **SthkH2:**
  - SBS ECU,
  - IoT framework running on the ECU,
  - IoT integration platform that manages the entire fleet of SBSs.
- **StkH3:**
  - External service with unknown EP, due to lack of agreement between the stakeholders or due to intellectual property issues.
- **StkH4:**
  - Applications for the maintenance operator and the consumer.
- **StkH5: Installation technician.**
- **StkH6: Final user.**



A model for the Value Chain

A model for the Supply/Value Chain

It is crucial to describe and visualise the entire supply/value chain associated with the CPS in a complete, understandable, efficient and executable way.

- Value Chain Engineering Process map (VCEP-map) allows to:
  - highlight the VC dynamics,
  - the relations between the engineering phases,
  - the tool chains and tools,
  - the relations and synergies between the stakeholders,
  - and the components of the system.
- The VCEP map combined with the EP ontology, provides a 360° view of the CPS and the associated value chain across the entire lifecycle.

A model for the Supply/Value Chain (2)

- A VCEP map is structured in a tabular format, where each stakeholder is identified by a specific colour and a unique ID.
- The columns represent the EP phases
- The rows contain a specific aspect of the value chain:
  - The stakeholders involved in the CPS engineering.
  - Tool-Chains and the Tool-Chains Automation Level (in %).
  - The component of the CPS is mapped on the EP and on the tool-chains that are used during its life cycle.
  - Aggregated info (e.g. the stakeholders that are responsible for designing, developing and operating each system component).
  - The stakeholders and the toolchains used to integrate the CPS.
  - The estimated normalised costs of each EPPs that every stakeholder expects during the life cycle of the CPS, providing an overview of costs distribution.
  - Etc.

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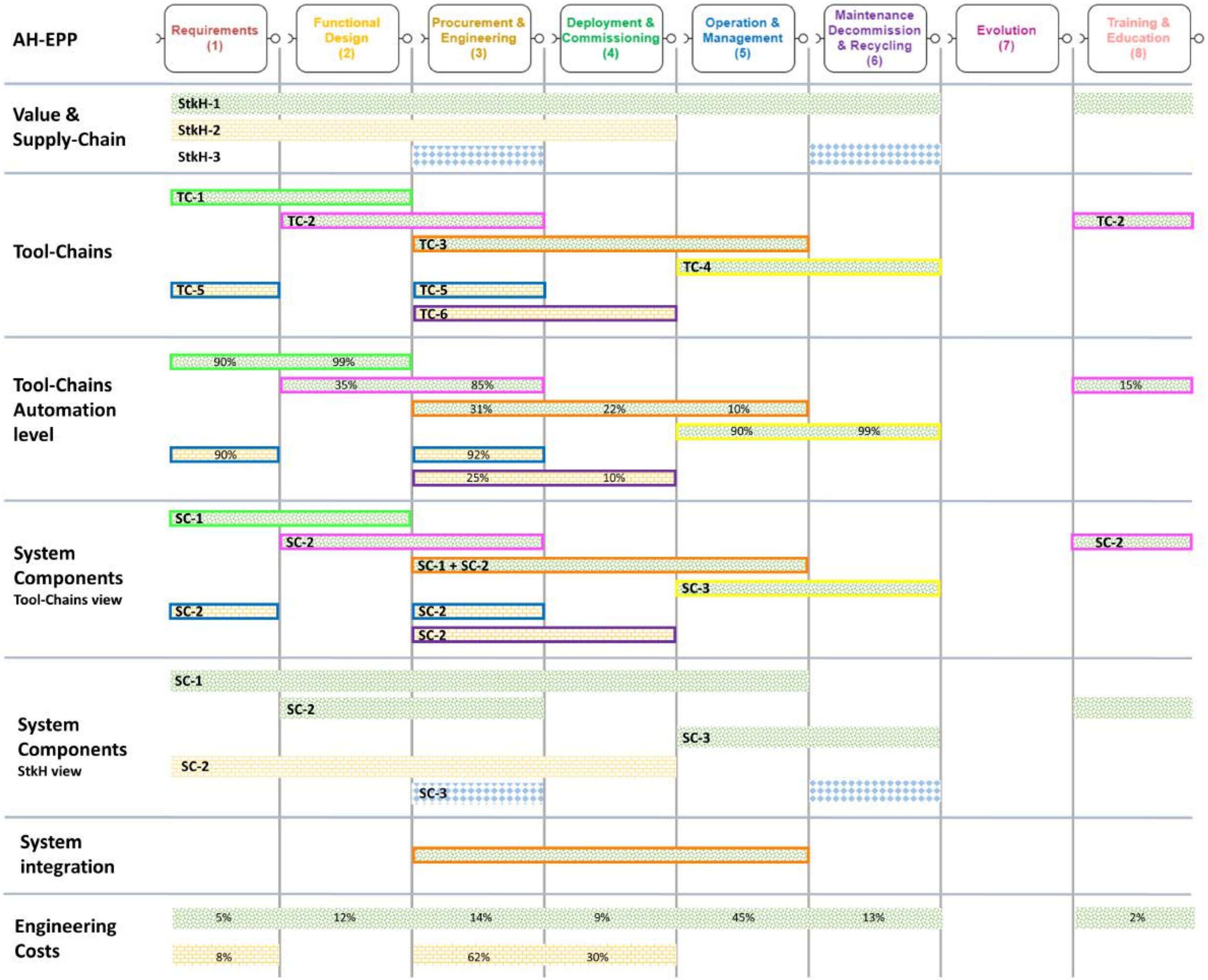
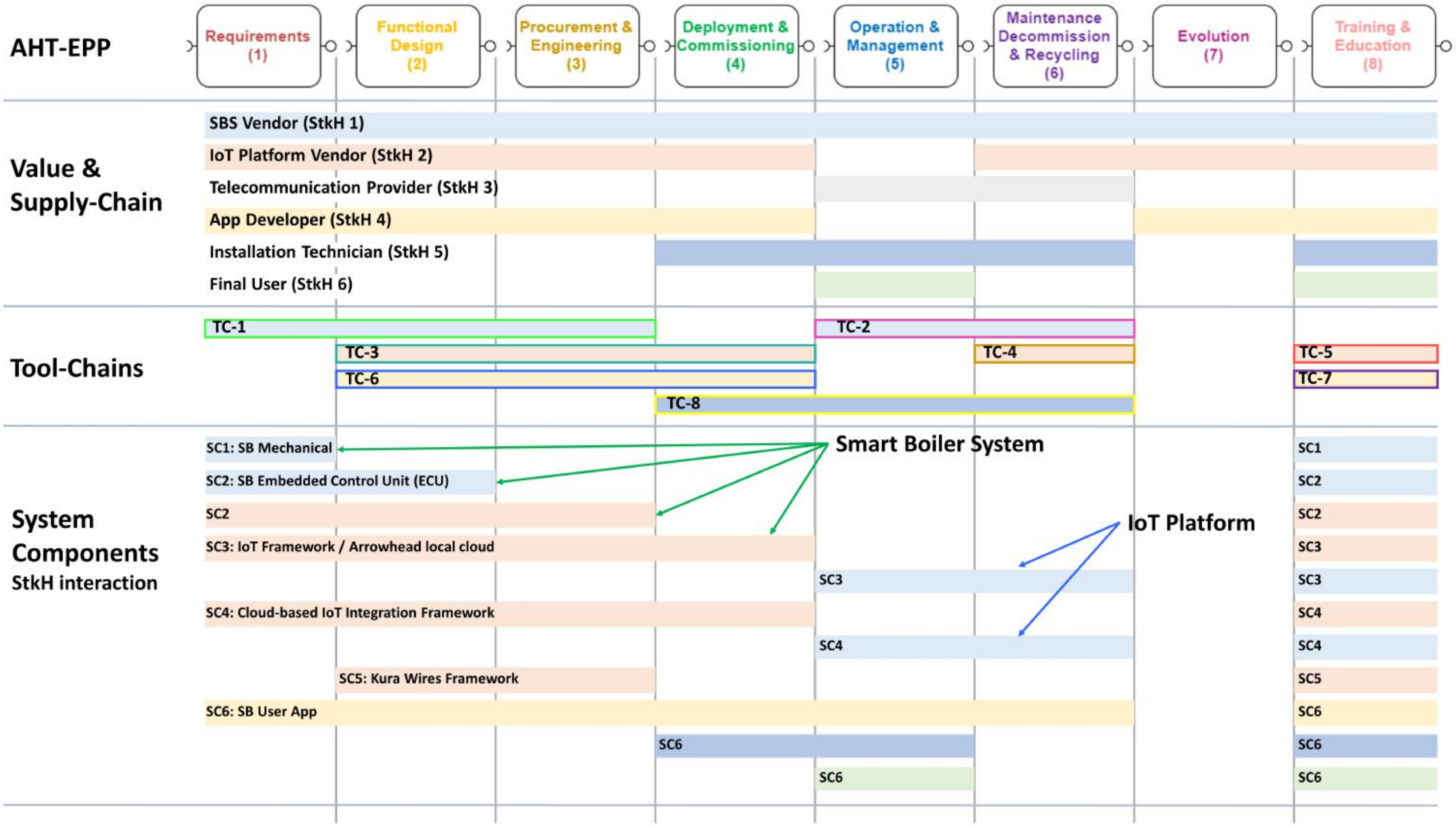
A model for the Supply and Value Chain (3)

RAMI 4.0 is difficult to visualise due to the complexity of its 3D representation.
The linearity and simplicity of the VCEP-map considerably improve the readability of the model, with a potential impact on the EP efficiency and costs.



The Smart Boiler example



Executing the models

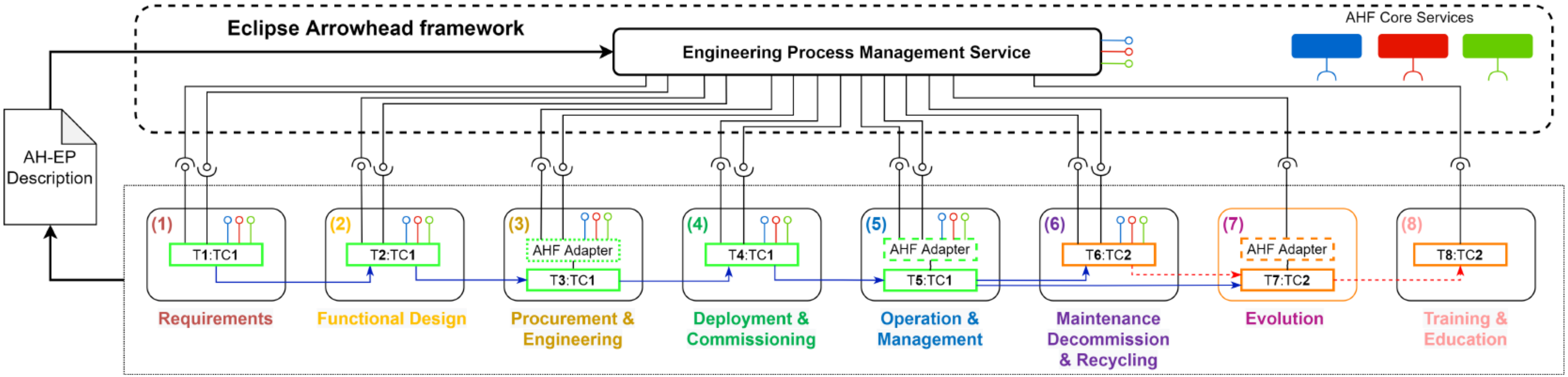
The EP and VCEP Map model can be executed and automated, with ontologies, system modelling languages and SOA!

- System modelling languages (e.g. SySML) potentially makes complex multistakeholder EPs simpler to model, control, and extend, while simplifying their practical management, and improves the efficiency, flexibility, and scalability of the modelling process.
- Starting from the ontology of a specific EP, a service-oriented framework allows the management of the EP and facilitates its automation.
  - For example, the Eclipse Arrowhead framework simplifies the creation and management of the links and dependencies between tool-chains/tools, provides security and authentication support, and facilitates the integration, automation and practical management of the EP in real use cases.

Executing the model (2)

The Engineering Process Management System (EPMS) manages the EP:

- It acts as a scheduler and orchestrator of the EP and is required to monitor the ongoing activities to ensure that the dependencies between phases, stakeholders, tool-chains and tools are respected.
- It is responsible for scheduling and controlling sequential and concurrent EP activities and managing tool inputs and outputs.
- Due to the SOA/microservice architecture of the Eclipse Arrowhead framework, the EPMS can be implemented by adopting a scheduler already available on the market or extending some Eclipse Arrowhead framework (EAf) services.



Business impact

Who is investing in modelling and digitally managing the EP and the supply/value chain?

EDA domain

And other big player like:

…


SYNOPSYS
cadence
Siemens EDA
ANSYS
Empyrean 华大九天
KEYSIGHT TECHNOLOGIES
Altium
ZUKEN
PDF/SOLUTIONS
SILVACO
SMiT 国微集团
PRIMARIUS 概伦电子
Semitronix
XPEEDIC
NineCube
芯华章
ARCAS
cogenda
立芯科技
IC manage
FRACTAL
DJEL
metrics
JEDAT
MunEDA
SILICON FRONTLINE

References

Some references

- ISA95, Enterprise-Control System Integration. ISA.
- Peter Adolphs et al. “Reference architecture model industrie 4.0 (rami4. 0)”. In: ZVEI and VDI, Status report 2015.
- ISO/IEC 81346-1:2009, Industrial systems, installations and equipment and industrial products Structuring principles and reference designations. ISO/IEC.
- International Electrotechnical Commission et al. “IEC 81346-1, In- dustrial systems, installations and equipment and industrial products – Structuring principles and reference designations – Part 1: Basic rules”. In: IEC Standard 81346 (2009).
- Urgese, G.; Azzoni, P.; van Deventer, J.; Delsing, J.; Macii, E. An Engineering Process model for managing a digitalised life-cycle of products in the Industry 4.0. In Proceedings of the IEEE NOMS Workshop on Management for Industry 4.0, Budapest, Hungary, 20–24 April 2020.
- Urgese, G.; Azzoni, P.; van Deventer, J.; Delsing, J.; Macii, A.; Macii, E. A SOA-Based Engineering Process Model for the Life Cycle Management of System-of-Systems in Industry 4.0. Appl. Sci. 2022, 12, 7730. https://doi.org/10.3390/app12157730

Thank you
for watching

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