Alliance for AI, IoT and Edge Continuum Innovation

Cloud-Edge-IoT Continuum: opportunities and challenges for the Manufacturing Industry

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Executive Summary

This paper of the vertical **AIOTI WG Manufacturing** aims to analyse the current European landscape in edge computing, cloud, and the Internet of Things (IoT) using the CEI (Cloud Edge IoT) continuum strategic vision.

The objective is to explore how the convergence of CEI technologies in an edge-to-cloud continuum can facilitate their integration and adoption in the European manufacturing sector. The paper provides an overview of ongoing Horizon Europe research and innovation projects and initiatives in this area, highlighting the advantages of the CEI approach, particularly its ability to foster seamless information flow across the cloud-edge continuum via IoT communication and networking systems.

The CEI vision emphasises a synergistic relationship between cloud and edge computing, leveraging IoT systems to ensure an efficient and adaptive information exchange. This approach is crucial for the European manufacturing sector, which faces challenges such as increased demand for flexibility, resilience, and environmental sustainability. By integrating CEI principles, manufacturers can better respond to dynamic market demands, improve operational efficiency, and reduce costs.

Key to this integration is the concept of a continuum between cloud and edge. This continuum enables real-time processing at the edge while maintaining centralised cloud resources for broader analytics and storage. This balance optimises resource allocation, reduces latency, and minimises data transfer, particularly relevant for resource-intensive industries. The European Union's Horizon Europe framework research programme has been instrumental in driving innovation in edge computing, cloud, and IoT. This paper examines Horizon Europe projects to identify trends, best practices, and areas of focus that align with the CEI vision.

An analysis of opportunities and challenges for the full adoption and impact assessment of CEI Continuum technologies in manufacturing has been made through an online survey. This analysis is intended as a starting point for an open and constructive dialogue on how CEI can support the European manufacturing sector. By identifying best practices, advantages, challenges, and opportunities, we aim to provide stakeholders with a roadmap for adopting CEI principles. This discussion is essential for ensuring that Europe remains at the forefront of technological innovation and contributes to economic growth, environmental stewardship, and societal well-being in the years to come.

The survey aimed to gather insights into the opportunities and challenges presented by the Cloud-Edge-IoT (CEI) Continuum in the manufacturing industry. The increasing adoption of advanced technologies focuses on enhancing efficiency, sustainability, and human-centric processes within Industry 4.0 and Industry 5.0 scenarios.

In advanced manufacturing, we explored key areas such as **Smart Factory Automation**, **Smart Product Lifecycle**, **Smart Supply Chains**, and **Industry 5.0,** investigating how CEI technologies can improve production quality, enable predictive maintenance, and enhance supply chain agility. Additionally, we examined the role of these technologies in promoting sustainable manufacturing practices, fostering human-machine collaboration, and building resilience to internal and external disruptions.

At the end, the paper provides conclusions and outlook that can serve as the basis for future discussions and proposals with the manufacturing industry.

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1. Introduction

1.1 The EUCloudedgeIoT Initiative

The EUCloudEdgeIoT Initiative is EU funded project that initiative aims to realise a pathway for the understanding and development of the **Cloud, Edge and IoT (CEI)** Continuum by promoting cooperation between a wide range of research projects, developers and suppliers, business users and potential adopters of this new technological paradigm.

Cloud and edge computing are essential technologies in a computing continuum to ensure data is managed more efficiently – closer to the originating source rather than transmitting raw data to data centres. As recent studies suggest, data processing is moving closer to the edge. Thus, advancing the IoT can reduce communication and storage costs and energy consumption and produce benefits for citizens and businesses thanks to the integration of AI and Machine Learning. These trends call for a shift towards the technical and business convergence of the so-far formally separated Cloud, Edge and IoT domains.

Emerging **Cloud, Edge and IoT** computing technologies can help an increasing number of businesses to optimise their systems by shifting data processing to the sources rather than depending on remote endpoints. CEI technologies also ensure quicker and smoother data access, avoiding speed and connectivity issues, thus improving user experience and reducing hindrances. Moreover, their decentralised systems enhance data security and reduce operational costs due to the minimal need to move data to the cloud.

Cloud, Edge and IoT technologies are critical for Europe's future in different domains, leveraging low latency responses that can positively impact several domains – from energy infrastructures to national security to healthcare and economics in larger terms. These technologies also play an essential role in achieving sustainability goals in both rural and urban contexts. From an industrial perspective, the cloud, edge and IoT convergence creates a wide range of opportunities for different companies by significantly improving network latency and traffic.

However, because this is still a relatively fragmented market with no dominant player, EU policies can influence its future shape. Currently, Europe is a strong leader in some technology fields (e.g. Telecom Network Technologies), but it lags in others, such as semiconductor chip production. In both instances, policies (or the lack of such) have played a central role in determining the success of these technologies.

EUCloudedgeIoT.eu will try to help business users, industrial associations, tech providers and tech developers, research and innovation organisations, and policymakers access the benefits of CEI enhancing supply-demand dialogue and collaboration.

It will also provide value added services for citizens in areas like health (e.g., improving at-home medical monitoring, providing healthcare services in remote or rural areas), mobility (e.g., car performance monitoring, autonomous driving), and retail (e.g. identification, reduction and prevention of out-of-stock, supply chain traceability to be informed about food origin and quality).

Open Source Software (OSS) is already at the core of modern Cloud Computing and Big Data infrastructure and is rapidly gaining ground at all levels of the Internet of Things. From a European perspective, a solid consensus (now corroborated by systematic studies and official EC policy directions) has formed around the critical role of OSS and Open Source Hardware for multiple European objectives, from GDP growth to digital autonomy.

In light of the ongoing cloud, edge, and IoT convergence towards a computing continuum and the objectives of the Digital Decade, an open ecosystem spanning from Cloud to Edge to IoT is key to unleashing the potential of the European industry in driving green and digital transformation while preserving EU strategic autonomy. The **EUCloudEdgeIoT.eu** initiative will promote the establishment of a global and open ecosystem for the Cloud-Edge-IoT technologies by supporting industries and researchers to create impact, promoting the link between open source and open standards, and engaging relevant industrial alliances in actions directed toward open approaches.

EUCloudEdgeIoT.eu will act as an enabling force, serving and empowering the community towards reaching multiple key outcomes, including a baseline common open architecture for computing continuum research projects, a reinforced collaboration between European public and private initiatives from cloud to edge to IoT, and increased awareness of the importance of Open Source and standards for EU digital autonomy. These contributions, arising from project results, will evolve towards larger-scale impacts and strategic objectives for European technological, economic, and societal advancement.

Standards are a critical challenge for Europe as they enable the development of fast, affordable, and interoperable smart solutions. Improving existing standards and creating open standards is crucial also to the development of a computing continuum, relying on communication infrastructures, IoT and edge computing platforms.

EUCloudEdgeIoT.eu will engage in standardisation efforts and initiatives by investigating approaches to contribute to standards through associated open-source implementations and by supporting computing continuum research projects on pre-standardisation and standardisation initiatives.

1.2 The Made in Europe SRIA

Made in Europe is the manufacturing partnership with the European Commission under the Framework Programme Horizon 2021-2027.

In May 2019, a Made in Europe Partnership draft proposal was tabled and is since then been discussed between the relevant bodies involved, namely the European Commission, Member States and EFFRA.

To better define the possible scope and ambition of the Partnership, the Made in Europe guidance document and the Strategic Research and Innovation Agenda (SRIA) have been prepared by EFFRA in cooperation with the European Commission. The document reflects the need for and the ambition of this new manufacturing partnership.

The Made In Europe partnership will be the voice and driver for sustainable manufacturing in Europe based on joined expertise and resources. It will boost European manufacturing ecosystems towards global leadership in technology, towards circular industries and flexibility. The Partnership will contribute to a competitive, green, digital, resilient and human-centric manufacturing industry in Europe. It will be at the centre of a twin ecological and digital transition, being both a driver and subject to these changes.

In the meantime the first Made in Europe projects have started. You can find these here on the EFFRA Innovation Portal.

The Made in Europe calls 2023 and 2024 have been adopted in November 2022. You can find more information here.

More information about the Made In Europe Partnership and its Strategic Research & Innovation Agenda is here.

Factories 4.0 and Beyond (baseline for the FoF work programme 2018-19-20)

"Factories 4.0 and Beyond"[1] is at the heart of EFFRA's strategic discussions with the European Commission on the key priorities and headlines for the 'Factories of the Future' work programme 2018-19-20.

The key priorities and research headlines described in 'Factories 4.0 and Beyond' are based upon the 'Factories of the Future' vision laid out in the 'Factories of the Future 2020' roadmap.

'Factories 4.0 and Beyond' provides an update of 'Factories of the Future 2020' by taking into account the increasing impact of advanced ICT technologies in manufacturing in synergy with advanced material processing technologies and mechatronics systems.

- 'Factories 4.0 and Beyond' identifies five key priorities focus areas and targets which EFFRA proposes for the 'Factories of the Future' work programme 2018-19-20:
- Agile value networks: Lot-size one–distributed manufacturing.
- Excellence in manufacturing: Advanced manufacturing processes and services for zero-defect and innovative processes and products.
- The human factor: Developing human competences in synergy with technological progress.
- Sustainable value networks: Manufacturing driving the circular economy.
- Inter-operable digital manufacturing platforms: Supporting an ecosystem of manufacturing services.

Factories of the Future 2020

The 'Factories of the Future' public-private partnership (PPP) under Horizon 2020[2] is centred on the priorities of 'Factories of the Future 2020', an ambitious and far-sighted strategic multi-annual research roadmap produced by EFFRA.

'Factories of the Future 2020' is the basis for research call topics and the overall direction of research in the 'Factories of the Future' public-private partnership under Horizon 2020.

The roadmap was developed over a period of 24 months though working meetings including discussions with the European Commission within the 'Factories of the Future' public-private partnership Ad-hoc Industrial Advisory Group (AIAG) and close consultations with representatives of companies and RTOs organised in other related European technology platforms.

Research Priorities

Against a background of mega-trends (such as globalisation, resource scarcity and the global knowledge society) and following the Manufacturing 2030 vision, European manufacturing sectors need to undergo innovation-driven transformations.

[1] https://effra.eu/wp-content/uploads/2023/12/factories40_beyond_v31_public-1.pdf

[2] https://effra.eu/wp-content/uploads/2023/12/factories_of_the_future_2020_roadmap.pdf

The 'Factories of the Future' PPP identifies and realises these transformations by pursuing a set of research priorities along the following research and innovation domains:

- Advanced manufacturing processes
- Adaptive and smart manufacturing systems
- Digital, virtual and resource-efficient factories
- Collaborative and mobile enterprises
- Human-centred manufacturing
- Customer-focused manufacturing

Each of these domains embodies a particular aspect of the required transformations towards the factories of the future.

Challenges and Opportunities

- The research and innovation activities undertaken within the domains will focus on a concrete and measurable set of targets, described as manufacturing challenges and opportunities:
- Manufacturing the products of the future: Addressing the ever changing needs of society and offering the potential of opening new markets
- Economic sustainability of manufacturing: Combining high-performance and quality with cost-effective productivity, realising reconfigurable, adaptive and evolving factories capable of small scale production in an economically viable way
- Social sustainability of manufacturing: Integrating human skills with technology
- Environmental sustainability of manufacturing: Reducing resource consumption and waste generation

Addressing these challenges and opportunities is at the core of what the Factories of the Future PPP is determined to achieve.

Technologies and Enablers

Achieving the identified transformations requires a coordinated research and innovation effort, where manufacturing challenges and opportunities are addressed by deploying technologies and enablers identified as advanced manufacturing processes and technologies, mechatronics for advanced manufacturing systems, ICT, manufacturing strategies, knowledge-workers and modelling, simulation and forecasting methods and tools.

1.3 CEI market landscape overview in manufacturing

The European market for technologies and solutions in the cloud-edge-IoT computing continuum is emerging strongly. Most companies across the European economy are familiar with these technologies and are either using or planning to use them. The primary benefits they seek from CEI investments are productivity and efficiency, though companies also expect CEI to enable a range of other benefits, such as improved product quality, new products and services, and improved customer experience. Yet CEI deployments remain challenging, as companies struggle with the complexity of CEI solutions, as well as high costs and concerns about ensuring security.[3] Nonetheless, the strong adoption rates have generated significant investment among European companies. IDC estimates that European spending on CEI in 2024 will amount to hundreds of billions of euros, and the market will continue to grow at a double-digit growth rate to 2028.[4]

Manufacturing is one of the industries with the most to gain from deployment of CEI technologies and solutions. The integration of these technologies is transforming the manufacturing sector, driving significant improvements in efficiency, productivity, and innovation. For example, IoT devices and edge computing enable real-time monitoring and optimization of manufacturing processes, enabling significant gains in efficiency and productivity. CEI solutions can also predict equipment failures before they occur, reducing downtime and maintenance costs. And they can help in maintaining high product quality by providing real-time data and analytics, which can be used to detect and correct defects early in the production process. Cumulatively, CEI technologies are a crucial part of the Industry 4.0 revolution, which focuses on the digital transformation of manufacturing. This includes the use of advanced technologies like artificial intelligence, robotics, 5G and augmented reality to create smart factories.

Manufacturers are already among the leaders in embracing CEI technologies. In 2024, European manufacturers will spend EUR 8.7 billion on edge computing, EUR 30.8 billion on cloud, and EUR 66.0 billion on IoT (source: IDC; note: IoT solutions incorporate cloud and edge spending, so there is overlap between the categories).

Figure 1 European Spending by Manufacturers on CEI Technologies and Solutions[5]

Among the broad CEI categories, cloud computing usage is highest, with 42% using it extensively, according to the results of Unlock-CEI project[6]. IoT usage trails that of cloud, though adoption levels are high (25% using extensively, and another 31% using to a limited extent) and rising rapidly (21% claimed they plan to start using it). Edge usage is the least mature, though 38% of respondents said they are using it at least to a limited extent, and another 27% said they intend to start using it within two years. (see **Figure 2**)

[3] Updated report of CEI demand landscape (https://zenodo.org/records/8107103)

[4] IDC's Worldwide Cloud, Edge and IoT Spending Guides, May 2024

[5] Source: IDC's Worldwide Cloud, Edge and IoT Spending Guides, May 2024.

[6] Updated report of CEI demand landscape (https://zenodo.org/records/8107103)

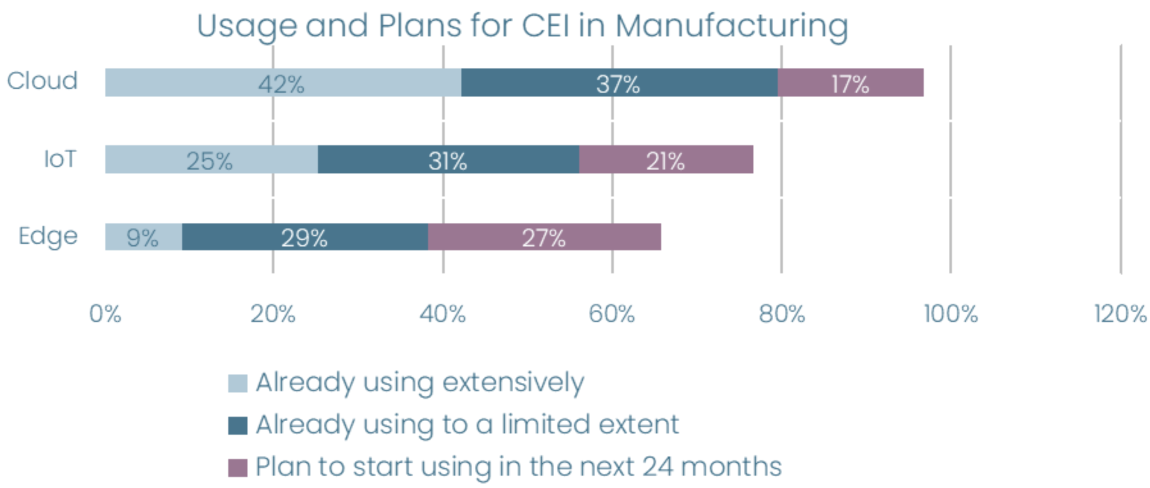


Figure 2 Usage of CEI Among European Manufacturers[7]

By comparison to other industries, manufacturers are relatively advanced in their usage of edge computing. Healthcare organizations are more likely to be using edge extensively, but manufacturers also have above-average usage, while energy, transport, and agriculture companies are lagging behind.

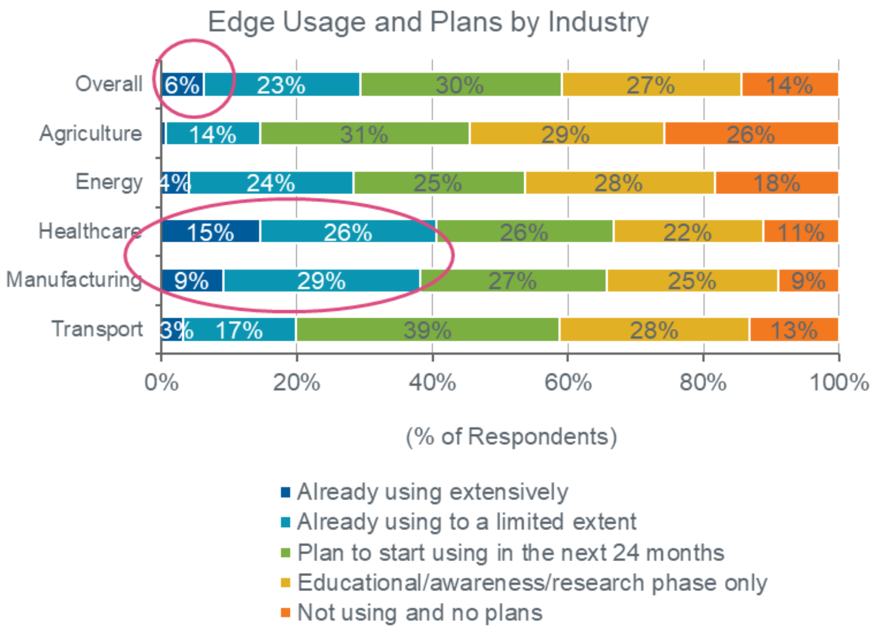


Figure 3 Usage of Edge Computing Among European Companies by Industry[8]

[7] Source: UNLOCK CEI Survey, March 2023
[8] Source: UNLOCK CEI Survey, March 2023

Manufacturers are embracing the CEI continuum for a variety of reasons. Most commonly, manufacturers aim to achieve **productivity and efficiency gains**. These can be achieved, for example, through reduced energy usage, reduced waste, reduced downtime of assets, reduced maintenance costs and increased automation. Many companies also cite a desire for better customer experience, improved product quality and better decision-making.

Manufacturers choose to use cloud computing, edge computing, or both, based on several factors. Key benefits of cloud computing include a view held by many companies that the cloud can deliver greater security than is feasible for internal IT teams, as well as the ability to quickly build and test new ideas, flexibility and reliability.

On the other hand, **edge computing limits the need for data to travel** far and wide across the network, thereby increasing security and compliance. Edge also enables deployment of AI analytics models close to end devices, and it reduces network traffic and energy usage. It is also crucial for selected use cases that require very low latency.

As the CEI continuum continues to develop, use cases are maturing and becoming more sophisticated, leveraging advanced technologies, such as AI and 5G, to deliver greater functionality and automation. Many such projects increasingly require distributed computing resources at the edge of the network, either close to the end devices or on-board those devices.

By putting computing resources at or close to the edge, companies aim to address a variety of issues, and these benefits often differ by industry. Manufacturers most often cited the benefits of increased security, the ability to deploy AI models close to end devices, reduced data volumes sent across the network, very low latency, and overcoming unreliable connectivity. In fact, of all industries, manufacturers were most likely to note issue of putting AI models close to end devices.

The priorities for manufacturers differ slightly from those of other industries. Manufacturer priorities reflect their usage of **large amounts of operations technology in concentrated areas** that is increasingly being automated. That situation lends itself to using edge computing close to those systems. Much of that computing may be on premises or nearby, with some of it also on the devices.

By contrast, energy and transport companies are much more likely to have assets that are widely distributed. Their assets likely need edge computing on the device, because those devices are likely to be distant and isolated. The clear top benefit cited by these industries was increased security, because data is not traveling across the network.

For agriculture companies, which operate in rural areas where mobile network coverage is often poor, the top benefit of edge computing is that it overcomes unreliable connectivity.

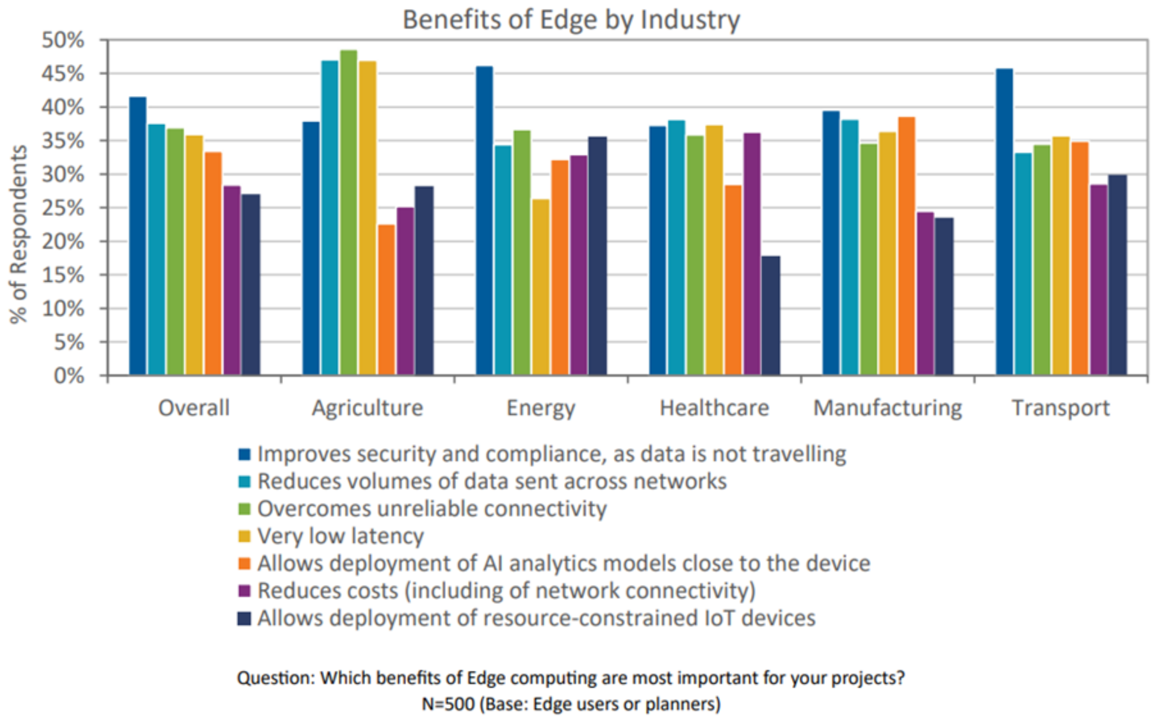


Figure 4 Benefits of Edge According to European Companies by Industry[9]

Manufacturers are embracing a range of use cases that leverage the CEI continuum. These include asset monitoring, predictive maintenance, autonomic operations, employee safety, fleet tracking, visual inspection, regulatory compliance, physical security, building automation and many others.

Each use case provides its own benefits and requires its own solution and infrastructure design. For example:

Asset monitoring with predictive maintenance

- Description: IoT systems can monitor asset conditions, such as temperature, vibration, pressure, etc., to provide real-time visibility, identify changes or problems, and initiate maintenance

- Benefits: Equipment is monitored more effectively, maintenance is optimized, and such systems can be integrated with other operations and IT for better efficiency and automation. More efficient monitoring and maintenance, reduced downtime, and better decision-making and increased automation

- Computing infrastructure: Basic computing power may be close to the edge, but such solutions send modest data volumes and are less latency-sensitive, allowing much of the compute in the cloud.

[9] Source: UNLOCK CEI Survey, March 2023

Autonomic operations

- Description: Real-time assessment of current demand and capacity availability, enabling the automated resequencing of work on the factory floor

- Benefits: The factory functions on its own based on a multitude of data collected through sensors and analysed through cognitive computing systems, resulting in lower energy costs, attainment of sustainability goals, optimization of resources, higher throughput levels due to lower factory unit costs, and lower capital requirements

- Computing infrastructure: To run such critical systems, ultra-low latency is needed, which results in significant use of edge computing, though such solutions also utilize the cloud for less time-sensitive analysis

Autonomously guided vehicles (AGVs) and robots

- Description: AGVs and robots enable automation of many processes. AGVs can transport items throughout the facilities without requiring a worker's attention, before robots use them in production

- Benefits: Reduced labour, reduced accidents, fewer interruptions, greater precision, increased safety, and increased efficiency due to the right parts getting to the right places as needed and being utilised precisely

- Computing infrastructure: AGVs and robots require significant computing resources on the device for basic navigation, manipulation and accuracy, and to avoid sending unnecessarily large data volumes across the network. Additional edge resources can manage the fleets of assets.

Visual inspections and quality control

- Description: Using cameras and AI-based analytics, many quality control functions may be automated, for example, identifying problems in welds or ensuring the right components are installed.

- Benefits: Increased quality and product safety, greater precision and accuracy, higher efficiency and reduced waste, improved customer experience

- Computing infrastructure: Such systems tend to utilize computer vision, which may include machine-learning models on or near the devices, though in some cases, limited data volumes and modest latency requirements may lead to greater reliance on cloud resources.

The large demand for CEI solutions creates significant opportunities for European suppliers. However, the CEI market remains challenging.

The diverse use cases each require separate solution designs, value chains and business models, making it hard for the industry to achieve scale in the solutions it delivers.

Moreover, these use cases often rely on a suite of technologies that are far from mature, such as AI analytics, robotics, digital twins and 5G.

As a result, solution developers must develop expertise across many advanced new technologies.

Yet the CEI continuum is a critical enabler of the comprehensive digital transformation in the manufacturing space. European technology leaders and the manufacturing industry stand to gain by mastering CEI and deploying CEI solutions at scale.

1.4 Objectives

This paper aims to analyse the current European landscape in the domains of edge computing, cloud, and the Internet of Things (IoT) through the lens of the CEI (Cloud Edge IoT) vision. Our aim is to explore how this perspective can facilitate the integration of advanced technologies into the European manufacturing sector. The study provides an overview of ongoing Horizon research projects and R&D activities in this area, highlighting the advantages of the CEI approach, particularly in fostering seamless information flow across the cloud-edge continuum using IoT communication systems.

The CEI vision emphasises a synergistic relationship between cloud and edge computing, leveraging IoT systems to ensure an efficient and adaptive information exchange. This approach is crucial for the European manufacturing sector, which faces challenges such as increased demand for flexibility, resilience, and environmental sustainability. By integrating CEI principles, manufacturers can better respond to dynamic market demands, improve operational efficiency, and reduce costs.

Key to this integration is the concept of a continuum between cloud and edge. This continuum enables real-time processing at the edge while maintaining centralised cloud resources for broader analytics and storage. This balance optimises resource allocation, reduces latency, and minimises data transfer, which is particularly relevant for resource-intensive industries.

The European Union's Horizon framework has been instrumental in driving innovation in edge computing, cloud, and IoT. This paper examines several Horizon projects to identify trends, best practices, and areas of focus that align with the CEI vision.

By aligning these research efforts with CEI principles, the European manufacturing sector can leverage advanced technologies to achieve greater operational coherence and efficiency.

A significant aspect of this work is exploring how CEI principles contribute to environmental sustainability. The CEI approach encourages the efficient distribution of computational tasks between edge and cloud resources, reducing the energy footprint of data processing and transfer. For instance:

- **Optimised Data Movement**: By processing data closer to its source, edge computing minimises the need for large-scale data transfers to centralised clouds, thereby lowering energy consumption and associated costs.

- **Energy-Efficient Solutions**: Integrating energy-efficient hardware and software solutions at the cloud and edge levels helps reduce industrial operations' overall carbon footprint. These sustainability benefits align with Europe's broader goals of achieving carbon neutrality and resource efficiency, making CEI a compelling choice for the manufacturing sector.

While the CEI approach offers numerous advantages, its implementation is not without challenges. Key issues include:

- **Interoperability**: Achieving seamless communication between diverse devices, platforms, and networks.

- **Scalability**: Ensuring solutions can handle increasing data volumes and processing demands.

- **Standardisation**: Establishing common standards to guide the development and integration of CEI-compatible systems.

However, these challenges also present opportunities for innovation. By addressing these issues, European manufacturers can lead the way in adopting and refining CEI technologies, setting global benchmarks for efficiency and sustainability.

The analysis presented in this paper is intended as a starting point for an open and constructive dialogue on how CEI can support the European manufacturing sector. By identifying best practices, advantages, challenges, and opportunities, we aim to provide stakeholders with a roadmap for adopting CEI principles.

The CEI approach represents a transformative opportunity for the manufacturing sector, enabling it to adapt to emerging challenges while enhancing competitiveness and sustainability. We hope this paper sparks further discussion and collaboration among researchers, policymakers, and industry leaders to realise CEI's full potential in shaping the future of European manufacturing.

This discussion is essential for ensuring that Europe remains at the forefront of technological innovation and contributes to economic growth, environmental stewardship, and societal well-being in the years to come.

2. Horizon Europe Projects in Cloud, Edge and IoT (CEI) for Manufacturing

This Chapter will briefly describe projects that recently implemented and adopted CEI technologies in the Manufacturing domain. In Section 2.1, we will focus on the "technology user" perspective and analyse the Made in Europe partnership projects, while in Section 2.2, we will take the "technology provider" perspective and analyse how manufacturing scenarios could provide challenging needs and requirements for CEI technologies.

2.1 Made in Europe projects: the Manufacturing Industry viewpoint

Looking for mature industrial cases where CEI technologies are adopted, Section 2.1 is analysing the 2021 and 2022 Horizon Europe calls regarding i) Green, flexible and advanced Manufacturing (new manufacturing technologies addressing sustainability – green – and resilience – flexible – requirements); ii) Advanced digital technologies for manufacturing (with particular emphasis on CEI technologies and their applications embedded in production systems or deployed at the edge).

In the **Green, flexible and advanced Manufacturing** call, we collected inputs from **two** twin transition topics in **2021** (**01** AI enhanced Robotic systems 4 projects, **02** Zero-defect Manufacturing 6 projects), and **three** other twin transition topics in **2022** (**01** Reconfigurable process chains 3 projects, **03** Distributed control and modular manufacturing 4 projects, **04** Intelligent work piece handling 4 projects), for a total of **21 projects** analysed, 10 in the 2021 call and 11 in the 2022 call. On 25 November 2024, we ran an interactive workshop (see Section 4.2) where we asked some questions and collected inputs from both 2021 and 2022 calls about relevance of CEI technologies adoption in their **five** domains: robotics, zero-defect, resilient chains, distributed control, workpiece handling. They are collected in Chapter 4.

In the **Advanced digital technologies for manufacturing** call, we collected inputs from **two** twin transition topics in **2021** (**07** AI for sustainable agile manufacturing with ADRA 3 projects, **08** Data-driven industrial environments 3 projects), and **two** other twin transition topics in **2022** (**06** ICT Innovation and I4MS2 4 projects, **07** Digital tools for Circular manufacturing 5 projects), for a total of **15 projects** analysed, 6 in 2021 and 9 in 2022. On 25 November 2024, we ran an interactive workshop where we asked some questions and collected inputs from both 2021 and 2022 calls about relevance of CEI technologies adoption in their **four** domains: sustainable manufacturing, distributed data spaces, manufacturing SMEs, circular manufacturing. They are collected in Chapter 4

2.1.1. Call 2021 Green, flexible and advanced manufacturing

2.1.1.1. [HORIZON-CL4-2021-TWIN-TRANSITION-01-01:] AI enhanced robotics systems for smart manufacturing (AI, Data and Robotics - Made in Europe Partnerships) (IA)

This Innovation Action should seize the opportunities arising from the latest state-of the art-developments in AI and robotics to deploy intelligent and autonomous systems for flexible production.

Under this topic, **4 Innovation Actions have been funded**:

Fluently

The essence of human-robot interaction 101058680. Fluently leverages the latest advancements in AI-driven decision-making process to achieve true social collaboration between humans and machines while matching extremely dynamic manufacturing contexts. The Fluently Smart Interface unit features: 1) interpretation of speech content, speech tone and gestures, automatically translated into robot instructions, making industrial robots accessible to any skill profile; 2) assessment of the operator's state through a dedicated sensors' infrastructure that complements a persistent context awareness to enrich an AI-based behavioural framework in charge of triggering the generation of specific robot strategies; 3) modelling products and production changes in a way they could be recognized, interpreted and matched by robots in cooperation with humans. Robots equipped with Fluently will constantly embrace humans' physical and cognitive loads, but will also learn and build experience with their human teammates to establish a manufacturing practise relying upon quality and wellbeing.

FLUENTLY targets three large scale industrial value chains playing an instrumental role in the present and future manufacturing industry in Europe, that are: 1) lithium cell batteries dismantling and recycling (fully manual); 2) inspection and repairing of aerospace engines (partially automated); 3) laser-based multi-techs for complex metal components manufacturing, from joining and cutting to additive manufacturing and surface functionalization (fully automated in the equipment but strongly dependent upon human process assessment).

CONVERGING

Global economic crises and the COVID19 pandemic have dictated manufacturing firms to rethink their production and business models. Production systems need to adopt both human and automated resources that can work together seamlessly. As a response, CONVERGING aims to Develop, deploy, validate and promote smart and reconfigurable production systems including multiple autonomous agents (collaborative robots, AGVs, humans) that are able to act in diverse production environments.

The diversifying factors will be a multi-level AI based cognition (line, station, resource levels) which will exploit the collective perception (Digital Pipeline) of these resources, allowing them to interact with each other and seamlessly coexist with humans under a "social industrial environment" that ensures trustful, safe and inclusive user experience The project proposes the development of systems that can: 1. Perceive: Identify and recognize processes/resources/environment and their status by introducing Big Data, Real Time Integration & Communication Architecture, Digital Twins and Human in the Loop techniques 2.

Reason: Analyze the production system status and autonomously formulate plan of actions using AI, Planning and Reconfiguration Algorithms as well as Resource Autonomy solutions 3. Adapt: Automatically modify h/w and control systems to execute the formulated plans through the use of Robotics and Autonomous Systems, Smart Devices and Adaptable Mechatronics 4. Collaborate: Seamlessly work with humans or other resources establishing a social industrial environment which exploits Smart Human Machine Collaboration, User experience assessment and User centric workplace design 5. Innovate: Expand its capabilities and Openness via an Open Pilot Network as well as links to local and international innovation ecosystems

CONVERGING will demonstrate its results in the Automotive, Aircraft Production, White Goods and Additive Manufacturing products processing sectors.

AI-PRISM

AI-PRISM is an industrial-end-user driven project that will provide a human-centred AI-based solutions ecosystem targeted to manufacturing scenarios with tasks difficult to automate and where speed and versatility are essential. The result will be an integrated and scalable ecosystem with installation-specific solutions for semi-automated and collaborative manufacturing in flexible production processes and for which specific robotic programming skills will not be required, thanks to its programming-by-demonstration modules.

The ecosystem will be composed by four main pillars including 1) Human Centred Collaborative Robotic Platform, 2) Human Robot Cooperation Ambient, 3) Social Human-Agent-Robots Teams Collaboration and 4) Open Access Network Portal. In order to facilitate the assessment of the performance, transferability, scalability and large-scale deployment of these solutions, the demonstrations will be conducted under real operational environments in four pilot involving key manufacturing sectors - Furniture (ES), Food/Beverage (GR), Built-in Appliances (TR) and Electronics (PL) -, plus one generic demonstration facility (AT).

The project is not just aiming at quantitative improvements in a specific sector, but to use technology innovation to support a change of paradigm where AI, robotics and Social Sciences and Humanities (SSH) integrated in the manufacturing domain for the improvement of flexible production processes, become a feasible and widespread alternative for European factories, especially SMEs. To achieve this, the project relies on a strong consortium of 25 partners from 12 countries including international cooperation with Korea. The consortium brings together all the actors of the Human Robot Collaboration (HRC) value chain including relevant competence centres, technology providers, equipment providers, integrators, and manufacturers/end users; and involves key expert partners in SSH, standardisation, exploitation, and dissemination.

COGNIMAN

Glass fibre production, precision machining of large parts (e.g. wind turbines), additive manufacturing of medical implants and high-temperature metal production are manufacturing examples with processes that are difficult to automate. The main reasons for the actual labour intensive efforts in these scenarios are lack of full understanding and control over the individual manufacturing steps and the high complexity of the tasks. This has severe impacts on sustainable growth, manufacturing productivity, efficiency and flexibility due to the large amount of unpredictive waste in production and processing time.

COGNIMAN is devoted to improving these situations by developing and demonstrating a novel concept of digital cognitive smart manufacturing? that will shift the future design of manufacturing processes towards autonomous and predictive manufacturing with improved flexibility, safety and efficiency. This initiative will provide the means to facilitate flexible, resilient, reconfigurable, safe, sustainable, and efficient smart manufacturing by integrating key technologies.

They include simulations, digital twins, advanced sensors, machine learning toolbox and cognitive robotics integrated in human-centric modular toolboxes that can be easily adapted to substitute varying manual manufacturing processes. By tackling significant challenges COGNIMAN will provide the means to facilitate flexible, resilient, reconfigurable, safe, sustainable, and efficient smart manufacturing by integrating simulation, models, digital twins, sensors, Artificial Intelligence (Machine Learning), data processing and analytics, robotics, and autonomous systems in a human-centric modular toolbox that can be easily adapted to new manufacturing processes and environments with the ultimate objective of boosting the European technology and manufacturing sectors competitiveness towards industrial leadership in global markets, as well as to reduce the environmental footprint of manufacturing activities.

2.1.1.2 HORIZON-CL4-2021-TWIN-TRANSITION-01-02: Zero-defect manufacturing towards zero-waste (Made in Europe Partnership) (IA)

This Innovation Actions should demonstrate **increased sustainable production**, **prevent and monitor defects, reduce waste and cost**, and ensure **efficient use of materials and repair strategies**. They must address the full production line or system, with an holistic approach, and focus on defects that affect the **quality of the final product**. They should also include **life-cycle analyses and environmental assessments**. The projects should integrate control systems and/or in-line non-destructive inspection methods that enable rapid feedback and/or feedforward control. They could also use large data sets and analysis, possibly supported by data-sharing, for machine learning algorithms.

Under this topic, **6 Innovation Actions have been funded**:

ZDZW

Non-destructive Inspection Services for Digitally Enhanced Zero Waste Manufacturing 101057404. ZDZW excels in offering a catalogue of IoT based non-destructive inspection technologies, providing an accurate inline evaluation of key product parameters that have an effect in quality requirements within different technical areas, such as: Part Integrity, Visual Requirements and Thermal Process efficiency. The ZDZW Inspection Solutions follow the concept of Inspection as a service, guaranteeing its cost effectiveness and improved return of investment, offering different types of subscription and pay-per-use models depending on the offered functionalities.

To pursue the main goal of reducing defects and the waste generated in manufacturing processes, ZDZW addresses defects and waste reduction in three key areas that cover the entire manufacturing process and product lifecycle: (i) Monitoring and control improvement for process quality assurance, where first-time-right manufacturing rate can be increased, including improved durability properties and reduced waste generation; (ii) digitally enhanced Rework & Repair procedures for necessary part recovery and scrap reduction; and (iii) Continuous Sustainability evaluation to ensure the efficient use of materials and components across the full production line.

ZDZW is strongly supported by collaboration with relevant EU initiatives such as ZDMP and i4Q, providing components and services that enhance key ICT aspects such as interoperability, interlinking, security, data reliability and digital platforms. ZDZW will demonstrate its ZD and ZW approach in 6 Pilots involving production processes with an important waste reduction potential, such as injection moulding, thermoforming, welding and coating, induction hardening, lithography and packaging, involving key industrial sectors as automotive, home appliances, renewable energy, e-health, and food and beverages.

TURBO

Towards tURbine Blade production with zero waste 101058054. >10000 wind turbine blades (WTBs) were installed in Europe in 2019, and the largest are >100 m long. Yet the manufacturing methods have not changed significantly since the 1970s, with little or no NDT or in-line control, leading to high defect, repair and scrap rates. TURB0 will reduce defects and improve repair strategies in WTB composites and coatings.

Improved composite production processes: By using the latest simulation techniques to avoid defect formation and understand how defects affect structural integrity.

In-line NDT: Combining three cutting-edge NDT technologies (dielectric, wireless, sensor-less) for the first large scale in-line in situ composite production monitoring.

Sub-surface WTB coating inspection: Currently coatings only undergo visual surface inspection or destructive testing. TURB0 will combine ultrasound and mid-IR OCT for the most detailed coating assessment ever performed.

Digital twin and data warehouse: Production equipment, monitoring and in-line NDT data will be combined to establish a digital twin for real-time analysis of production. This has never been attempted for a large-scale composite part. It will populate a data warehouse accessible from multiple production sites.

FLASH-COMP

Flawless and sustainable production of composite parts through a human centred digital approach 101058458. The reduction of manufacturing waste is a key challenge to achieve a European transition towards climate neutrality and the goals of the Green Deal. In this context, to achieve the zero-defect manufacturing paradigm has becomes a must for those European productive companies that wants to take the step towards sustainable production.

Composites play an important role in strategic European manufacturing sectors like energy, aerospace, naval or automotive, with a growing forecast. So, FLASH-COMP project will develop a human-oriented solution, capable of identifying in an early-manner feasible defectiveness in composite parts manufacturing and to determine if corrective actions should be adopted. All with the ultimate goal of optimizing the composite manufacturing process, reaching zero-defects and consequently, reducing the generation of waste ?process and product associated.

FLASH-COMP will develop non-destructive inspection and monitoring instruments to retrieve key process parameters. Will develop an on-line Defect Severity Estimation Tool that will predict the appearance of defects and will estimate their severity to suggest the optimum Feedback and Feedforward control strategies. And will develop a decision support system. In addition, an interoperable software platform for data-sharing will be created.

The full FLASH-COMP solution will be demonstrated in a test bed, enabling the experimental validation of the FLASH-COMP concept, and 2 industrial use cases, assuring its future replicability, and paving the way for a future exploitation of results. FLASH-COMP will include a complete skills development training program since the FLASH-COMP solution has been conceived to assist the operator in controlling and making decisions about the manufacturing process.

ENGINE

Zero-defect manufacturing for green transition in Europe 101058179. The main objective of ENGINE is to develop a first-time-right (FTR) and zero-defect metal product design and manufacturing system, then demonstrate it on marine engine supply-chain. Our ambition is to increase competitiveness of industry and SMEs, reduce manufacturing defects and waste, create new business cases, and improve employee well-being. To achieve it ENGINE will: 1. Create and demonstrate a novel metal product design and manufacturing system. 2. Develop computational modelling toolbox for product and process design, non-destructive diagnostic tools for production monitoring, and data solution for seamless integration of the whole supply-chain. 3. Research methodologies for first-time-right and zero-defect manufacturing (ZDM).

4. Investigate LCA and life-cycle cost (LCC) methods for design and business decisions. 5. Present a strategy for employee skills development. 6. Transform innovations into promising business cases. ENGINE's main objective is split into 10 specific objectives to ensure that all relevant areas are covered, the projects roadmap is well thought-out, and the separate steps create an achievable pathway to success.

Assuming the current market shares, we expect an increase in turnover 2 000M EUR/year. When we succeed in the deployment plans of ENGINE, and we can decrease the cost per kilowatt, we can assume to double the current market share, thus leading another increase of 2 000M EUR/year. ENGINE is paramount to ensure the manufacturing quality and technical feasibility of new environmentally friendly fuel engines. It will create a huge impact on global CO2 emissions. We estimate that annually CO2 emissions will be reduced by 170 million tons through green fuel engines with the expected market share.

OPENZDM

Open Platform for Realising Zero Defects in Cyber Physical Manufacturing 101058673

The openZDM project addresses a critical challenge in the manufacturing industry, delivering high-quality products at necessary production rates. It aims to minimize waste, reduce energy consumption, and maximize efficiency and ROI. As an Innovation Action, openZDM develops and tests an open platform with its integrated applications across 5 representative production lines towards enabling ZDM. This platform integrates advanced ICT solutions with innovative non-destructive testing methods, providing a scalable, flexible solution applicable to diverse manufacturing sectors.

The 5 pilots encompass a broad cross-section of the EU's manufacturing sector, geographically (including plants in northern and southern areas of Europe), technologically (fully & semi-automated, and manual processes) and from their value chain positioning (including Tier 1, Tier 2 suppliers, technology suppliers and OEMs).

Furthermore, partners were selected based on their alignment with strategic sectors for the green transition.

In particular two energy intensive production processes (glass bottles, steel suspension arms), one strategic process for the electrification (production of batteries), one process consuming renewable materials (wood-based panels) and one highly digitalized automotive assembly plant.

These strategic pilots provide the foundation for the openZDM digital platform, which builds on the state-of-the-art RAMI 4.0 and Asset Administration Shell (AAS) to implement intra-factory quality management practices, applicable to these different production environments. This involves the deployment of several non-destructive inspection (NDI) methods and data-driven quality assessment techniques for inline defect identification and online quality assessment, distributed across various stages of the manufacturing process. Central to the project is the use of Digital Twin technology, enabling real-time process adaptation, defect prediction, and prevention. Through the integration of these tools with advanced information management systems, the openZDM platform collects, analyzes, and leverages data to drive decisions, optimize processes, and pursue sustainable production in Cyber-Physical Production Systems (CPPSs).

Finally, openZDM emphasizes improving quality and efficiency by enhancing data interoperability, integrating seamlessly with third-party applications such as lifecycle analysis tools and enterprise-level information management systems.

Platform-ZERO

Customisable AI-based in-line process monitoring platform for achieving zero-defect manufacturing in PV industry 101058459.

Platform-ZERO kicked-off in January 2023, and within the next four years, this 10M€ innovation project co-funded by the European Commission will contribute to increase the production quality of photovoltaic (PV) devices. The project is targeting to reduce the cost of high-tech PV devices and increase the competitiveness of EU’s PV industry which allows this green technology to become a key energy source for Europe’s transition towards climate-neutral energy generation.

Solar photovoltaic (PV) already provides an important contribution to the European energy mix (3.1% of EU-28 gross electricity generation in 2020 (Eurostat), and solar energy has the potential to meet 20% of the EU electricity demand in 2040 (Bloomberg). The latest generation of PV technologies combine high performance with a strong flexibility for integration in buildings, vehicles, agrivoltaics and internet-of-things devices. However, their high-complexity makes them prone to the appearance of critical defects with just small deviations from standard manufacturing conditions, leading to significant production waste. Platform-ZERO addresses this challenge by developing a new customizable in-line process monitoring platform, supported by artificial intelligence, for achieving zero-defect manufacturing in the third generation PV industry to allow an early detection, correction and/or prevention of pre-critical production faults. The strategy will be tested in four pilot plants from PV and PV-related industrial partners in Spain, Germany, Austria and Poland. The pilots are devoted to smart coatings for PV, high-efficiency solar modules and flexible solar foils of different photovoltaic materials and processes.

2.1.2 Call 2021 Advanced digital technologies for manufacturing

2.1.2.1 HORIZON-CL4-2021-TWIN-TRANSITION-01-07: Artificial Intelligence for sustainable, agile manufacturing (AI, Data and Robotics - Made in Europe Partnerships) (IA)

This Innovation Action (IA) topic focuses on manufacturing and process industries, addressing the entire lifecycle of products and services from design to remanufacturing and including all the aspects primarily relevant for industrial production. The objective is to **exploit the potential of AI** as a transformation tool to support circular production in the entire **manufacturing and process industry**, with due consideration for standardisation activities when relevant. AI will be a strategic instrument to improve **sustainability, agility and resilience** to external and internal influences, taking account of the **European Green Deal** objectives. AI applications will be capable of optimising their actions based on limited human input, thanks to context awareness and information sensed from the physical environment and will have the long useful lifetime typical of industrial environments.

Under this topic, **3 Innovation Actions have been funded**:

AIDEAS

AI Driven industrial Equipment product life cycle boosting Agility, Sustainability and resilience 101057294. Machinery industry in Europe is a basis for employment, growth and wealth, with around 3.2 million people employed. Industrial equipment is considered a key enabler for industrial development and the EU has a historically strategic position in this sector. However, it lives from a technological edge in a very competitive landscape. Hereby, it is crucial to provide all stakeholders of the EU with AI technologies that guarantee a resilient design, deployment and reuse of industrial equipment for an increased global competitiveness and a reinforcement of its industrial strategic autonomy and resiliency.

AIDEAS will develop AI technologies for supporting the entire lifecycle (design, manufacturing, use, and repair/reuse/recycle) of industrial equipment as a strategic instrument to improve sustainability, agility and resilience of the European machinery manufacturing companies. AIDEAS will deploy 4 integrated Suites: 1) Design: AI technologies, integrated with CAD/CAM/CAE systems, for optimising the design of industrial equipment structural components, mechanisms and control components; 2) Manufacturing: AI technologies for industrial equipment purchased components selection and procurement, manufactured parts processes optimisation, operations sequencing, quality control and customisation; 3) Use: AI technologies with added value for the industrial equipment user, providing enhanced support for installation and initial calibration, production, quality assurance and predictive maintenance for working on optimal conditions; 4) Repair-Reuse-Recycle: AI technologies for extending the useful life of machines through prescriptive maintenance (repair), facilitating a second life for machines through a smart retrofitting (reuse) and identification of the most sustainable end-of-life (recycle).The AIDEAS Solutions will be demonstrated in 4 Pilots of machinery manufacturers that provide industrial equipment to different industrial sectors: metal, stone, plastic and food.

Circular TwAIn

AI Platform for Integrated Sustainable and Circular Manufacturing 101058585. Circular TwAIn will lower the barriers for all the stakeholders in manufacturing and process industry circular value chains to adopt and fully leverage of trusted AI technologies, in ways that will enable end-to-end sustainability, i.e. from eco-friendly product design to the maximum exploitation of production waste across the circular chain. To this end, the project will research, develop, validate and exploit a novel AI platform for circular manufacturing value chains, which will support the development of interoperable circular twins for end-to-end sustainability. Circular TwAIn will unlock the innovation potential of a collaborative AI-based intelligence in production based on the use of cognitive digital twins. Moreover, based on the use of trustworthy AI techniques, Circular TwAIn will enable human centric sustainable manufacturing, fostering the transition towards Industry 5.0. Furthermore, Circular TwAIn will enable the integration and combination of different data from various sources over entire product life cycle considering sustainability aspects.

The goal is to create and deliver innovative services among the members of the data ecosystem; these services will be embedded in AI-based Digital Twins, supporting an unambiguous communication when realizing complex services for sustainable manufacturing. The ambition of Circular TwAIn is to unleash the sustainability potential of AI technologies in circular manufacturing chains through: (i) Introducing AI optimizations in stages where AI is still not used (e.g., AI-based product design);

(ii) Using AI for multi-stage and multi-objective circular optimizations that could improve sustainability performance. In this direction, the project will leverage information from a circular manufacturing dataspace that will provide access to the datasets needed for multi-stage and multi-objective optimizations.

s-X-AIPI

Self-X Artificial Intelligence for European Process Industry digital transformation 101058715. The s-X-AIPI Horizon Project will research, develop, test and experiment an innovative toolset of custom trustworthy self-X AI technologies. These applications will minimize human involvement in the loop and exhibit self-improving abilities. s-X-AIPI aims towards the core functions of the European process industry with projected improvements in productivity (throughput / output increased by max. 30%), improvement of quality (overall scrap rate reduction of max. 20%), and an improvement of response time (manufacturing cycle -throughput- time reduction 20%).

2.1.2.2 HORIZON-CL4-2021-TWIN-TRANSITION-01-08: Data-driven Distributed Industrial Environments (Made in Europe Partnership) (IA)

Fully reaching the opportunities of sharing and exploiting industrial data, including deep industrial data[1], requires to strike the right balance between storing and handling data centrally in the cloud or locally at the edge of industrial network. Such a balance has to take into account not only efficiency but also the real-time requirements and cybersecurity aspects as well as the ability to systemically integrate and upgrade operational technology to the innovative developments in (self-) configuration, therefore building a flexible industrial Internet for distributed control and modular manufacturing while keeping the high-level of reliability and safety required by the manufacturing sector.

Computing, storage and networking technologies will have to show also flexibility along the industrial value chains and promote the introduction of new business models, based on the availability of deep industrial data from different data sources and ontologies, within an agreed data governance, with mutual trust and adequate distribution of the value created by sharing data.

Under this topic, **3 Innovation Actions have been funded**:

Zero-SWARM

Zero-SWARM is a mission to achieve climate neutral and digitised production via a multidisciplinary, human centric, objective oriented innovative approach resulting in technical solutions for open swarm framework, non-public 5G network, active information continuum and digital twin. At the core, it establishes a unique forum where separately maturing technologies of 5G and cloud-edge continuum, data technologies and analysis (including data spaces and GAIA-X) and operational technology (automation and agility) break their siloes to co-design and co-create through 10 trials. It will showcase key achievements such as smart assembly, sustainable powertrains, improved resilience with remote operation, 5G powered PLC?s for real time distributed control systems, safe and autonomous transport of goods in factory, 5G enabled process aware AGVs, plug & connect 5G for industry, mobile intelligent agents for zero plastic waste, smart maintenance and optimization, remote quality control for zero defect resilient manufacturing.

The project includes 3 nodes (north, centre and south) with industrial test facilities from previous public/private investments co/creating with reputable industry players. Aligned with the technical activities, Zero-SWARM includes a tailored engagement program towards a wide audience, including collaboration with Digital Innovation Hubs and key initiatives in Europe. In addition, open innovation practices involves industry player as clients of developed technologies via Zero-SWARM community with 400 users and the expression of interest mechanism. It allows them to be the pioneer of the Zero-SWARM technologies, establishing an impact pathway even after the project end. Zero-SWARM puts strong emphasis on developing various learning materials to promote skill development of talented workforces with minimum efforts in prominent twin transformation, which will strongly contribute to build up European leadership in sustainable data driven manufacturing.

RE4DY

As part of the green, circular and digital transformation of the European manufacturing community, it is extremely important that data-driven digital manufacturing processes urgently incorporate innovative and active resiliency strategies at production and supply chain levels to maintain their sovereignty and competitiveness levels, respecting European digital values (excellence, privacy, trust) to improve individual and value chain flexibility. In order to achieve long-term resilience to reorganise supply chains or speed up decision making to dealt with any disruption, it is imperative to ensure the implementation of distributed data-intensive intelligent and dynamic industrial decision support, augmentation and automation processes, integrating Artificial Intelligence (smart anticipation) and Intelligent Automation (rapid response) capabilities in Human-Automation symbiosis. Hence, only businesses that can articulate their data, based on AI, digital thread and digital twin solutions, will be able to react rapidly to external shocks.

RE4DY mission is to demonstrate that the European industry can jointly build unique data-driven digital value networks 4.0 to sustain competitive advantages through digital continuity and sovereign data spaces across all phases of product and process lifecycle, proposing ?Data as a Product? core concept to facilitate the implementation of digital continuity across digital threads, data spaces, digital twin workflows and AI/ML/Data pipelines. This concept leverages resiliency on top of advanced manufacturing digital processes and value ecosystems supporting the development and implementation of digital continuity, so distributed data management solutions implemented to deal with factory resiliency can be immediately and seamlessly reused to enhance connected factory and value network level processes.

5G-TIMBER

5G-TIMBER project aims to validate through robust evidence the latest 5G Industrial Private Network features and standards specifications for Wood Value Chain (WVC) under realistic conditions. In particular, to conduct advanced field trials of the more representative and innovative data-driven material, production and installation flows that implicate manufacturing across 4 prominent industries in the wood sector including, machinery and wood house elements manufacturing, construction and renovation towards green buildings, wood waste valorisation, and established telecom SME industries in a project remit that spans 3 representative European regions (Norway, Estonia, Finland). The project incentivises the opportunistic uptake of 5G in real-life business conditions.

Specifically, 5G- TIMBER will target to increase wood-based materials recycling by 50%, increase manufacturing productivity by 15%, reach 99% of the work done in the factory (vs. 85% today), reduce on-site work by 10%, reduce product nonconformities by 10%, and increase the safety of workers in wooden houses production and onsite assembling.

Validation of above overall targets through >100 interdisciplinary innovation driven technical, business and service-level KPIs for 09 diverse WVC use cases across 3 categories i.e., data driven sawmill woodworking machines; modular wood-house factory; construction and renovation with wooden elements, valorisation of composite waste. Use cases will be incrementally validated by 2 lab trials followed by 2 field trials in iterative cycle covering significant portions of end-to-end WVC. 5G-TIMBER also includes a comprehensive business case and exploitation strategy that incorporates novel approaches to materializing the value of data produced in industrial environments based upon 4 distinct business models. Our 16-partner consortium is driven by strong industrial and SME partners, renowned organisations the majority of which participate in FoF cPPP, 5G-PPP, GD projects.

2.1.3 Call 2022 Green, flexible and advanced manufacturing

2.1.3.1 HORIZON-CL4-2022-TWIN-TRANSITION-01-01: Rapid reconfigurable production process chains (Made in Europe Partnership) (IA)

In times of disrupted supply chains or rapidly changing customer demands, production lines will need to be built flexible enough to be able to handle these variations. Rapid reconfiguration technologies of more flexible systems, will enable industries with many production process steps to maintain a resilience against sudden changes in ordering and/or supplies.

The projects should address reconfiguration of production systems in which the lines are running at medium or high volume manufacturing rates (MVM and HVM respectively), and include a variety of production steps, such as cleaning, forming, thermal treatments, cutting, joining, surface treatments, painting, printing, assembly, etc. It should also consider complex logistics and non-manufacturing operations enabling the production runs. Projects should provide strategies for awareness and early detection of reconfiguration needs, e.g. by using A.I. and data technologies, to enhance their resilience towards threatening events or crisis situations.

Under this topic, **3 Innovation Actions have been funded**:

FLEX4RES

Flex4Res

Manufacturing industries continuously face the challenge of delivering high-quality products under high production rates while minimizing non value-adding activities. The recent COVID-19 pandemic is causing manufacturers to rethink and reassess their global supply chains and the flexibility of their production sites. Resilience means the ability to withstand difficult situations, while flexibility can be considered as the ability to accommodate changes without incurring significant extra costs. Production processes demanding high human skill such as forming processes, requires readjustment of the process parameters of all production steps as a new product evolves.

The deficiencies can be attributed largely to the lack of efficient ways for trusted data sharing among the stakeholders without interoperability barriers. There is a need to be able to determine when such changes lead to deterministic-chaotic behavior with far reaching consequences. FLEX4RES provides an open platform to support production networks' reconfiguration for resilient manufacturing value chains. FLEX4RES will utilize platform-based manufacturing that builds on the state-of-the-art Gaia-X and IDS technologies for data-sharing in the horizontal supply chain and the Asset Administration Shell (AAS) that is to implement intra-factory reconfiguration practices. FLEX4RES considers the Digital Twin of the value-adding network a key enabling technology to achieve reconfiguration processes in highly flexible production systems and networks. The key element of technology linkage is represented by the Self-Descriptions with linked, standardized information models, especially in terms of resilience. The developed platform and specialized hardware aim to improve the existing industry-established lean management approaches related to Reconfiguration Management through the digitalization of the production, characterized as Industry4.0, by allowing for the information sharing between value chain stakeholders.

RaRe2

The global objective of RaRe2 project is to create a flexible and resilient Holistic Ecosystem Platform, enabled by the interaction among many European organizations cooperating in the fast reconfiguration of process chains, through collaborative systems and adaptable workforce upskilling. RaRe2 will help make the European manufacturing landscape sustainably robust to unexpected market change, sudden disruption, legal change, or every kind of crisis and changing scenario including climate and weather related. RaRe2 has set strategic and operational objectives, which include innovative digital solutions and knowledge about standards and methodologies, which can support the quickness in reconfiguration and certifications at early stages. RaRe2 will enable the generation of a green wave that will early detect an upcoming issue, alert the decision maker, quickly propose simulations about potential new destinations (adjacent reasonable sectors and products), new routes (how to produce it, with internal reconfiguration and supply chain involvement), the plan to put the change in place, the expected speed of each connected node of the new route, robustness.

Key pillars: i) AI-based early detection of reconfiguration needs, from internal and external sources; ii) rapid adaptation of products, processes and supply chain to the changed situations; iii) empowering and upskilling humans, supporting decision makers to make fast and concrete decisions and quickly ramp up of the workforce. RaRe2 will be exploited to create a strong and reliable network of organizations interested in cooperating in rapid reconfiguration events, able to take into account social, market, legal, sustainability and economical factors. The consortium is based on 22 European partners, which will develop and validate the solution in four industrial pilots plus one value chain oriented demonstrator. The International Cooperation is guaranteed by a pilot which has the main headquarter in Japan.

R3GROUP

Implementing and improving rapid reconfigurability and digitalization in manufacturing processes. The R3GROUP project is an initiative funded by the European Union's Horizon Europe programme that aims to support the resilience of European manufacturing firms by providing tools to enable rapid reconfigurability.

2.1.3.2 [HORIZON-CL4-2022-TWIN-TRANSITION-01-03:] Excellence in distributed control and modular manufacturing (Made in Europe Partnership) (RIA)

Projects are expected to contribute to the following outcomes: Significant advance in modular technologies for flexible manufacturing operations, which respond to disrupted supply chains, or rapid changes in customer and societal demands;

Transition of modular technology to sustainable production for varying batch sizes, including single lots, with a clear integration of control and decision-making strategies at different levels and throughout the supply chain;

Improved understanding among industrial users, including SMEs, of how to organise and control reconfigurable manufacturing systems built from modules with defined interfaces, including quality assessments, environmental impact, energy use, end-user involvement and business models.

Under this topic, **4 Innovation Actions have been funded**:

MODAPTO

To respond to market changes, a reconfigurable manufacturing system (RMS) rapidly changes its structure and adjusts its production capacity and functionality. The EU-funded MODAPTO project envisages flexible industrial systems composed of modules empowered by distributed intelligence through interoperable digital twins (DT) based on industrial standards. The project will enable collective intelligence within modular production schemes for efficient module and production line design, reconfiguration and decision support. Moreover, it will realise reconfigurability through the use of all six RMS principles, augmenting the production module by a DT offering additional distributed intelligence functionalities. MODAPTO will focus on two technological pillars: distributed intelligence and control via interoperable DT and a modular production framework and toolkit.

MODUL4R

EU manufacturing is constantly becoming "more productive with less", both in terms of material usage and energy consumption. The dynamics of global markets demand shorter product lifecycles and higher product variety, impacted by an increased volatility in demand. Traditional manufacturing systems are unsuitable to meet the new "think small" paradigm. They enable flexibility but at high operational complexity and for high volume operations to get lower cost production. To realise resilient factories and supply chains, it is mandatory to reduce complexity and cost of plug & produce modular manufacturing.

MODUL4R envisions reliable, maintainable, affordable, (re)usable, and changeable SME-friendly autonomous modular factories and supply chains, able to manufacture new product in low-volumes and rapidly respond to unexpected events as well as the overall supply chain. MODUL4R proposes a holistic framework applicable both to new and existing manufacturing lines to achieve flexibility, rapid responsiveness, and sustainability. MODUL4R will be demonstrated in specialized mould manufacturing for the automotive sector, CPPS for flexible & modular assembly of PCBs, and tools manufacturing for the aerospace.

MARS

European manufacturing SMEs represent a major pillar of the EU economy but, even though some of these SMEs are world's champion in their own business area, they are still threatened by the lack of radical technical innovation as well as successive crises of their supply chains. The MARS project aims to remedy to both issues by enabling SMEs to access advanced European breakthrough innovations in the field of AI-driven digital manufacturing processes and enter into process chains that are geographically distributed. Specifically, by gathering diverse expertise coming from complementary European partners, MARS will develop Industry4.0 emerging technologies including digital twins of products, processes and machines, bio-intelligent production devices with local intelligence and high sensing coverage, central intelligence with fleet learning approaches, data-driven manufacturing process models from different sources, blockchain technology for data hashing, traceability and securitization, multi-agent based manufacturing planning, multi-criteria intelligent optimization of processes and resources especially addressing environmental footprint.

As a result, the impact of the project will lie into introducing radical flexibility in all different aspects of manufacturing processes, in particular by redefining the process route, raw material, resources, technology, throughput, manufacturing site, delivery date in no time, while keeping up with product's requirements, proven product quality and sustainability of both processes and products. By demonstrating its results on two case studies exhibiting advanced manufacturing processes (incl. homogeneous and heterogenous data), MARS will show how SMEs can decrease time delivery under difficult economical boundary conditions, while targeting ambitious energy-saving environmental objectives.

ONE4ALL

ONE4ALL aims to boost manufacturing plants' transformation, especially SMEs, towards industry 5.0 (I5.0), reinforcing their resilience under unexpected changes in social needs. It is done through a human-and-sustainability-centred development of plug-and-produce reconfigurable cyber-physical production modules (RCPMs). Those will consist of self-reconfigurable mobile collaborative robots embedded with IIOT devices for real-time monitorisation and interconnectivity. In addition, the physical modules and the processes addressed by those will be replicated digitally through data-driven digital twins and controlled by a self-learning AI-based distributed and multidisciplinary decision support system (DSS).

In addition, the open-source approaches will be promoted throughout the whole project to ease the interoperability of the components. All in all, interconnected and efficiently managed by an intelligent orchestration platform, with defined modules interfaces for the RCPM, production, product quality, sustainability aspects, business model, DSS and help desk to involve the end-user in everything that is going on across the whole supply chain, improve the understanding and assess the decision making. An adaptive training programme for digital upskilling will be implemented over the entire project to prepare the workforce for the I5.0 transformation and fully exploit the potential of the technologies.

The resilience of manufacturing operations will be enhanced by better anticipating the demand changes and providing more flexibility to act, thanks to the digital tools and modular and flexible structure integrated within the whole system.

The potential of ONE4ALL will be demonstrated in two relevant environments from different sectors (agri-food and pharmaceutical), both highly affected by disruption given their high and fluctuant demand and not fully impacted yet by I5.0 transformations. Consequently, it is expected to have a high impact and replicability opportunities.

2.1.3.3 HORIZON-CL4-2022-TWIN-TRANSITION-01-04: Intelligent work piece handling in a full production line (Made in Europe Partnership) (RIA

The global trends towards product customization have increased production complexity. To maintain global leadership and competitiveness of European manufacturing industry, there is a strong need for efficient, flexible, reconfigurable and data-driven agile factories. The recent pandemic crisis highlighted even further the need of manufacturing lines that can switch production within a matter of hours.

Products and component handling is an integral part of the manufacturing industry and its optimization increases productivity while minimizing production costs and time. However, the increasing complexity and customization of products coupled to the paradigm shift towards circular economy requires new assembly and disassembly lines able to handle a high variety of work pieces which might be available as 3D models or just as physical artefacts. Therefore, there is an increasing demand for innovative smart automated handling systems.

Under this topic, **4 Innovation Actions have been funded**:

AGILEHAND

The Conveyor System market and, in particular, robot segment for the automated material handling are experiencing double-digit growth at a compound annual growth rate (CAGR). EU manufacturers in this sector plays an important role, covering 23% of the market but this technological edge is being challenged due to the astonishing growth of China, Japan and Korea. In real world, many objects to be handled, including food, clothes, bottles, or plastic items, are soft or deformable and robots are not yet efficient and effective in handling these objects.

In this context, AGILEHAND aims at developing advanced technologies for grading, handling and packaging autonomously soft and deformable products, as a strategic instrument to improve flexibility, agility and reconfigurability of production and logistic systems of the European manufacturing companies.

MASTERLY

Over the last years, production has been shifted from mass production to customization. The conventional production lines, traditionally focused on one product variant or one family of products do show their limitations to cope with the new needs. Moreover, unprecedented worldwide events, such as the recent pandemic crisis, indicated even more the need for flexible production systems that can rapidly switch production to a totally different one (e.g. automotive manufactures had to produce respirators, facemasks etc.).

As a response, MASTERLY aims to develop flexible robotic solutions, constituting of modular grippers combined with state-of-the-art robotic technologies, such as mobile, high and low payload industrial and collaborative robots and smart cranes, enhanced with AI driven advanced control and perception capabilities that will allow them to act autonomously, handling a large variety of parts varying in size, shape and material, while being acceptable by both genders of workforce.

The developments will focus around the following 5 pillars:1) Innovative, efficient and low consumption systems for storage, retrieval, conveying and pick-and-place using a multi-disciplinary approach combining technologies , 2) Robust handling devices and systems, with integrated –AI driven- advanced control, 3) User-friendly interfaces for robot/machine control and programming, 4) Interoperable S/W and H/W interfaces , 5) Industrial Pilot Cases for work piece handling in full production line.

SMARTHANDLE

Manual and automated production lines must evolve to "produce more and diverse with less", however they need to address shortcomings. SMARTHANDLE will research technologies to address these needs and support European industry, by implementing a) intelligent, reconfigurable agents to provide dexterity in a range of handling applications, b) AI based reasoning enablers to optimize the flexibility potential of these agents and c) Higher-level planning and coordination mechanism to allow the successful and scalable deployment of such solutions in real life use cases.

HARTU

HARTU will provide the necessary tools to implement three basic stages of parts handling, i.e., grasping, assembly and releasing. These tools aim to address the key challenges for creating handling applications by means of innovative technical approaches: (1) self-supervised grasp and release planning policies identification and control; (2) to learn and control contact-rich assembly skills from human demonstrations; (3) to develop an AI-based multi-modal perception for visual-servoing and continuous monitoring in handling operations, supported by virtual and continuous learning; and (4) to develop versatile and dexterous soft grippers with electro-active fingertips.

HARTU is an industry-driven research project that includes the deployment of technologies in 5 industrially relevant scenarios: 4 manufacturing lines in different sectors: automotive, household appliances, hand tool manufacturing and food processing, and 1 in logistics to validate that the technologies can be transferred to other sectors. They offer an enormous variability of products in terms of shape, material and sizes.

2.1.4 Call 2022 Advanced digital technologies for manufacturing

2.1.4.1 HORIZON-CL4-2022-TWIN-TRANSITION-01-06: ICT Innovation for Manufacturing Sustainability in SMEs (I4MS2) (Made in Europe Partnership) (IA)

This Innovation Action (IA) topic (ICT Innovation for Manufacturing SMEs I4MS) aims to support **manufacturing SMEs and mid-caps** in adopting the latest innovative digital technologies for their business operations. I4MS2 builds on I4MS and addresses more significantly a **sustainable and resilient production**. The pandemic and economic crises demonstrated the key role of digital technologies in responding quickly to external changes. Digitalisation improves **resilience, agility and competitiveness, and enables cost-efficient production in Europe**. It will also support a radical reduction of the environmental footprint of the sector. In this context, experimentation with innovative and secure digital technologies in their production processes, products and business models guided notably by **competence centres** specialised in the technologies mentioned below will enhance manufacturing companies to successfully manage the twin digital and green transformation of the coming years. I4MS2 calls for Innovation Action projects that will support European SMEs and mid-caps to innovate and make more sustainable their products, production processes and business models through **experimentation and testing**.

Under this topic, **4 Innovation Actions have been funded**:

WASABI

White-label shop for digital intelligent assistance and human-AI collaboration in manufacturing 101092176.WASABI aims at providing SMEs with the tools and knowledge to improve workers capacities and performance, providing advanced user interfaces for continuous augmented hybrid-decision-making. Such interfaces assist employees in interacting with complex software, effectively reducing its skill floor. In consequence, humans will find using software easier and be more open to applying it effectively at work. WASABI's advanced interfaces will cover, for instance, situation analysis, intervention identification, action planning and execution, and impact monitoring and mitigation. One of the key technologies in WASABI's solution portfolio is the digital intelligent assistant (DIA) - an anthropomorphic, task-oriented AI with a conversational interface. A network of DIHs that will help boosting impact by guiding SMEs in this new path will be created and integrated within other existing DIH networks. Our customized, federated, white-label shop will include such DIAs and skill-packages to help organizations reach their sustainability goals. Blue-collar and white-collar workers will be capable of using it for hands-free or eyes-free computer-interaction, AI-based advice and guidance, and augmented analytics.

AI REDGIO 5.0

Regions and (E)DIHs alliance for AI-at-the-Edge adoption by European Industry 5.0 Manufacturing SMEs 101092069.The I4MS program in H2020 has been and is a great success for the Digital Transformation of European Manufacturing SMEs. Phase IV of the program was focussing on DIHs and on highly innovative technologies like Digital Twins and AI.

In particular, the AI REGIO Innovation Action developed a virtuous alliance between Regions, DIHs, AI solution providers and Manufacturing SMEs, which is materialised by a new methodology for DIHs service portfolio and customer journey analysis, an AI4EU -oriented toolkit of Data and AI resources, a network of Didactic Factories and their TEchnology and REgulatory SAndboxes (TERESA) and an ecosystem of SME-driven experiments and their Digital Transformation pathways.

It is time now to align such important outcomes to the evolution of Manufacturing towards Industry 5.0, the evolution of cloud AI Technologies to AI-at-the-Edge, the evolution of H2020 to

Horizon and Digital Europe programmes e.g. to EDIH, Data Spaces and AI TEFs (Testing and Experimentation Facilities) for Manufacturing.

Some of the AI REGIO I4MS Phase IV motivations are now evolved: it is time for AI REDGIO 5.0 for keeping momentum of AI technologies adoption in Manufacturing SMEs. AI REDGIO 5.0 aims at renovating and extending the H2020 I4MS AI REGIO alliance between Vanguard EU regions and DIHs for a competitive AI-at-the-Edge Digital Transformation of Industry 5.0 Manufacturing SMEs. AI REGIO outcomes (methods and tools for DIHs governance and cross-DIH collaboration; Data Space and AI for Manufacturing toolkit; Didactic Factories network and TERESA facilities; SME-driven experimentations in 14 Vanguard regions) will be i) extended to the I5.0 principles; ii) enabled by the newest trusted technologies along the edge-to-cloud continuum; iii) supported by European open source HW/SW reference implementations, preserving EU values and ethical principles; iv) interconnected with the EDIH network in DEP as well as with the AI TEF nodes and the Data Spaces deployment program.

AIRISE

Artificial Intelligence in Manufacturing for Sustainable Applications at SMEs 101092312. The AIRISE project will support European SMEs in the uptake of Artificial Intelligence applied to manufacturing, with a specific focus on the use of AI-enabled applications at the edge. The key objective for applications is a reduction of waste and carbon footprint while ensuring the resilient operation of manufacturing. The consortium will create an eco-system where the project's AI experts will support experimenting SMEs and connect them to Digital Innovation Hubs and commercial companies to achieve real-world applications. Open Calls will allow SMEs to easily access AI expert competence through first-stage assessments that identify the status and potential and through further proposals that support them in running pilot applications and validation experiments. The ambition of AIRISE is to support more than 500 cases from SMEs and mid-caps on key AI applications at the edge. Support from the consortium will be complemented on security and connectivity by involving external resources in cybersecurity and IoT and on smart working environments by offerings on operator interfaces and collaborative robots.

CIRCULOOS

Circular and Dynamic Manufacturing Supply Chain Orchestration and OptimiSation 101092295. CIRCULOOS aims to deliver circular manufacturing tools which orchestrate and continuously optimise the supply-chain end-to-end and comprehensively integrate planning and execution. Combining these with direct calculation of the product sustainability and circularity profile, both internally and with external partners, this environment will enable them to configure and execute disruptive circular manufacturing processes for sustainable production that cover the entire life cycle of products which become waste and are recycled in the same or other life cycles.
To achieve this objective the project aims at deploying: Circular end-to-end supply chain orchestration of collaborative workflows and connecting planning and execution metrics with advanced and multimodal visualisation -DT of supply chains formulated, factory processes and product design- and analytics. Supply Chain Optimisation that monitors the global (across the supply chain) and local (within the factory) processes and execution.

2.1.4.2 HORIZON-CL4-2022-TWIN-TRANSITION-01-07: Digital tools to support the engineering of a Circular Economy (Made in Europe Partnership) (RIA)

This Research and Innovation Action (RIA) topic focusses on developing new **concepts, methods, and digital tools** to support further engineering of the industrial processes for **recycling,**

re-manufacturing, refurbishing, and reuse of manufactured products and components. New solutions will enable remanufacturing and high-quality recycling by digitalisation of product and component information throughout the whole product lifecycle, in line with the 2020 **Circular Economy Action Plan**. Another challenge that falls within this scope is the **human dimension**. The support tools need to work with the user, and training, knowledge transfer, cognitive interfaces, as well as acceptance and uptake will be vital in the solutions proposed. Proposals should cover all of the following aspects: i) Development of **innovative concepts, methods, and tools** that track and trace the status of relevant manufactured products and components; ii) Inclusion and handling of **real-time production data** in analysis software and tools, notably for decision making and control, as well as knowledge management; iii) Demonstration of the support tools in at least two different realistic production environments with a clear target of improving **quality and sustainability** with significant economic value. If applicable, legal obstacles to implementation of the proposed solutions should be identified.

Under this topic, **5 Research and Innovation Actions have been funded**:

CIRC-UITS

Circular Integration of independent Reverse supply Chains for the smart reUse of IndusTrially relevant Semiconductors 101091490.Several products embed different types of electronic components, and they are even more fundamental in some of the European strategic markets (e.g. automotive). However, reference producers come from extra-EU countries in the far-east side of the world (e.g. China and Taiwan). Trying to cope with all these challenges and the current semiconductors crisis, the European Commission (EC) published (and in some cases is still working on) specific EU strategies/directives for automotive, e-waste (e.g. Digital Product Passport) and, specifically, semiconductors (e.g. European Chips Act). However, trying to make these sectors more sustainable, circular and resilient, it is mandatory to boost both EoL strategies (e.g. sorting, reuse, remanufacturing and recycling) and intra-EU production through innovations and investments. The current international scenario represents a good chance to decouple the European economy from both natural resource depletion (e.g. Critical Raw Materials - CRMs) and dependency from extra-EU supplies of strategic products. In order to better prove what the benefits are of a joined circular/resilient use of secondary resources, the automotive and mass electronics sectors have been identified as the reference contexts for establishing a set of innovative solutions. To this aim, the CIRC-UITS project will focus on demonstrate the improvement to the circularity of automotive and mass electronics sectors by reuse of semiconductors from different sources, as well as support the reuse & remanufacturing of semiconductors into new (high added-value) components and products in these sectors.

DACAPO

Digital assets and tools for Circular value chains and manufacturing products 101091780. DaCapo aims at establishing a systematic approach enabling the creation of human-centric digital tools and services for improving the adoption of Circular Economy strategies along both manufacturing value chains and products lifecycles (design and engineering, manufacturing, use phase and End of Life). These tools and services, focused on the creation of new digital assets, AI-based systems and the application of process and product Digital Twins, will greatly improve sustainability, efficiency, and use of imported and CRM in manufacturing, towards digital-enabled industrial sustainability and resilience.

The backbone of the project will be a new methodological approach supporting decision-making, considering business models, material flows and circular strategies along the manufacturing value chains. Digital Product Passports and a Circular Economy Decision Support System will be developed as high-level tools, facilitating the trustful exchange of assets, the selection of optimum circular stock management strategies and tools, and the definition of informed and coordinated products lifecycle management decisions in a safe, reliable and agile way. A modular Digital Thread concept will be developed as a normalized method for orchestrating the gathering and contextualization of data at different points of the product lifecycle, enhancing data availability for the definition of indicators and optimisation criteria. On top of that, DaCapo will develop a digital architecture aligned with interoperability and connectivity standards, guaranteeing end-to-end horizontal and vertical integration, boosting data sharing and exploitation under the EU Data Spaces framework and maximizing replicability potential.

AUTO-TWIN

Data-driven method based on a process mining approach for
Automated Digital Twin generation, operations, and maintenance in circular value chains 101092021.

AUTO-TWIN is a new method for creating digital twins, which are digital replicas of physical systems. It aims to address the limitations of current system engineering models by introducing a breakthrough method for automated process-aware discovery towards autonomous Digital Twins generation. This is done by adopting an International Data Space (IDS)-based common data space, which enables the automated process of creating digital twins, thus making it more efficient and cost-effective. Additionally, AUTO-TWIN integrates novel hardware technologies into the digital thread, which is a key component of creating digital twins, to create smart Green Gateways.

ALICIA

Assembly Lines In CIrculAtion – smart digital tools for the sustainable, human-centric and resilient use of production resources 101091577.The aim of ALICIA is to create and demonstrate a Circular Manufacturing Ecosystem (CME) for production resources, such as robotic arms or conveyor belts. The underlaying vision is that within five to ten years, production resources will be traded and reused to their maximum utility in-between factories in Europe, ultimately contributing to "closing the loop" of production assets as circular economy subjects.

The project aim will be achieved by integrating and demonstrating in two real industrial environments (at Continental and Comau) a combination of innovative and symbiotic digital tools as key enabling technologies behind the ALICIA CME, ultimately enabling to design, deploy, run, decommission and re-circulate second-hand production lines 40% faster, reduce material consumption by up to 80% and reuse up to 100% of the assets. The innovations behind ALICIA include a machine-readable ontology for mapping factory owner requirements, an AI-matchmaking engine for combining incumbent factory assets with second-hand assets coming from the ALICIA online marketplace, a Plug & Produce middleware for seamlessly connecting the production assets and a Digital Shadow/Digital Twin to ramp-up and operate the ALICIA second-hand line. Novel Circularity-as-a-Service business models will be evaluated.

DiCiM

Digitalised Value Management for Unlocking the potential of the Circular Manufacturing Systems with integrated digital solutions 101091536.

The aim of the current project is to bring about the development of the full demonstrator of DiCiM, a set of integrated digital solutions that makes use of Internet of Things (IoT), Machine Learning (ML) based Artificial Intelligence (AI), Big Data, Image Processing and Augmented Reality (AR) to support different actors of the industrial value chain such as managers, engineers and operators in their decision making and to carry out value recovery activities for circular economy. The integrated digital solutions include an open access digital platform for lifecycle information management and support solutions for value recovery activities.

DiCiM project revolves around the value use and value recovery phases of the Circular Value Model (CVM) with the specific data, technology and the management needed to support its implementation. In particular, it focuses on integrated digital solutions to enabling condition monitoring during the use phase, optimizing the reverse logistics, and achieving efficiency and responsiveness in the value recovery activities (i.e. collection, inspection, sorting, disassembly, testing and repairing/refurbishing/remanufacturing/recycling) to enable reuse of products, parts and materials.

2.2 Cloud Edge IoT projects: the Technological viewpoint

2.2.1 Cloud Edge IoT in H2020

2.2.1.1 ICT-40-2020 Cloud Computing: towards a smart cloud computing continuum

Cloud computing is changing from a pure elastic provisioning of virtual resources (or platforms) to a transparent and adaptive hosting environment that fully realizes the "everything as a service" provisioning concept, from centralised cloud to the edge, and from network and computing infrastructure up to the application layers.

The challenge is to develop comprehensive cloud solutions and testbeds combining various execution platforms for ubiquitous and seamless execution computing environments as a foundation for a complete computing continuum. This requires novel solutions for federating infrastructures, programming applications and services, and composing dynamic workflows, which are capable of reacting in real-time to unpredictable data sizes, availability, locations, and rates. This will provide application developers with greater control over network, computing and data infrastructures and services, and the end-user will benefit from seamless access to continuous service environments. Such solutions should also address security, semantic interoperability, heterogeneous data integration, organisation and linking, data protection, performance, resilience and energy-efficiency requirements to respond to the future digitisation needs of industry and the public sector. Addressing these challenges will also be part of and contribute to the technological ambitions of the Next Generation Internet (NGI).

Under this topic, 6 Innovation Actions have been funded:

AI-SPRINT

To become fully pervasive, artificial intelligence (AI) needs resources at the edge of the network. The cloud provides the processing needed for big data, but edge computing is close to where data live, and crucial to their timely, flexible, secure management. EU-funded AI-SPRINT builds powerful tools for AI applications in computing continua which allow a finely-tuned tradeoff between performance and AI model accuracy, putting security and privacy early in the design stage. The project provides programming models, specialised building blocks, and mechanisms for automatic deployment and dynamic reconfiguration. All this enables flexible and secure AI applications, benefiting developers, integrators, cloud providers, and end-users. AI-SPRINT will be demonstrated in real-world use cases: farming 4.0 maintenance and inspection, and personalised healthcare.

PHYSICS

The EU-funded PHYSICS project is empowering European cloud service providers to leverage cutting-edge, scalable and cost-effective cloud models, such as function-as-a-service (FaaS) ones, operated across multiple hardware types, locations, edge computing nodes and multi-cloud resources. The project will apply a vertical solution consisting of a cloud design environment enabling the design of visual workflows and an optimised platform-level FaaS.

A back-end optimisation toolkit should enable cloud service providers to enhance baseline resource performance, tackling issues such as cold-start problems, multitenant interference and data locality. The project's outcomes will be validated in three applications – eHealth, agriculture and manufacturing.

SERRANO

The EU-funded SERRANO project aims to introduce a novel ecosystem of cloud-based technologies, ranging from specialised hardware resources to software tool sets. The project will introduce an abstraction layer that transforms the distributed edge, cloud and high performance computing resources into a single borderless infrastructure, in addition to facilitating their automated and cognitive orchestration. These initiatives will enable application-specific service instantiation and optimal customisations based on the workloads to be processed, in a holistic manner, thus supporting highly demanding, dynamic and security-critical applications.

DataCloud

Nowadays, the increasing pervasiveness of data and computing results in the proliferation of edge applications for timely and effective processing of data and advanced analytics. However, as the available data grows, new solutions are needed to ensure a fluid integration of resources to support dynamic, data-driven application workflows. In that direction, the EU-funded DataCloud project introduces a groundbreaking paradigm with a complete life cycle managing Big Data pipelines through discovery, design, simulation, provisioning, deployment and adaptation across the computing continuum. It will allow Big Data pipelines to interconnect the end-to-end industrial operations from the preprocessing and collecting of data to the realisation of a business target. DataCloud will make Big Data advancements more accessible regardless of hardware.

HUB4CLOUD

The EU-funded HUB4CLOUD project aims to magnify the impact and relevance of cloud computing research, innovation, and policy-driven efforts in Europe. To that end, it nurtures an open, inclusive and sustainable ecosystem through dedicated activities, including road mapping, dissemination, event organisation, mapping of open-source and (pre)standardisation initiatives, and business acceleration programmes. To yield effective results, the project will guarantee continuity with previous and ongoing cross-programme initiatives by building on the results and major achievements produced so far by EU-funded endeavours. HUB4CLOUD's ultimate ambition is to foster secure, interoperable, scalable, affordable, and environmentally sustainable cloud technologies and solutions, strongly rooted in core European values, from fundamental individual rights to market openness and environmental sustainability.

2.2.1.2 ICT-56-2020 Next Generation Internet of Things

Specific Challenge: Internet of Things (IoT) technologies and applications are bringing fundamental changes to all sectors of society and economy and constitute an essential element of the Next Generation Internet (NGI). The challenge is to leverage EU technological strength to develop the next generation of IoT devices and systems which leverage progress in enabling technologies such as 5G, cyber-security, distributed computing, artificial intelligence (AI), Augmented Reality and tactile internet. In addition it is important to build and sustain a competitive ecosystem of European technology and system providers in IoT as well as ensuring end-user trust, adequate security and privacy by design.

Under this topic, 7 Innovation Actions have been funded:

IoT-NGIN

It is well known that the Internet of Things (IoT) has been identified as one of the next big concepts to support societal changes and economic growth. To address this opportunity, the EU-funded project IoT-NGIN introduces novel research and innovation concepts to establish itself as the 'engine' that will fuel the next generation IoT. It starts by uncovering a pattern based meta-architecture and optimises IoT/machine-to-machine and 5G/machine-cloud-machine communications by extending the edge cloud paradigm. Moreover, it enables user and self-aware autonomous IoT systems through privacy-preserving federated machine learning and ambient intelligence, with augmented reality support. Finally, IoT-NGIN researches towards distributed IoT cybersecurity and privacy. IoT-NGIN will be validated using dozens of heterogeneous devices, including drones and robots.

iNGENIOUS

Expanding into huge networks of heterogeneous organisations involved in the manufacture and delivery of products to end users, supply chains of the future are in for a big change, thanks to the many new technologies such as 5G, big data, blockchains, virtual reality and artificial intelligence. The EU-funded iNGENIOUS project will design the next generation of internet of things (IoT) technology to add digital value to future supply chains. It will also propose technical and business enablers to build a complete platform for supply chain management. Formed by 21 partners from 8 countries, including telecommunications vendors and manufacturers, logistic partners, universities, research institutes and high-tech small and medium-sized enterprises, the project will address interoperability between IoT and blockchain platforms for transport.

ASSIST-IoT

The evolution of human-machine interaction is just as remarkable as the technological advances that made the impossible possible and changed the way we live. The relationship with machines has been redefined: machines moved from tool to partner and from automation to autonomy. The Internet of Things is connecting physical, digital, virtual and cyber worlds, leading to a new evolution in human-machine interaction. The next-generation tactile internet will allow real-time interaction between humans and machines, as well as between machines. The EU-funded ASSIST-IoT project will develop the reference architecture in which intelligence can be distributed among nodes by implementing artificial intelligence and machine learning close to data generation and actuation, and hyper-connecting nodes, in the edge-cloud continuum, over softwarised smart networks.

VEDLIoT

As the Internet of Things (IoT) continues to take shape, promising widespread automation and data exchange, one of the biggest challenges is to act on the data generated. The amount of data collected is huge, the computational power required for processing is high, and the algorithms are complex. The EU-funded VEDLIoT project develops an IoT platform that uses deep learning algorithms distributed throughout the IoT continuum. The proposed new platform with innovative IoT architecture is expected to bring significant benefits to a large number of applications, including industrial robots, self-driving cars, and smart homes. The project offers an Open Call at project midterm, incorporating additional VEDLIoT-related industrial use-cases in the project, increasing the market readiness of the VEDLIoT solutions.

EU-IoT The European IoT HUb

An increasing number of organisations and industries today use the Internet of Things (IoT) to improve their decisions, operation or products. The IoT is crucial for an inclusive, trustworthy and sustainable digital future. But in Europe, IoT communities, research and technology remain dispersed. Enforcing and consolidating the current IoT community of researchers to address future challenges is an essential European goal, formulated in the Next Generation Internet initiative. The EU-funded EU-IoT project will create a strong consortium to elaborate a strategy for an open and inclusive ecosystem and facilitating the creation of a self-sustaining, European IoT community. EU-IoT will act to foster the interactions of all players, know-how exchange, the creation of strategic partnerships and long-term collaboration of a new European ecosystem that is ready for future transformations.

TERMINET

Tens of billions of devices are connected to the Internet of Things (IoT), and the number of connections is growing every second. Information is being constantly sent and received from one smart device to another. Based on cutting-edge technologies such as software-defined networking (SDN), multiple-access edge computing, and virtualisation for next-generation IoT, the EU-funded TERMINET project will develop a novel next-generation reference architecture. Its main aim is to simplify the connection of a vast number of different devices through a flexible SDN-enabled middleware layer. To improve supply chain processes, the project will design an IoT-driven decentralised and distributed blockchain framework within manufacturing. TERMINET's approach will be tested in real-life situations such as energy, smart buildings, smart farming, healthcare and manufacturing.

IntellIoT

The Internet of Things (IoT) merges physical and virtual worlds. The European Commission is actively promoting the IoT as a next step towards the digitisation of our society and economy. The EU-funded IntellIoT project will develop a framework for intelligent IoT environments that execute semi-autonomous IoT applications, enabling a suite of novel use cases in which a human expert plays a key role in controlling and teaching the AI-enabled systems. Specifically, the project will focus on agriculture (tractors semi-autonomously operated in conjunction with drones), healthcare (patients monitored by sensors) and manufacturing (automated plants shared by multiple tenants who utilise machinery from third-party vendors). It will establish human-defined autonomy through distributed AI running on intelligent IoT devices.

2.2.2 Cloud Edge IoT in Horizon Europe

2.2.2.1 HORIZON-CL4-2021-DATA-01-05 Future European platforms for the Edge: Meta Operating Systems (RIA)

Proposal results are expected to contribute to the following expected outcomes: Next generation of higher-level (meta) operating systems for the smart Internet of Things with strong computing capacity at the smart device, system and edge-level, embedded in a compute continuum from IoT-to-edge-to-cloud. Such Operating system should be device independent and implement advanced concepts such as ad-hoc clouds, time-triggered IoT, and decentralised intelligence.

Increasing European autonomy in data processing required to support future hyper-distributed applications by building open platforms and an open edge ecosystem including business models, driven by European actors. Achieving trust in these (meta) operating systems among actors in diverse industrial ecosystems by leveraging open standards and - where applicable - open source.

The emergence of an open edge ecosystem including midcaps, SMEs and start-ups that foster the up-take of an edge operating system, e.g. through a modular functional spectrum of executable apps and services, for nurturing a European network of innovators and developers. Demonstrators in key industrial and societal applications, which in future require more power at the edge.

Under this topic, 6 Innovation Actions have been funded:

NEMO

NEMO aims to establish itself as the game changer of IoT-Edge-Cloud Continuum by introducing an open source, flexible, adaptable, cybersecure and multi-technology meta-Operating System, sustainable during and after the end of the project, via the Eclipse foundation (NEMO consortium member). To achieve technology maturity and massive adoption, NEMO will not “reinvent the wheel”, but leverage and interface existing systems, technologies and Open Standards, and introduce novel concepts, tools, testing facilities/Living Labs and engagement campaigns to go beyond today’s state of the art, make breakthrough research and create sustainable innovation, already within the project lifetime.

NEMO will introduce innovations at different layers of the protocol stack, enabling on-device Cybersecure Federated ML/DRL, deliver time-triggered (TSN) multipath ad-hoc/hybrid self-organized and zero-delay failback/self-healing multi-cloud clusters, multi-technology Secure Execution Environment and on-Service Level Objectives meta-Orchestrator, Plugin and Apps Lifecycle Management and Intent Based programming tools. Moreover, NEMO will be “by design” and “by innovation” cybersecure and trusted adopting state of the art mechanisms such as Mutual TLS and Digital Identity Attestation.

aerOS

The project aerOS aims at transparently utilising the resources on the edge-to-cloud computing continuum for enabling applications in an effective manner, incorporating multiple services deployed on such a path. Therefore, aerOS will establish the missing piece: a common meta operating system that follows a collaborative IoT-edge–cloud architecture supporting flexible deployments (e.g., federated or hierarchical), bringing tremendous benefits as it enables the distribution of intelligence and computation – including Artificial Intelligence (AI), Machine Learning (ML), and big data analytics – to achieve an optimal solution while satisfying the given constraints.

FluiDOS

FluiDOS leverages the enormous, unused processing capacity at the edge, scattered across heterogeneous edge devices that struggle to integrate with each other and to coherently form a seamless computing continuum. By way of a disruptive, open-source paradigm that hinges upon secure protocols for advertisement and discovery, AI-powered resource orchestration and intent-based service integration, FluiDOS will create a fluid, dynamic, scalable and trustable computing continuum that spans across devices, unifies edge and cloud in an energy-aware fashion, and possibly extends beyond administrative boundaries. Notwithstanding its innovation signature, FluiDOS will build upon consolidated Operating Systems and orchestration solutions like Kubernetes, on top of which it will provide a new, enriched layer enacting resource sharing through advertisement/agreement procedures (in the horizontal dimension), and hierarchical aggregation of nodes, inspired by Inter-domain routing in the Internet (in the vertical dimension). Intent-based orchestration will leverage advanced AI Algorithms to optimize costs and energy usage in the continuum, promoting efficient usage of edge resources.

2.2.2.2 HORIZON-CL4-2022-DATA-01-02 Cognitive Cloud: AI-enabled computing continuum from Cloud to Edge (RIA)

Highly innovation cloud management layer making the best application of artificial intelligence techniques and AI models with automatic adaptation to the computing resources (i.e., connectivity, computing & storage) in cloud and edge to optimize where data are being processed (e.g. very close to the user at the edge, or in centralised capacities in the cloud). Seamless, transparent and trustworthy integration of diverse computing and data environments spanning from core cloud to edge, in an AI-enabled computing continuum.

Automatic adaptation to the growing complexity of requirements and the exponential increase of data driven by IoT deployment across sectors, users and contexts while achieving optimal use of resources, holistic security and data privacy and credibility. Interoperability challenges among computing and data platform providers should be addressed and cloud federation approaches (based on open standards, interoperability models and open platforms) should be considered where appropriate.

Under this topic, 9 Innovation Actions have been funded:

COGNIFOG

Next generation enablers, such as IoT, AI and cloud computing, open new opportunities to deal with world's current and future societal, environmental, and economic challenges. However, they come with significant data management challenges. According to IDC, the total amount of data generated only by connected devices will exceed 40 trillion gigabytes by 2025. In most of the current systems, data storage and analysis happen on centralized locations on the cloud. This is pushing network capacity to its limits. Furthermore, centralized storage and processing lead to single point of failure situations, which are critically inefficient in case of disasters and crisis. Our world is continuously living natural disasters, health crisis, climate change and security threats that show the importance of resilient and energy-efficient information systems.

COGNIFOG targets those challenges and proposes to build a Cognitive Fog Framework to: (i) reduce energy consumption and latency in next generation IT systems by reducing the network traffic, by analysing data at the edge in a distributed manner, closer to where they are generated, rather than routing them through the communication networks to a data center; (ii) reduce OPEX and faster service provisioning by providing a cognitive, self-adaptive framework with minimum or no human intervention, with dynamic provisioning of computing, storage and networking resources along the far-edge-to-edge-to-cloud path; (iii) ensure European leadership by providing an open interoperable framework with open APIs for application developers to rapidly create and deploy applications benefiting the edge-cloud continuum on top of heterogenous IoT/IT systems.

CODECO

The overall aim of CODECO is to contribute to a smoother and more flexible support of services across the Edge-Cloud continuum via the creation of a novel, cognitive Edge-Cloud management framework. To achieve this aim, CODECO proposes a unique, smart, and cross-layer orchestration between the decentralised data flow, computation, and networking services, to address Edge-Cloud challenges derived from the rising Internet and IoT service decentralisation.

DECICE

In DECICE, we develop an open and portable cloud management framework for automatic and adaptive optimization of applications by mapping jobs to the most suitable resources in a heterogeneous system landscape. By utilizing holistic monitoring, we construct a digital twin of the system that reflects on the original system. An AI-scheduler makes decisions on placement of job and data as well as conducting job rescheduling to adjust to system changes. A virtual training environment is provided that generates test data for training of ML-models and the exploration of what-if scenarios. The portable framework is integrated into the Kubernetes ecosystem and validated using relevant use cases on real-world heterogeneous systems.

EDGELESS

EDGELESS is set to efficiently operate serverless computing in extremely diverse computing environments from resource-constrained edge devices to highly-virtualised cloud platforms. By taking advantage of AI/ML solutions, it will enable automatic deployment and reconfiguration to fully exploit compute resources available on clusters of nearby edge nodes.

EDGELESS will define novel orchestration systems that provide a flexible horizontally scalable compute solution able to fully use heterogeneous edge resources, while preserving vertical integration with the cloud and the benefits of serverless, including its application programming model. It will address edge systems at design stage, particularly targeting low-latency, high-reliability applications with computationally-intensive tasks, requiring specialised hardware or a trusted environment. This ambitious challenge will be met via distributed computing solutions to partition the edge environment in clusters, each managed as a local decentralised serverless platform. In each cluster, orchestration and scheduling of jobs will run smoothly thanks to real-time monitoring of short-term load/network/energy conditions and anticipatory AI-powered algorithms to manage lightweight virtualised lambda executors, e.g., unikernels.

ACES

The increasing need for cloud services at the edge (edge–services) is caused by the rapidly growing quantity and capabilities of connected and interacting edge devices exchanging vast amounts of data.

This poses different challenges to cloud computing architectures at the edge, such as i) ability to provide end-to-end transaction resiliency of applications broken down in distributions of microservices; ii) creating reliability and stability of automation in cloud management under increasing complexity iii) secure and timely handling of the increasing and latency sensitive flow (east-west) of sensitive data and applications; iv) need for explainable AI and transparency of the increasing automation in edge-services platform by operators, software developers and end-users.

ACES will solve these challenges by infused autopoiesis and cognition on different levels of cloud management to empower with AI different functionalities such as: workload placement, service and resource management, data and policy management.

ACES key outcomes will be: i) autopoiesis cognitive cloud-edge framework; ii) awareness tools, AI/ML agents for workload placement, service and resource management, data and policy management, telemetry and monitoring; iii) agents safeguarding stability in situations of extreme load and complexity; iv) swarm technology-based methodology and implementation for orchestration of resources in the edge; v) edge-wide workload placement and optimization service; vi) an app store for classification, storage, sharing and rating of AI models used in ACES.

SovereignEdge.EU

An effective platform for the cognitive cloud-edge continuum must address a number of unsolved challenges, many of them derived from constrained resource devices, infrastructure heterogeneity, and the need to meet criteria such as performance, resilience, security, data sovereignty, and energy efficiency. A disaggregated architecture is required, making use of AI, automation, and portability to manage and adapt resources and workloads, and to respond in real time to possible incidents and security threats.

Edge application developers willing to speed up computation, save energy, and cut costs will need a way to combine their edge devices with the many resources available across the cloud-edge continuum. This innovative approach requires computationally-intensive data processing functions to be easily executed outside edge devices, sensors, and actuators. It is with that vision in mind that this project proposes a new distributed Function-as-a-Service (FaaS) paradigm for edge application management and smart orchestration, which will change how applications and services are deployed and executed in the cloud-edge continuum. Our AI-enabled adaptive serverless framework will provide applications with secure and portable access to a continuous data processing environment that abstracts the large-scale, geo-distributed, and low-latency capabilities provided by the cloud-edge continuum.

2.2.2.3 HORIZON-CL4-2022-DATA-01-03 Programming tools for decentralised intelligence and swarms (RIA)

Develop agile and secure architectures, dynamic programming environments and tools for the compute continuum from the device and edge perspective, including energy-efficient, lightweight AI-based approaches, tools for decentralised device and edge intelligence, innovative mesh architectures with mixed topologies to support concepts like tactile internet and swarm intelligence. This should support a paradigm shift from programming environments for individual devices to dynamic groups of devices like swarms. Research should include actionable data streams, contextual interaction and data fusion between the users and the objects as well as. analytical model distribution, delocalized computation and new mesh architectures.

Under this topic, 5 Innovation Actions have been funded:

SMARTEDGE

The objective of the SMARTEDGE project is to enable the dynamic integration of decentralised edge intelligence at runtime while ensuring reliability, security, privacy and scalability. We will achieve this by enabling a semantic-based interplay of the edge devices of such systems via a cross-layer toolchain that facilitates the seamless and real-time discoverability and composability of autonomous intelligence swarm. Hence, an application can be freely built by distributing the processing, data fusion and control across heterogeneous sensors, devices and edges with ubiquitous low-latency connectivity. The goal of this project is to develop a SMARTEDGE solution with a low-code tool programming environment with various tools: (1) Continuous Semantic Integration (CSI); (2) Dynamic Swarm Network (DSW); and (3) Low-code Toolchain for Edge Intelligence. CSI allows the SMARTEDGE solution to interact with devices according to a (i) standardized semantic interface, via a (ii) continuous conversion process based on declarative mappings and scalable from edge to cloud, and (iii) providing a declarative approach for the creation and orchestration of apps based on swarm intelligence.

TaRDIS

TaRDIS proposes a language-independent event-driven programming paradigm that exposes, through an event-based interface, distribution abstractions and powerful decentralised machine learning primitives. The programming environment will assist in building correct systems by taking advantage of behavioural types to automatically analyse the component's interactions to ensure correctness-by-design of their applications, taking into account application invariants and the properties of the target execution environment. TaRDIS underlying distributed middleware will provide essential services, including data management and decentralised machine learning components. The middleware will hide the heterogeneity and address the dynamicity of the distributed execution environment by orchestrating and adapting the execution of different application components across devices in an autonomic and intelligent way. TaRDIS results will be integrated in a development environment, and also as standalone tools, both of which can be used for developing applications for swarm systems.

OpenSwarm

The ambition of the OpenSwarm project is to trigger the next revolution in these data-driven systems by developing true collaborative and distributed smart nodes, through groundbreaking R&I in three technological pillars: efficient networking and management of smart nodes, collaborative energy-aware Artificial Intelligence (AI), and energy-aware swarm programming. Results are implemented in an open software package called "OpenSwarm", which is verified in our labs on two 1,000 node testbeds. OpenSwarm is then validated in five real-world proof-of-concept use cases, covering four application domains: Renewable Energy Community (Cities & Community), Supporting Human Workers in Harvesting (Environmental), Ocean Noise Pollution Monitoring (Environmental), Health and Safety in Industrial Production Sites (Industrial/Health), Moving Networks in Trains (Mobility).

INCODE

INCODE envisions the design and development of an open platform for the deployment and dynamic management of end user applications, over distributed, heterogeneous and trusted IoT-Edge node infrastructures, with enhanced programmability features and tools at both the network infrastructure level and the service design and operational level. The platform is implemented following three innovative design approaches: i) The deployment and management of the applications is conducted by an orchestration framework that follows a vertical layered approach from the end user interface to the infrastructure management while spanning horizontally across the device-edge-core-cloud continuum. The deployment follows the user-defined networking and operational features of the application in its northbound interface and a tight integration with state-of-the-art IoT, edge/cloud computing, and networking platforms in its southbound interface through a well-define driver API framework. With this approach the full programmability and reconfigurability of resources across the continuum is enabled. ii) An open and extensible, programming toolset facilitates application development and deployment for large swarms of devices at the edge through a multi-role Internal Developer Platform (IDP) and new feature development and testing, iii) A secure and trusted framework for registering and authenticating IoT device and edge nodes entering the system as well as the data sharing and application deployment.

OASEES

OASEES aims to create an open, decentralized, intelligent, programmable edge framework for Swarm architectures and applications, leveraging the Decentralized Autonomous Organization (DAO) paradigm and integrating Human-in-the-Loop (HITL) processes for efficient decision making. The OASEES vision is to provide the open tools and secure environments for swarm programming and orchestration for numerous fields, in a completely decentralized manner. An important aspect in this process is identification and identity management, in which OASEES targets the implementation of a portable and privacy preserving ID federation system, for edge devices and services, with full compliance and compatibility to GAIA-X federation and IDSA trust directives and specifications. This situation solidifies the need for an integrated enabler framework tailored to the edge's extreme data processing demands, using different edge accelerators, i.e. GPU, NPU, SNN and Quantum.

3. Industrial Cases in CEI Continuum for Manufacturing

This Chapter will briefly report on some Industrial Pilots conducted inside the projects mentioned in Chapter 2.

3.1 Made in Europe projects: CEI adoption in Industrial Pilots

3.1.1. Zero-defect manufacturing towards zero-waste

OPENZDM

Open Platform for Realising Zero Defects in Cyber Physical Manufacturing. The following industrial Pilot regards EV Batteries manufacturing (APTIV).

Pilot – EV Battery modules manufacturer [APTIV]

Description

APTIV is a manufacturer located in Torino, Italy. APTIV's primary products include the manufacturing of plastic connectors and EV battery modules, included inside battery packs. The facilities of APTIV can be seen in the figure on the right. APTIV's competitive advantage is the offering of unique battery modules for EVs, thus giving the manufacturer a significant advantage within the EV battery market and the broader company itself. APTIV's manufacturing line is mainly automated with little human intervention.

Overview of the APTIV plant.

Scope of the pilot

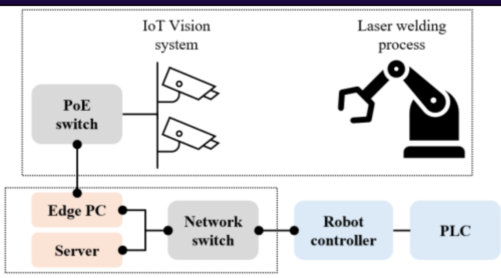
One of the main manufacturing processes of APTIV's system includes an automated laser welding station. However, due to the large size of the battery module (approximately 1 meter in length), consistent and high-quality welding is difficult to achieve. This increases the chances of defect generation, and the implementation of proactive quality control is of utmost priority. Additionally, the battery cells, included in the battery modules, are vulnerable to aesthetical defects, such as scratches, dents and bumps due to their soft plastic enclosure as well as positioning defects that can result in defective welding. Thus, an approach for early aesthetical and positioning defect detection is crucial to prevent further processing of defective battery modules.

Stakeholder/s

The EV battery modules pilot is managed by APTIV. Additionally, APTIV is supported by LMS and COMAU. COMAU is responsible for the development of the two IoT vision systems. The first system is composed of IR cameras capable of capturing a video of each weld, and through an AI algorithm developed by COMAU detect the welding defects on the battery module. The second vision system is made of 2D monochrome cameras, designed by COMAU, coupled with an AI detection algorithm, created by LMS, that recognises and reports identified aesthetical and positioning defects on the battery cells.

Existing infrastructure & assets

APTIV's various operations are managed by a PROFINET connection. Any data received from equipment in the system are sent to the APTIV network and are managed by the DMS system. Battery cells and modules are traced through barcodes, present on all components. In addition to the DMS, a dedicated server and PC on the edge is available. The PC and server are responsible for the management of the two IoT NDI vision systems and the execution of the AI algorithms for detecting welding defects and aesthetical defects. Storage for NDI-acquired data is provided by the edge server, enabling fast and continuous access to historical NDI data. The architecture of the vision system infrastructure can be seen in the figure on the right.



Architecture of the vision system infrastructure.

<table>
<tr><th colspan="2">Technical goals</th></tr>
<tr><td colspan="2">Through openZDM, APTIV is aiming at several improvements in terms of its defect generation to hit its sustainability future goals. In more detail, an overall 50% reduction in generated welding defects is expected. This will be a direct result of the 2D monochrome vision-based NDI system since it will enable proactive quality control through the detection of defective modules and battery cells before they are welded. In addition, an increase in throughput by 5% is foreseen due to the application of the 2D monochrome vision-based system since positioning defects will be early detected and the cell placement of the cells on the modules will be adjusted to prevent the rework of parts in the laser welding process. Lastly, a 10% decrease in production costs is expected, through the prevention of further processing of defective battery modules after the laser welding process.</td></tr>
<tr><th colspan="2">Key Results</th></tr>
<tr><td colspan="2">Up to now, the impact of the openZDM solution, concerning the goals set out by APTIV, is too early to be measured, given the limited amount of time the system has become available to the manufacturer. However, it has been documented that the AI algorithm capable of detecting welding defects using the IR vision system, has demonstrated a 90% accuracy in terms of the detected defects. In addition, through simulations, it has been estimated that by the end of openZDM, the digitalization of APTIV using IoT systems and AI algorithms will impact the pilot with an approximate 10% reduction in CO_2 eq. emissions; thus, contributing to the greening of the manufacturer. Lastly, based on current estimates in APTIV, by the end of openZDM, defects related to laser welding will be reduced to 0.8% from 1.9% which is the current defect rate. This will ultimately result in a substantial increase in yearly revenue by approximately 300K €.</td></tr>
<tr><th colspan="2">Available Data</th></tr>
<tr><td>Data sources available for the project</td><td>In APTIV, openZDM has access to both historical and real-time data from manufacturing processes (legacy systems) and IoT devices. To enable such data access the following approaches are used:

Data stored on the edge server: Data from both NDI systems are being stored in dedicated databases on the edge server. This enables fast and secure access to historical NDI data that are being used by the rest of the openZDM system.
Data stored on the DMS: Data from the legacy systems are being stored in the APTIV DMS. This provides the openZDM system with access to legacy systems-related historical data.
Data stored in AAS: Multiple instances of product AASs contain product-related historical data which can be accessed by the openZDM system through an AAS server deployed on the edge.

In addition, to access data from the various data sources, the openZDM system utilizes the following communication protocols:

MQTT: An MQTT broker is deployed in APTIV. Through the MQTT broker, the openZDM system has access to real-time data from both the legacy systems and the NDI IoT devices.
HTTP Requests: Using HTTP Requests, product, legacy systems and NDI historical data can be accessed by the openZDM system.
</td></tr>
</table>

3.1.2 Artificial Intelligence for sustainable, agile manufacturing

AIDEAS

AI Driven industrial Equipment product life cycle boosting Agility, Sustainability and resilience is bringing one industrial pilot about AI for a machining center (PAMA)

Pilot - PAMA - AI for Machining Centres

Description

AI Driven Industrial Equipment Product Life Cycle Boosting Agility, Sustainability and Resilience
AIDEAS Kick off Meeting – 18th October 2022, Thessaloniki
Presenter: Fabrizio Defant (PAMA)

Scope of the pilot

- **DESIGN phase:** The aim is to reduce the time and improve the accuracy of evaluating and optimizing the performance of precision machine tools and manufacturing equipment during the early design stages using advanced CAE simulation tools.
- **MANUFACTURING phase:** Our goal is to implement systematic tracking and storage of manufacturing errors and legacy data to facilitate knowledge extraction from design and production events, enhancing error correction and efficiency.
- **USE phase:** The objective is to develop and implement robust strategies for compensating geometric and thermal errors in machine tools, tailored to various application scenarios and adaptable to changes in machine configurations.
- **REPAIR/REUSE/RECYCLE phase:** We aim to establish preventive maintenance strategies and deepen the knowledge of the actual 'health' state of machine parts/components at end of life, to support the sustainable extension of the machine's overall life cycle.

Stakeholder/s

Industrial partner: PAMA
Technology provider: CESI
Solution providers: UNIVPM

Existing infrastructure & assets

1. **CAE Simulation Tools**: Advanced computer-aided engineering tools for performance evaluation and optimization at the early design stages.
2. **Data Recording Systems**: PCs used by operators to record manufacturing errors.
3. **Error Compensation Strategies**: Systems and software in place to compensate for geometric and thermal errors during machine operation.
4. **Maintenance and Repair Systems**: Established maintenance protocols based on run-to-failure strategies and preventative tasks.
5. **Legacy Data Systems**: Digital storage solutions for sporadically storing manufacturing data.

Technical goals

- **DESIGN phase:** The AI-based prediction models enhance the performance evaluation and optimization of machine tools at the design stage, significantly reducing development time and fostering digital transformation.
- **MANUFACTURING phase:** AI tools are used to retrofit design with manufacturing insights to optimize future designs by correlating part measurements with assembly accuracy.
- **USE phase:** AI predicts and compensates for geometric and thermal errors during machining through adaptive control, optimizing energy usage and operational conditions.
- **REPAIR/REUSE/RECYCLE phase:** AI tools assess the performance and potential reuse of machine parts at the end of their first life cycle, identify optimal retrofitting strategies, and estimate costs and maintenance plans for extended use.

Key Results

1. **Increased Efficiency:** Significantly reduced product development time in the design phase through smarter and faster optimizations.
2. **Enhanced Accuracy:** Improved precision in the manufacturing process by using AI to analyze and retrofit designs based on historical data and production outcomes.
3. **Reduced Operational Errors:** Effective prediction and compensation for geometric and thermal errors during use, leading to minimized machine downtime and optimized performance.
4. **Sustainable Practices:** Advanced assessment and retrofitting strategies at the end of the first life of machines, promoting reuse and recycling, which helps in extending the lifecycle of the equipment and reducing waste and costs.

Available Data

Data sources available for the project	• Dataset of historical results obtained by correlation of **design parameters** values and **machine performances** (e.g. precision, chip removal capacity, cycle time, Kv, Jerk…) actually obtained in real field applications. • Consistent (labelled) data set obtained by correlation of outcomes of single part measures with part assembly ones.

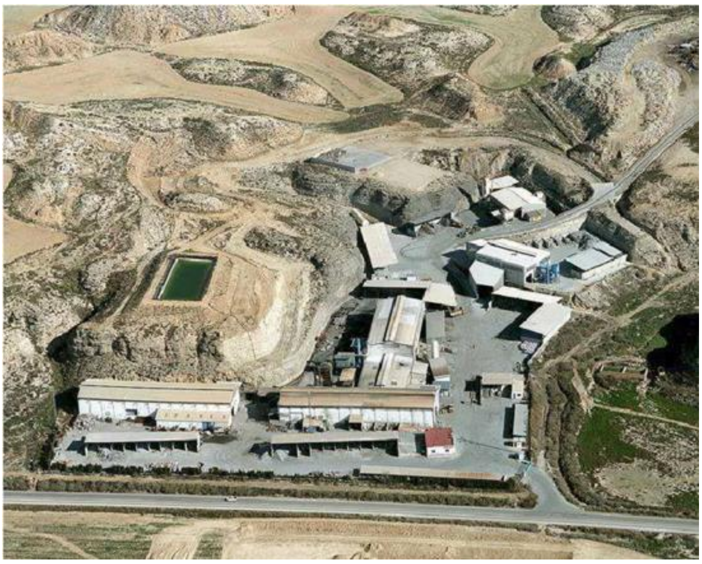
s-X-AIPI

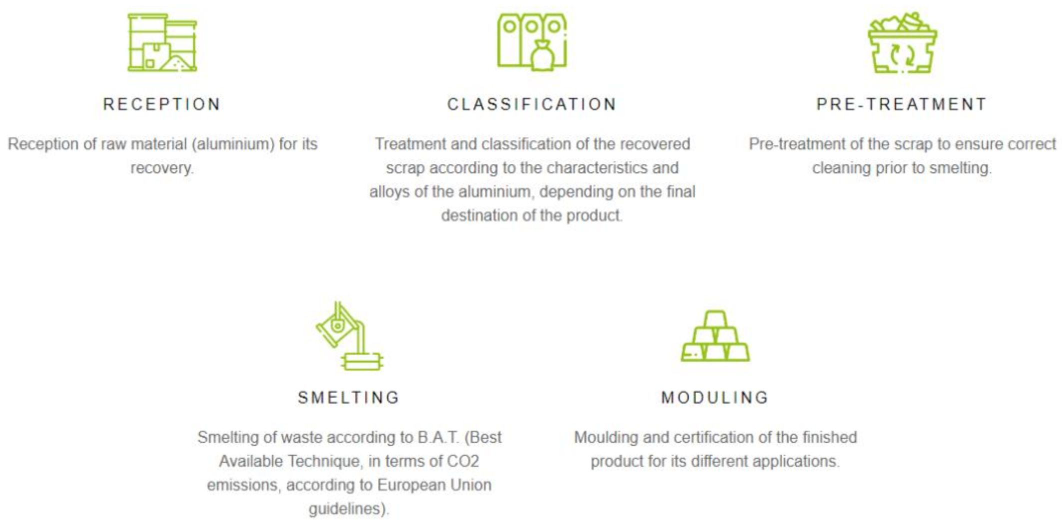
Self-X Artificial Intelligence for European Process Industry digital transformation is bringing one industrial pilots ion the process industry: Aluminium (DALSA)

Pilot - [IDALSA Aluminium use-case]

Description

IDALSA is dedicated to the manufacture of 100% green and sustainable aluminium ingots from the recycling and smelting of waste and scraps. Aligned with its commitment for a more sustainable manufacture, all raw material is used and re-used to give it a new life, thus promoting Circular Economy. The aluminium recycling plant of IDALSA is located in Pradillo del Ebro (Zaragoza, Spain).





Scope of the pilot

In the s-X-AIPI Project, the development and deployment of AI-based technologies will optimize the recycling process by supporting plant operators in their daily operational decisions with an Intelligent Decision Support System (IDSS). The IDSS will support operators based on data-driven methods that cover information from the complete value chain of aluminium products.

Stakeholder/s

IDALSA (end-user), AIMEN (developer)

Existing infrastructure & assets

Information comes from IDALSA's production database, and it is stored in a local MongoDB database for project developments.

All software developments are deployed in a Dockerized format at an AIMEN private server.

Technical goals

The main goals of the s-X-AIPI Project in the Aluminium use-case can be summarized in two objectives:

- Provide optimized information to operators in a user-friendly approach to enhance their knowledge of the process and materials.
- Provide data-driven, AI solutions to support operators in their daily operational activities, specifically in the selection of materials for the aluminium-making process (short-term planning with potential scalability to medium and long-term).

These goals contribute to specific KPIs (target values are confidential), including the improvement of productivity and quality, the reduction in the use of resources, and increase of competence, skills, and qualification.

Key Results

One of the key challenges of the IDSS is supporting the decision-making process of the recipe of materials i.e., combination of scraps, which is currently performed by aluminium experts, and it is highly dependent on human expertise. For this purpose, several AI solutions are being developed:

- A ML regressor model to estimate the chemical composition of scrap mixtures.
- A ML regressor model to estimate the final chemical composition of melted scrap mixtures and alloys.
- A Generative-based Reinforcement Learning Framework to propose new recipes based on user requests (products and quantities).

All AI solutions are deployed as part of an AI Data Pipeline with Autonomic Computing capabilities for self-management. The AI Data Pipeline includes the following components: Data Ingestion & Transformation, (MongoDB) database, Data Exploration, Model Training, and Real-World Usage. The Autonomic Computing capabilities include self-configuration, self-X optimization, self-X healing, and self-X protection, and they are triggered via the analysis of metadata coming from the AI Data Pipeline. In addition, communication with external platforms from the project (Autonomic Manager and Influx Platform) is guaranteed via REST APIs.

A web application has been developed to facilitate user interaction with the system. As a human-centric solution, user feedback is essential for all developments. There are two actions that require and consider human feedback actively. On one hand, human feedback is used in the Reinforcement Learning model to evaluate the generated recipes and adapt the results of the system considering the operators' preferences (on-going). On the other hand, user feedback is considered as part of the metadata to trigger the different self-X abilities in the pipeline. There is a first version of all the components of the pipeline available and being used by IDALSA at the moment.

Image of the main page of web application:

Image of the web page for the ML regressor that predicts the chemical composition of the mixture of scraps:

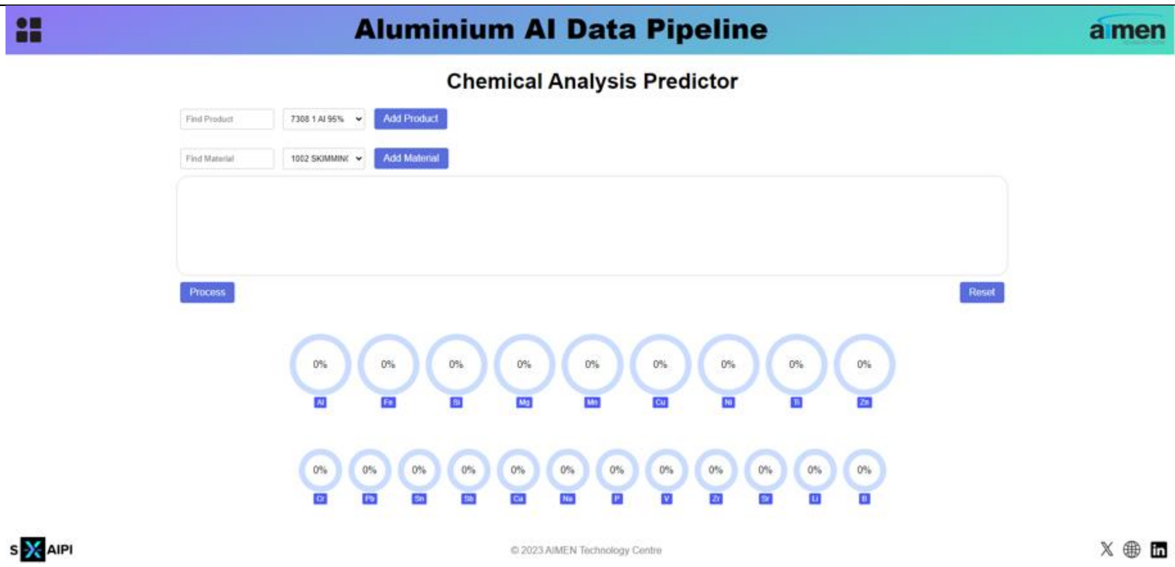
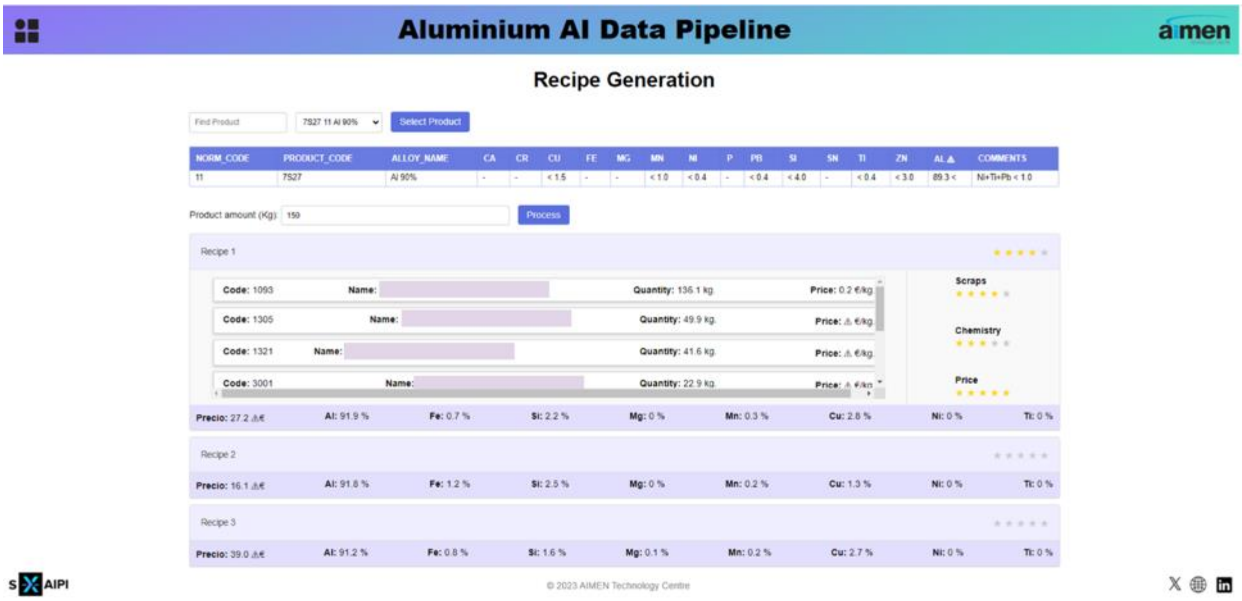


Image of the web page of the Generative RL Framework to generate recipes upon user requests on products (and quantity):



More info about the preliminary results of the ML algorithms and the pipeline/digital architecture/others can be provided upon request.

Available Data	
Data sources available for the project	Reports coming from IDALSA database: scraps analysis, aluminium recipes, chemical analysis of the mixtures through the process, and process information: duration of the heat, oxygen and gas consumption, furnaces used, etc.

3.1.3 ICT Innovation for Manufacturing Sustainability in SMEs (I4MS2)

WASABI

White-label shop for digital intelligent assistance and human-AI collaboration in manufacturing is bringing one industrial case about Hospital assets management.

Pilot - [title]
Description
Several locations: • Central sterilisation of: o Burgos Hospital (Avenida de las Islas Baleares, Burgos) o Madrid Hospital (Paseo de la Castellana, 261, Madrid) o Murcia Hospital (Paraje Torre Octavio, Pozo Aledo) The "Recycling and Revamping of Surgical Tools" pilot, spearheaded by CROMA, focuses on enhancing the sustainability practices within the healthcare sector, particularly in the management of surgical tools. This pilot addresses the lifecycle of surgical instruments by assessing their condition post-surgery to determine their suitability for reuse or the need for recycling. By integrating Cloud, Edge, and IoT technologies, CROMA can efficiently track and analyze the usage and status of each tool. Instruments deemed fit for use are sterilized and prepared for subsequent surgeries, while those unfit undergo a process to determine the most environmentally friendly recycling or disposal method. This systematic approach not only helps in reducing medical waste significantly but also ensures compliance with health and safety standards, thereby supporting sustainable practices in healthcare facilities. This pilot represents a critical step towards reducing the environmental footprint of healthcare services while maintaining high standards of patient care and safety.
Scope of the pilot
1. Tool Lifecycle Management: The primary focus is on extending the lifecycle of surgical tools through systematic assessments post-use. The pilot aims to identify tools that can be sterilized and reused, thereby reducing waste and the demand for new tools. 2. Sustainability Practices: The pilot is designed to integrate sustainable practices into the daily operations of healthcare facilities, focusing on minimizing environmental impact through efficient resource utilization and recycling processes. 3. Technology Integration: Utilizing Cloud, Edge, and IoT technologies, the pilot facilitates real-time tracking and management of tools. These technologies enable precise tracking of tool usage, condition assessments, and decision-making regarding sterilization, reuse, or recycling. 4. Compliance and Safety: Ensuring that all processes adhere to strict health and safety regulations is a critical component of the pilot. This includes maintaining the sterility and functional integrity of surgical tools that are reused. 5. Cost Efficiency: By reducing the need to purchase new tools through effective reuse and recycling, the pilot aims to provide cost savings for healthcare providers, which can be redirected towards other critical areas of patient care. This pilot not only aims to enhance operational efficiencies and compliance with environmental standards but also sets a precedent for implementing CEI technologies in critical healthcare processes.
Stakeholder/s
The stakeholders of the "Recycling and Revamping of Surgical Tools" pilot include a diverse group that spans from healthcare providers to technology developers and regulatory bodies. Key stakeholders are: 1. Healthcare Providers: Hospitals and clinics that utilize surgical tools are primary stakeholders. They are directly impacted by the pilot's outcomes, which aim to reduce operational costs and enhance sustainability practices within their facilities. 2. CROMA: As the pilot leader, CROMA is responsible for the execution and oversight of the pilot activities. They play a crucial role in coordinating between different stakeholders, managing technology integration, and ensuring the pilot meets its objectives. 3. Technology Developers/Providers in the WASABI Consortium: These include companies and research institutions that develop and supply the Cloud, Edge, and IoT technologies used for tool tracking and data management. Their expertise is vital for the successful integration of these technologies into the healthcare setting. 4. Regulatory Bodies: Entities that govern healthcare safety and environmental standards are also stakeholders. They are interested in ensuring that the pilot adheres to all relevant regulations and contributes to broader goals of environmental sustainability and patient safety. 5. Environmental Organizations: Advocacy groups and organizations focused on environmental sustainability have a vested interest in the pilot. They support initiatives that promote recycling and reduce waste within healthcare, aligning with their broader environmental agendas.

6. Medical Staff and Technicians: These end-users of the surgical tools are crucial stakeholders as they interact directly with the technologies and processes being piloted. Their feedback is essential for refining tool management practices and ensuring the usability and effectiveness of the new systems.

Existing infrastructure & assets

1. Hospital Facilities: Existing hospital and clinic facilities provide the operational setting for implementing the pilot. These facilities already have established procedures for handling surgical tools, including sterilization and disposal processes.

2. Sterilization Equipment: The current sterilization equipment in hospitals is a critical asset, used for preparing reusable tools for subsequent surgeries. This equipment is essential for maintaining the safety and effectiveness of the recycling and revamping processes.

3. Tracking and Data Management Systems: Many healthcare facilities already have some form of inventory and tracking systems for surgical tools. These systems are enhanced with IoT technology to improve accuracy and integration with new cloud-based and edge computing solutions.

4. Waste Management Systems: Existing waste management protocols and equipment in hospitals provide a foundation for the pilot's recycling processes. These systems ensure that tools not fit for reuse are handled according to environmental and health standards.

5. CEI Technologies from WASABI Consortium: The pilot incorporates advanced Cloud, Edge, and IoT technologies provided by the WASABI consortium. These technologies are integrated into the existing IT infrastructure to enhance data collection, processing, and decision-making capabilities related to tool management.

6. Skilled Personnel: Medical staff, including surgeons, nurses, and technical staff familiar with surgical tool usage and maintenance, are key assets. Their expertise and daily interaction with the tools provide invaluable input into optimizing the pilot's processes.

Technical goals

The technical goals of the "Recycling and Revamping of Surgical Tools" pilot focus on enhancing the efficiency, sustainability, and compliance of surgical tool management through the integration of advanced technologies. Key technical goals include:

1. Real-Time Tracking and Monitoring: Implement IoT devices to enable real-time tracking and condition monitoring of surgical tools throughout their lifecycle. This technology aims to provide instant data on tool usage and sterilization status to facilitate timely decision-making.

2. Data Integration and Analysis: Develop a centralized platform that integrates data collected from IoT sensors with existing hospital management systems using cloud technologies. This platform will analyze the data to optimize the reuse and recycling processes and generate insights into tool lifecycle management.

3. Automation of Tool Assessment: Utilize edge computing to automate the initial assessment of tools post-surgery. This involves developing algorithms to quickly determine whether tools should be reused, reconditioned, or recycled based on their condition and usage history.

4. Enhanced Sterilization Protocols: Refine and enhance sterilization processes using data-driven insights to ensure that tools are safe for reuse. This involves integrating automated systems that adjust sterilization methods based on the specific conditions and histories of each tool.

5. Compliance with Health and Safety Standards: Ensure that all technological implementations comply with relevant health and safety regulations. This includes maintaining the integrity and cleanliness of tools, as well as adhering to environmental standards in the recycling process.

6. User Interface and Reporting Tools: Develop intuitive user interfaces for medical staff and technicians that provide easy access to information about tool status, history, and management options. Additionally, create reporting features that allow for tracking compliance and efficiency metrics.

These technical goals are designed to leverage CEI technologies to transform the current practices around surgical tool management into a more efficient, sustainable, and compliant system, ultimately improving the overall operational effectiveness of healthcare facilities.

Key Results

1. Increased Tool Reuse Rates: By implementing precise tracking and condition monitoring, the pilot expects to significantly increase the rate of tool reuse. This will reduce waste and the need for new tools, contributing to resource conservation and sustainability.

2. Enhanced Decision-Making Accuracy: The integration of IoT and edge computing technologies will enable more accurate and timely decisions regarding the sterilization, reuse, or recycling of surgical tools. This improvement in decision-making helps ensure that tools are managed efficiently and safely.

3. Reduction in Environmental Impact: By improving the recycling processes and increasing the reuse of surgical tools, the pilot aims to lower the carbon footprint associated with the production and disposal of these tools, thus mitigating the overall environmental impact. 4. Compliance with Regulatory Standards: The pilot will demonstrate compliance with health, safety, and environmental regulations through advanced data management and process control, ensuring that all activities meet or exceed the required standards. 5. Cost Savings for Healthcare Facilities: By extending the life of surgical tools and reducing the need for new purchases, the pilot will deliver significant cost savings to healthcare facilities. These savings can be redirected to other critical areas of patient care and facility improvement. 6. Improved Sterilization Processes: Leveraging data-driven insights to enhance sterilization protocols will ensure that tools are effectively sterilized, thus maintaining high standards of patient safety and care. 7. User Adoption and Satisfaction: Through the development of user-friendly interfaces and streamlined processes, the pilot aims to achieve high levels of user adoption and satisfaction among healthcare professionals, thereby ensuring the successful implementation and sustainability of the new systems.	
Available Data	
Data sources available for the project	1. Usage Data: Detailed logs of surgical tool use, including frequency, duration, and specific procedures they are used in. This data is essential for assessing wear and determining the appropriate point for tool refurbishment or recycling. 2. Condition Assessment Data: Data collected from IoT sensors attached to tools that assess their condition post-use. This includes parameters like temperature, pressure applied, or any detectable physical deformities, which help in making informed decisions about sterilization, reuse, or disposal. 3. Sterilization Cycle Data: Records of each tool's sterilization cycles, including methods used, cycle duration, and effectiveness, providing insights into the sterilization process and its impact on tool longevity and safety. 4. Environmental Data: Information regarding the environmental conditions of storage and usage areas, such as humidity and temperature, which can affect tool integrity and sterilization needs. 5. Maintenance and Repair Histories: Historical data on tool maintenance, repairs, and any failures, which is crucial for predicting future tool reliability and scheduling preemptive maintenance or replacement. 6. Regulatory Compliance Data: Documentation and data related to compliance with health and safety standards, which are critical for ensuring that all processes meet regulatory requirements. 7. Cost Data: Economic data related to the purchase, maintenance, and operation of surgical tools, providing insights into the financial impact of the current management practices versus the proposed improvements.

AI REDGIO 5.0

Regions and (E)DIHs alliance for AI-at-the-Edge adoption by European Industry 5.0 Manufacturing SMEs is bringing two industrial cases, run by SMEs, one in Spain in the food industry and another in Italy in the metal sheets industry.

.Pilot - SustGAIN

Description

SustGAIN is an SME-driven experiment that is being carried out in Galicia (Spain) within the framework of the AI REDGIO 5.0 project. The experiment is led by Quescrem and Gradiant and focused on the application of AI and Edge technologies to improve the quality of Quescrem's end product (cheese cream) and to reduce waste, in order to improve sustainability.



Scope of the pilot

The Galician region's industrial landscape in northwest Spain features an important weight of mid-sized manufacturing industries based on bio-inputs coming from its important bio- and primary sector (agrifood, fish, wood and others).

For Quescrem, a company with activities in this scenario, the main motivation behind the experiment is to improve the quality of the end product (cheese cream) and reduce waste to improve sustainability. The idea is to use process data stored in Quescrem's systems, as well as real-time data streams collected from production lines, in order to prescribe the optimal parameters that minimize waste (mainly permeate) and increase quality (e.g. homogeneize cream cheese texture) as well as efficiency.

To this end, trustworthy edge AI models for real-time regression and classification of data-streams will be developed and integrated. The experiment ensure efficient, secure and accurate response considering the device's common computational and communication constraints. It will also grant traceability, transparency and trustworthiness of its outputs to operators and stakeholders.

Real-time analysis of manufacturing process data through AI algorithms at edge level will enable discovery of complex patterns and provision of accurate predictions that support decision making. It is important to consider that traditional batch learning algorithms are designed to learn a model from the entire training data set at once. Thus, these AI models are not appropriate for real-time analysis of data streams as they reveal poor performance while handling concept drift issues. Concept drift describes common and unforeseeable deviations in the underlying distribution of data streams overtime. Machine learning applications for real-time analysis will result in poor performance if efficient adaptation of models to different types of concept drift is not correctly addressed. One of the main purposes of this experiment is to develop AI algorithms that address these issues and provide a solution for them.

Stakeholder/s

End-User: Quescrem

Located in Lugo, northwest Spain, Quescrem was founded in 2006 and during its 16 years of activity it has always been heavily committed to innovation, by creating high-quality products for the food industry, the professional cooking and bakery as well as consumers. This commitment has led Quescrem to design and manufacture cream cheeses, mascarpone and other dairy products that are known for their creaminess, taste and functionality. Thus, the industrial processes of the company are heavily oriented towards achieving the highest level of quality in its products as well as reducing variability in the organoleptic properties such as creaminess in its products. Also, one of the main objectives of the company to comply with sustainability goals is to reduce waste generation and optimise the use of raw materials, water and energy in manufacturing activities.

The main involved departments from this company in the experiment will be the following ones:

- Manufacturing department
- Quality department
- Maintenance department

Technology Provider: Gradiant

Gradiant, Spanish ICT technology centre, aims to improve the competitiveness of companies by transferring knowledge and technologies in the fields of connectivity, intelligence and security. With more than 150 professionals and 14 applied patents, Gradiant has developed more than 340 different R&D&i projects, becoming one of the main engines of innovation in Galicia. In 2022, Gradiant's turnover reached 8,5 million euros, working with more than 370 clients in 30 countries over the past 13 years.

Gradiant is backed by a board that includes representatives of the three Galician universities (Vigo, Santiago and A Coruña) and companies: Abanca, Altia, Arteixo Telecom, Egatel, Indra, Plexus, R, Telefónica, Televés; and INEO business association, which represents most of ICT Galician companies.

The commitment with quality is a constant from the beginning. Nine months after starting the activity, Gradiant achieved the Quality Management UNE-EN ISO 9001:2008; and one year later, UNE 166002 R&D&I Management Systems was obtained. In 2011, Gradiant was included in the demanding state registration of Technological Innovation Centres (known in Spanish as CIT). Since 2018, Gradiant has held the Certification in Information Security Management Systems UNE-EN ISO/IEC 27001.

After thirteen years of activity, Gradiant is positioned as a technology partner for the industry, oriented to their needs in the field of ICT, contributing their national and international experience in technologies for security and privacy; processing of multimedia signals; Internet of Things; biometrics and data analytics; and advanced communications systems.

In this experiment Gradiant aims to apply several edge computing and AI technologies in order to help Quescrem achieve its objectives.

Existing infrastructure & assets

Current systems don't use specific standards, apart from REST APIs, database connection through SQL languages and in some cases OPC-UA to get data from the process line. No AI or edge technologies have been incorporated into the company. Thus, during the AI REDGIO project a specific infrastructure will be deployed in order to orchestrate AI services at the edge and manage their lifecycle.

MES (TrakSYS)

The MES is currently being implemented in Quescrem's facilities and it is expected to be fully operative. It provides real-time data collection, analysis and reporting capabilities that allow it to monitor the production process and make data-driven decisions to improve efficiency and quality. The MES keeps track of all the process variables and allows to formulate manufacturing orders depending on the product that needs to be produced. It allows to send recipes to the machines in the physical process so they can start working with the established ingredients and quantities to create the final product. The MES interacts with the machines and sensors deployed in the manufacturing shopfloor, with the ERP and APS.

OPC-UA Server (KEPServerEx)

Real-time data of the whole production process is exposed via this OPC-UA server. Thus, this data can be directly consumed using this industrial protocol allowing the monitoring of all the processes' variables in real time, such as temperatures, pressures, etc. As long as the MES is not fully operational, the data provided by this server, together with the data stored in other Quescrem databases related to quality parameters and laboratory analysis, will be the one used as input for the AI/ML models to be developed.

APS (Siemens OPCENTER)

Its objective is to optimize production planning and scheduling and create the final manufacturing orders that will be passed to the formulation system and the MES. Thus, this service interacts basically with the ERP to get the MOs and with the MES to pass them in the correct order.

ERP (SAP)

The ERP solution used by Quescrem in their operations is SAP. It manages providers, customer orders, reception of raw materials as well as financial costs. This service interacts with the MES, the WMS and the APS.

WMS (Fast Process)

The WMS is used to manage and optimize the flow of materials and finished goods, helping to reduce costs and improve overall efficiency by providing real-time visibility into inventory levels and optimizing storage and picking processes. The WMS interacts mainly with the ERP.

Technical goals

This experiment will use ML models for real-time processing from sensor data-streams collected from production equipment and lines. These models will be able to solve multivariate regression and classification supervised problems. Moreover, they will be the basis of the prescription system to dynamically reduce waste and optimise fabrication setpoints to ensure quality.

Incremental learning (IL) algorithms and technologies will be selected, in addition to "traditional" AI/ML models, as they provide a noteworthy benefit within the scope of real-time analysis for edge AI applications. The model's goal is to be able to incrementally learn as new data becomes available, efficiently adapting to unseen patterns and concept-drift issues without significant performance losses. Despite the final algorithms will be selected during the execution of the experiment, some of the feasible AI technologies and IL algorithms that are being explored in this pilot include Deep Neural Decision Forests and Prototype-based models.

Key Results

The key results that are expected after the execution of this pilot are:

- **Decrease in the percentage of tanks released out of specification.** In Quescrem's daily production several tanks of 2500 litres of different products are prepared. For Quescrem this is a batch: quality collects samples of these tanks in hot and after a few days in cold, and the product is released or blocked depending on certain aspects of these samples. The product that is released can be within specifications set out in the product sheet or not. It does not mean that the product is wrong but for example if it should have a hardness of 24 +- 0.5 and the sample gives 26, it means that the end product's quality is not appropriate. The execution of this experiment aims to reduce the percentage of tanks that ended up being released out of the specification, thus improving the quality of the end product.

- **Waste reduction**. Waste is considered as the difference between kg at the beginning of the process minus kg at the end of the process. All waste needs to be sent to treatment plants. Thanks to the execution of this experiment, the percentage of waste that is generated during the production process is expected to be decreased.

Available Data	
Data sources available for the project	The dataset that will be generated during the execution of this experiment is a private dataset. It will be part of the AI REDGIO 5.0 datasets collection, being only the metadata released.

Pilot - SCAMM

Description

The SCAMM pilot is an SME-driven experiment carried out in Lombardy (Italy) within the framework of the AI REDGIO 5.0 project. The experiment has been proposed by SCAMM, in collaboration with the research consortium Intellimech, and revolves around a reconfigurable pressing line for sheet metal working automation. The main objective of the pilot is to implement and test an advanced monitoring system and a dedicated knowledge management tool to support the set-up and supervision of the line working conditions, enhancing efficiency and operators' well-being while reducing costs, time, and resource usage.

Scope of the pilot

The experiment revolves around a reconfigurable pressing line, made available by SCAMM and installed at "MOLLIS ANTONIO S.r.l." in Italy. The aforementioned line is an integrated solution for sheet metal working automation (forming, cutting, drawing …) which manufactures complex finished products such as large household appliances. The line consists of 5 working stations and an additional station for special operations, which in the proposed experiment will be used for quality control by installing industrial cameras. Dies are designed and built in-house, starting from specific customer drawings and the cycle time of the line is about 7 seconds. Given the short cycle time, quality controls, which are currently performed by the operators, are conducted only on some random samples, thus, issues on the lines are commonly identified late, leading to wasted production. If defects are highlighted, the operator performs specific adjustments based on their personal experience. The knowledge gained by expert operators is indeed hardly structured. Similarly, product quality is linked to process parameters only through empirical evidence, not by means of a quantitative analysis.

SCAMM aims at enhancing process efficiency through early identification of defective parts and parameter optimization. This objective will be achieved by implementing an automatic quality control system and optimization tools exploiting AI algorithms to assess the correlation between process parameters and final product quality. Moreover, the tool will allow the collection and analysis of historical data as well as a knowledge management system to digitalize and structure operators' technical knowledge, supporting knowledge transfer towards junior resources.

Stakeholder/s

End-User: SCAMM

Born in 1975, SCAMM operates in the industrial automation for cold metal sheet transformation process sector providing special solutions for forming and assembling sheet metal products for various applications. Its technical knowledge in prefabrication and assembling technologies and continuous research allows the company to be a worldwide leader, offering an integrated service capable of dealing with any specific automation requirement in appliances. The sector of operation is the manufacturing of special equipment for automatic sheet metal forming and assembling, mainly for major home and professional appliances.

SCAMM will provide access to the described pressing line as well as efforts from its employees for requirements elicitation and testing purposes.

Technology Provider: Consorzio Intellimech

Intellimech is a Consortium of more than 50 enterprises devoted to interdisciplinary research in Mechatronics. Intellimech aims to fill the gap between research and industries, promoting collaboration among companies of different sizes and from a variety of fields spread over the whole country. Intellimech research is mainly

focused on Smart Factories, including Data Analytics, AI, IT and ICT, AR/VR, and robotics for several industrial sectors.
Intellimech will support SCAMM in the AI system development and integration and will ensure knowledge transfer towards other process industries and manufacturing companies within the Intellimech consortium.

Technology Provider: Porini

Porini is specialized in strategic consultancy, design, development, integration, implementation and maintenance of complex solutions and infrastructures based on all the major technologies on the market. Porini's offer covers the entire ICT value chain.
Porini will support SCAMM in the definition of the ICT architecture and the front-end development.

Existing infrastructure & assets

Currently, proprietary software enables the operators to set the line process parameters (e.g., presses cylinders forces) and provides direct and indirect measures (e.g., temperature of the hydraulic oil, torque of the servomotors).
A machine vision system has been implemented to collect images of finished products, that are processed by AI algorithms and the results are stored in a dedicated SQL database. Collected images and quality control measurements are accessible through Rest API.
HW:

- Fully automatic transfer lines installed at MOLLIS ANTONIO S.r.l.
- Sensors (industrial cameras) for quality control.

SW:

- Tool to monitor and configure process parameters and to communicate with MES (User Interface, MES Integration, Machine Communication)
- Tool for quality data acquisition and evaluation (Data acquisition, Data analysis, User interface, Visualization)

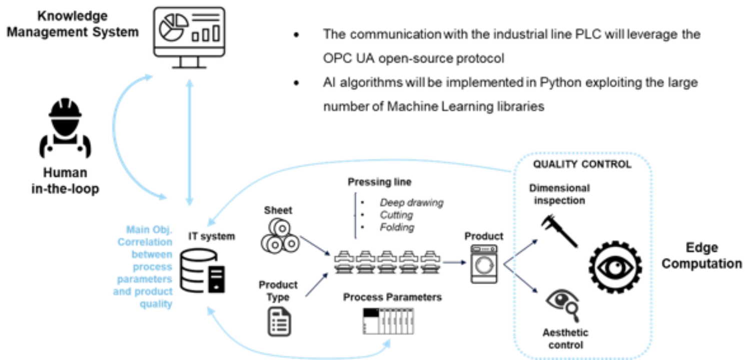
Standard used:

- OPC-UA, TCP, Rest API, HTTP Request

Technical goals

To improve process efficiency and operators' wellbeing, AI technologies will be applied for:

- Analysing images for automatic quality control
- Evaluating correlations between quality indexes and process parameters
- Structuring feedback collected from operators in natural language to build and continiusly update a knowledge base system



More specifically, the following objectives will be pursued:

- Implementation of the ICT architecture and monitoring system.
- Historicization of process parameters that are currently not monitored or available only from the PLC.
- Data collection and validation.
- Automatization of the quality control process for a specific product and historicization of quality data (synthetic index and images).
- Implementation of an AI model for process parameters and product quality correlation.
- Implementation of a dashboard for KPIs monitoring, anomaly detection, trend analysis, and knowledge management.

Key Results

The key results that are expected after the execution of this pilot are:

- **Waste Reduction**: Reducing the percentage of defective products by optimizing process parameters selection and through early identification of defective parts.
- **Reduce Energy Consumption**: Identifying the best parameters setting considering quality optimization and energy minimization. Monitoring and highlighting deviations. Reducing energy needed for reworking defective parts.
- **Improve maintenance efficiency**: Reducing maintenance costs through predictive scheduling and supporting operators with detailed information on identified defects and parameter trends as well as with access to the knowledge collected and structured through previous interactions.
- **Increase profit:** Reducing costs currently associated with inefficiencies. Exploiting the quantified advantages to improve the market competitiveness of the SCAMM solution.

Available Data

Data sources available for the project	The dataset that will be generated during the execution of this experiment is a private dataset. It will be part of the AI REDGIO 5.0 datasets collection, being only the metadata released.

3.1.4 Digital tools to support the engineering of a Circular Economy

Zero-SWARM

ZEROSWARM

Pilot – Clock synchronization of distributed industrial automation system over 5G
Description
This pilot was proposed by ABB, with the implementation supported by Aalto University and other partners based in Sweden and Finland in the project consortium. This pilot aims to validate and demonstrate the technical capability in performing clock synchronization based on IEEE 802.1AS (gPTP) protocol standard, utilizing also readily available solutions – technology stacks and devices - available in the market during the project. 
Scope of the pilot
The setup of the pilot consists of several distributed industrial automation islands, connected over 5G modems. Each industrial automation island consists of industrial drive of ABB connected to motor, where each motor represents motion enabler typical in various manufacturing cases, either for machining, conveyor for material flow, etc.
Stakeholder/s
End-User: ABB Motion ABB Motion, a global leader in motors and drives, is at the core of accelerating a more productive and sustainable future. We innovate and push the boundaries of technology to contribute to energy efficient, decarbonizing and circular solutions for customers, industries and societies. With our digitally enabled drives, motors and services we support our customers and partners to achieve better performance, safety and reliability. We deliver motor driven solutions for a wide range of applications in all industrial segments. Building on over 140 years of domain expertise in electric powertrains, our more than 22,000 employees across 100 countries learn and improve every day. **Technology provider & research performer: Aalto University, Huawei** **Aalto University** Aalto is a public research university located in Espoo, Finland. Being the second biggest university in Finland, Aalto was established in 2010 as a merger of three major Finnish universities: the Helsinki University of Technology, the Helsinki School of Economics and the University of Art and Design Helsinki. **Huawei** Founded in 1987, Huawei is a leading global provider of information and communications technology (ICT) infrastructure and smart devices. We have 207,000 employees and operate in over 170 countries and regions, serving more than three billion people around the world. We are committed to bringing digital to every person, home and organization for a fully connected, intelligent world.
Existing infrastructure & assets
• ABB drives (ACS series), ABB motors, 5G modems, 5G core (software defined)

- ABB motion testing site (located in ABB Pitajanmaki, Helsinki)

Technical goals

Clock synchronization of distributed industrial systems are critical in various cases, especially those that involves motion. Machining use cases rely on precise motion that is actuated by the motor, where drives play fundamental role in controlling the motion of the motors. Achieving accurate clock synchronization over 5G will open opportunities of new approaches to achieve clock synchronization without the reliance to fully wired solution – which has limited mobility and less cost competitive if the equipments are located far away from each other, or satellite-based solution which is less cost competitive and requires special equipment.

Key Results

- The currently available 5G solutions in the market are not yet capable to deliver highly demanding timing requirement of this pilot. The requirement of having clock deviation of less than 5 ms between the clock source and clock target wasn't met.
- Many existing 5G modems and devices are developed to fulfil requirements of mostly consumer use cases. Some 5G enabled devices have firmware / software stacks which are not compatible with requirement of technology stack in industrial manufacturing, in fact, some 5G devices are not forwarding communication packets that are based on industrial protocols.

Available Data

Data sources available for the project	Dataset generated during the experiment is private, which will be retained as part of Zero-SWARM dataset collection.

Pilot – 5G-enabled distributed automation for intelligent powertrain

Description

This pilot aims to validate and investigate the technical feasibility of distributed automation architecture enabled by IEC 61499 open automation standard, connected via 5G for powertrain system.

Scope of the pilot

The setup of the pilot consists of two mechanically coupled motors. One motor is a "load motor", which emulates mechanical load configurable via ABB programmable logic controller (PLC). The other motor is the controlling motor of the load motor. Both motors are connected to ABB drives ACS 880, each drive is connected to 5G modem. The drive of the controlling motor is controlled by Schneider Electric PLC Modicon M251, which is running IEC 61499 automation based on Universal Automation runtime implementation.

The configurable load motor can be programmed to emulate various motion cases typical in the manufacturing and process industry such as machining, pumping, conveyor, etc.

Stakeholder/s

<u>End-User: ABB Motion</u>

ABB Motion

ABB Motion, a global leader in motors and drives, is at the core of accelerating a more productive and sustainable future. We innovate and push the boundaries of technology to contribute to energy efficient, decarbonizing and circular solutions for customers, industries and societies. With our digitally enabled drives, motors and services we support our customers and partners to achieve better performance, safety and reliability. We deliver motor driven solutions for a wide range of applications in all industrial segments. Building on over 140 years of domain expertise in electric powertrains, our more than 22,000 employees across 100 countries learn and improve every day.

Technology provider & research performer: Aalto University, nxtControl (Schneider Electric), Universal Automation.org (UAO), ABB

Aalto University

Aalto is a public research university located in Espoo, Finland. Being the second biggest university in Finland, Aalto was established in 2010 as a merger of three major Finnish universities: the Helsinki University of Technology, the Helsinki School of Economics and the University of Art and Design Helsinki. The participation in Zero-SWARM consists of a research team belonging to School of Electrical Engineering and School of Engineering, covering advanced wireless technology, intelligent automation, and digital twinning expertise

nxtControl - Schneider Electric

nxtControl (now part of Schneider Electric based in Austria) offers unique software products that are the best in class solutions for distributed systems and control engineering based on the IEC 61499 standard.

With engineering independent of control hardware and seamless integration of control and HMI / SCADA, they are the better solution for distributed systems. With the IEC 61499 standard, nxtControl addresses today's needs for customers (End user, System integration companies or even the big players in the automation market). Current problems to be solved in every market segment – machine, process, building, energy, etc. – are: Interoperability (communication between different devices from different vendors), Portability (write the application one time and distribute it to as many different devices as needed), Configurability (Import/Export the same application resp. software objects between different software vendor tools). The key point is reducing engineering effort from the beginning of the project.

Part of Schneider Electric, nxtControl is involved in maintaining the EcoStruxure™ Automation Expert and its runtime, an open, software-defined automation platform for discrete, hybrid and continuous industrial processes where different hardware and software are orchestrated into one cohesive system.

Universal Automation (UAO)

UniversalAutomation.org / UAO is an independent, non-for-profit association managing the implementation of an industrial automation shared source runtime execution engine, based on the IEC 61499 standard. This new level of shared technology provides the basis for an ecosystem of portable, interoperable, "plug and produce" solutions and creates an entirely new category within industrial automation. UniversalAutomation.org is open to new members looking to advance the world of automation.
UniversalAutomation.org was officially established in November 2021 by 9 founding members representing both the user and vendor communities: Bucher Automation, ESA, Gr3n, Intel, Kongsberg Maritime, R.Stahl, Schneider Electric, Wood, and Yokogawa.

ABB

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Existing infrastructure & assets

- 5G private network (5G core implementation provided by Cumucore),
- various 5G modems and devices from different vendors
- Two ABB motors, ACS880 ABB drive, AC500 ABB PLC
- Modicon M251 PLC, based on IEC 61499 open automation standard following Universal Automation runtime implementation

Technical goals

Key Results

- Several 5G modems and devices (readily available in the market) were tested during the pilot, and it was found that some of them have very poor firmware implementation, which led to the instability of the device operation and overall poor technical performance

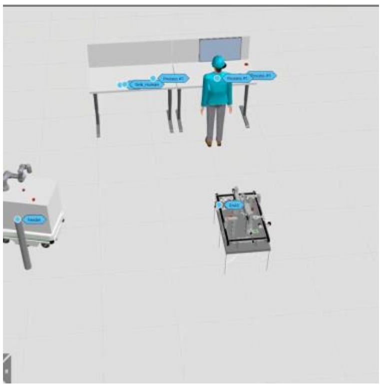
Available Data

Data sources available for the project	Dataset generated during the experiment is private, which will be retained as part of Zero-SWARM dataset collection.

Pilot – Digital twinning of collaborative enhanced (IT-enabled) human worker and robot in flexible factory floor

Description

This pilot aims to investigate and validate the benefits and technical performance of various technological building blocks – advanced wireless connectivity and digital twin of human worker – within the setting of collaborative human, robot, and automated production lines with distributed automation architecture.



Scope of the pilot

The setup of the pilot consists of two production cells – one automated production line and one manual assembly station, and one ROS (robotic operating system) -enabled autonomous guided vehicle / AGV. The automated production line is equipped with IEC 61499 automation system – PLC provided by Schneider Electric based on Universal Automation IEC 61499 runtime. The manual assembly station is manned by a worker, who is equipped / enhanced with wearable sensors to measure their movement and their biophysical signal. This setup is used to develop the digital twin of not only the physical machines but also the personnel (human) working in the environment.

Stakeholder/s

End-User: Industrial manufacturing partners such as ABB and Reepack in the Zero-SWARM consortium

ABB

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Reepack

Reepack is a leading manufacturer of high-quality flexible and tray packaging machinery including vacuum chambers, thermoformers, tray sealers, and horizontal flow wrappers with more than 25 years of experience.

Technology provider / research performer: Aalto University, Schneider Electric, Universal Automation

Aalto University

Aalto is a public research university located in Espoo, Finland. Being the second biggest university in Finland, Aalto was established in 2010 as a merger of three major Finnish universities: the Helsinki University of Technology, the Helsinki School of Economics and the University of Art and Design Helsinki. The participation in Zero-SWARM consists of a research team belonging to School of Electrical Engineering and School of Engineering, covering advanced wireless technology, intelligent automation, and digital twinning expertise

Universal Automation (UAO)

UniversalAutomation.org / UAO is an independent, non-for-profit association managing the implementation of an industrial automation shared source runtime execution engine, based on the IEC 61499 standard. This new level of shared technology provides the basis for an ecosystem of portable, interoperable, "plug and produce" solutions and creates an entirely new category within industrial automation. UniversalAutomation.org is open to new members looking to advance the world of automation.

UniversalAutomation.org was officially established in November 2021 by 9 founding members representing both the user and vendor communities: Bucher Automation, ESA, Gr3n, Intel, Kongsberg Maritime, R.Stahl, Schneider Electric, Wood, and Yokogawa. **<u>Schneider Electric</u>** Schneider Electric is a global industrial technology leader bringing world-leading expertise in electrification, automation and digitization to smart industries, resilient infrastructure, future-proof data centers, intelligent buildings, and intuitive homes. Anchored by deep domain expertise, Schneider provides integrated end-to-end lifecycle AI enabled Industrial IoT solutions with connected products, automation, software and services, delivering digital twins to enable profitable growth for their customers. Schneider offers EcoStruxure™ Automation Expert, an open, software-defined automation platform for discrete, hybrid and continuous industrial processes where different hardware and software are orchestrated into one cohesive system.
Existing infrastructure & assets
• Universal Robot - UR3 collaborative robot • Mobile Industrial Robot – MIR100 autonomous guided vehicle / AGV • Festo modular production system • Schneider Electric M251 Programmable Logic Controllers (PLCs) • Wearable biophysical sensors (heartbeat, IMU in a smart watch – gyroscope, accelerometer) • Aalto Factory of the Future testing site (https://www.aalto.fi/en/futurefactory) • Wifi 6 routers, 5G modems
Technical goals
Key Results
• It is possible to realize a prediction of time to completion of assembly task and product defect prediction based on analyzing the data from the digital twin of the system. However, the prediction requires larger dataset and longer data collection process in order to have a more scalable solution • Accurate measurement of cycle time of assembly task can be achieved and performed in more automated way based on the architecture used in this pilot.
Available Data

Data sources available for the project	Dataset generated during the experiment is private, which will be retained as part of Zero-SWARM dataset collection.

ALICIA

Assembly Lines In CIrculAtion – smart digital tools for the sustainable, human-centric and resilient use of production resources

<table>
<tr><th colspan="2">Pilot - [title]</th></tr>
<tr><th colspan="2">Description</th></tr>
<tr><td colspan="2">The demonstrator will be set up in the test field of the Institute for Machine Tools and Industrial Management (iwb) of the Technical University of Munich (TUM). The test field can be seen here:https://player.vrdirect.app/?project-code=5e51fc</td></tr>
<tr><th colspan="2">Scope of the pilot</th></tr>
<tr><td colspan="2">To demonstrate the middleware's ability to interact with legacy equipment and provide data to a cloud-based digital twin.</td></tr>
<tr><th colspan="2">Stakeholder/s</th></tr>
<tr><td colspan="2">Producing companies; system integrators; digital service providers;</td></tr>
<tr><th colspan="2">Existing infrastructure & assets</th></tr>
<tr><td colspan="2">ABB IRB-140 robot; ECI Connect (https://www.eci-connect.net/); DIMOFAC AAS Digital Platform (https://dimofac.eu/);</td></tr>
<tr><th colspan="2">Technical goals</th></tr>
<tr><td colspan="2">Connector integrated with legacy equipment; middleware forwarding real-time data to the digital twin; digital twin's capability to calculate KPIs based on real-time data;</td></tr>
<tr><th colspan="2">Key Results</th></tr>
<tr><td colspan="2">Validation of the technical goals;</td></tr>
<tr><th colspan="2">Available Data</th></tr>
<tr><td>Data sources available for the project</td><td>Production data from use-case partners; aggregated economical information; machine identification and description;</td></tr>
</table>

DiCiM

Digitalised Value Management for Unlocking the potential of the Circular Manufacturing Systems with integrated digital solutions is bringing one industrial case in home appliances.

<table>
<tr><th>Name</th><th colspan="2"></th></tr>
<tr><td>Involved Actors</td><td colspan="2">Appliance manufacturer (Gorenje): Provides access to appliance (hardware, software), necessary lifecycle information, and architecture for edge computing, IoT platform, data lake, and cloud computing.
Technology developers (project partners): Provide AI-based decision support, data sharing on open-access digital platforms, and digital support tools for value recovery activities.
Service providers (project partners): Engage in value recovery activities and proactive maintenance.</td></tr>
<tr><td>Preconditions</td><td colspan="2">Functional appliance (software, hardware, edge computing)
Established basic IoT infrastructure (data acquisition, (pre)processing, storage)
(Partial) availability of historical data for AI training</td></tr>
<tr><td>Trigger</td><td colspan="2">Initiation of Washing Machine Monitoring: Triggered by the operational start of the IoT-enabled washing machines.</td></tr>
<tr><td>End objective</td><td colspan="2">To enhance the efficiency and effectiveness of value use and recovery activities for washing machines through advanced lifecycle management.</td></tr>
<tr><td>Post conditions</td><td colspan="2">Enhanced Product Longevity: Through improved diagnostics and condition monitoring.
Optimized Reverse Logistics and Value Recovery: Enabled by IoT and AI solutions for end-of-life decision support.</td></tr>
<tr><td rowspan="6">Basic flow</td><td>Step</td><td>Action</td></tr>
<tr><td>Data Collection</td><td>Integrated sensors in washing machines collect operational and condition data.</td></tr>
<tr><td>Data Pre-processing</td><td>Integrated electronics perform edge computing, allowing real-time warning and error display, washing process adaptations, and partial data storage.</td></tr>
<tr><td>Data Transfer</td><td>WiFi connection allows for controlled data transfer to the IoT platform and storage in the data lake.</td></tr>
<tr><td>Data Processing
And
Desicison making</td><td>Cloud computing with integrated ML algorithms analyze the data for multi-stage decision support, including current health estimation and predictive maintenance support. It also leverages data for future end-of-life decision-making, optimizing reverse logistics, and identifying critical value recovery activities.</td></tr>
<tr><td>Customer support/Value recovery</td><td>Technical support is deployed to provide proactive service intervention (product repair and lifetime elongation). Optimal reverse logistics strategy is employed, and value recovery procedures are performed (product refurbishment, part reuse or refurbishment, material recovery, and recycling).</td></tr>
</table>

3.2 Cloud Edge IoT projects: CEI Validation in Industrial Scenarios

3.2.1 Cloud Computing: towards a smart cloud computing continuum

ASSIST-IoT

The evolution of human-machine interaction is just as remarkable as the technological advances that made the impossible possible and changed the way we live.

Pilot 1 - Port automation

Description

The pilot, led by the industrial partner and port terminal operator Terminal Link Group, is set to be implemented at the Malta Freeport Terminal (MFT), one of the largest transhipment ports in the Mediterranean region. MFT is approaching its maximum capacity, leading to ongoing congestion in the yard area. This congestion results in extended wait times for trucks on the landside, creating inefficiencies in the logistics process. As a consequence, vessels may have to remain at the port for longer durations, and in some cases, they may be redirected to alternative ports.

Scope of the pilot

At the MFT, container management heavily relies on the use of robust container handling equipment, including cranes, ship-to-shore cranes, and terminal tractors. Despite the integration of digital technology across various stages of terminal and shipping operations, the operation of position detection system still requires onboard operators to exchange crucial freight-handling data. Challenges persist in managing decentralized combinations of diverse data sources, ensuring secure data sharing for supply chain integration, and achieving high-speed network capabilities.
The pilot project aims to simplify the operation of complex industrial processes and equipment within the maritime industry while addressing the aforementioned challenges.

Stakeholder/s

- Terminal management
- CHE drivers

Existing infrastructure & assets

- Terminal Operating System
- GPS installed on CHEs
- Frontend adapted to mobile screens for truck drivers
- Security access for external truck drivers

Technical goals

The main problem to solve is to avoid losing containers and enhance the operational efficiency of terminal operators (including internal-external drivers). The reduction of the number of containers lost mandates the positions of all position detection systems to be tracked. Additionally, position detection system s must register all container handling operations (picking up and placing down a container by a crane or being loaded). All this information is registered in the terminal operating system.

Key Results

The edge-oriented and scalable architecture of ASSIST-IoT facilitates the efficient utilization of collected data at the edge. This enables stakeholders requiring specific information from specific assets to access it swiftly and securely.

Available Data

Data sources available for the project	Route recording of every position detection system with time and position of communication /identification by other devices within the terminal yard, information about containers handled by position detection systems. Timestamp and location where the container is picked up and placed.

Pilot 2 - Smart safety of workers

Description

Accidents in construction can occur suddenly, without any prior warning, making timely responses critical for saving lives. However, without adequate monitoring systems in place, swift responses to accidents may not be feasible. ASSIST-IoT aims to address these challenges by collecting reliable and relevant data to generate intelligent insights for safeguarding everyone on large construction sites. By ensuring the consistent application of data protection regulations, this initiative seeks to advance knowledge and promote awareness of occupational safety, contributing to the digital transformation of safety and health management in the construction sector, with human well-being at its core.

The construction site is located in the centre of Warsaw, on the campus of the University of Warsaw. The construction site consists of two parts: the office part and the construction part.

Scope of the pilot

In this pilot, the main goal of ASSIST-IoT is to proactively identify and address prevalent occupational safety and health risks promptly. These risks encompass a range of hazards such as stress, fatigue, prolonged exposure to heat and UV radiation, accidents like slips, trips, and falls from elevated surfaces, potential suspension trauma, immobilization due to unconsciousness, incidents involving heavy equipment collisions, emergency entrapment, and incorrect utilization of personal protective equipment.

Stakeholder/s

- Construction worker
- OSH manager
- Construction plant operator

Existing infrastructure & assets

- Wearable sensors and actuators (e.g., thermometer, cooling system etc.)
- BIM system
- Weather station
- Visual monitoring system

Technical goals

- Ensure the construction workers' health and safety at the worksite
- Ensure that the construction workers do not exceed acceptable fatigue and stress limits
- Ensure proper use of PPE
- Ensure that the construction workers are protected from overexposure to heat and UV radiation
- Prevent unauthorised access to restricted areas
- Construction workers can raise the alarm if they identify a danger
- Update the construction site's incident log
- Update the construction site health and safety performance metrics
- Ensure that the construction plant operator is aware of construction workers in the
- vicinity

Key Results

Smart devices and wearables are synchronized to monitor the condition of construction workers. Access to the construction site and facilities is regulated through controlled entry points for both workers and equipment. Construction workers are empowered to customize the operation of cooling systems based on their preferences. Sensitive data is transmitted to a central database only in the event of an incident detection or as periodic status report summaries. Additionally, construction workers have access to an interface to promptly send notifications in case of emergencies.

Available Data

Data sources available for the project	Location and proximity data, physiological parameter measurements, weather conditions measurements, personal identification information, the validity of training and medical test, building information, users' thermal comfort preferences, alerts, and notifications.

Pilot 3 - Cohesive vehicle monitoring and diagnostics

Description

The adoption of ICT within the automotive sector remains relatively low and is predominantly influenced by vehicle manufacturers. Connectivity between vehicle fleets and original equipment manufacturers is constrained primarily by the high costs involved and bandwidth limitations. This pilot is aimed at developing an application or deployment that seamlessly integrates and presents vehicle information to users within an interactive and user-friendly interface. The interface will be tailored according to the user's role and relationship with the vehicle, with the additional goal of minimizing the occurrence of recalls.
The Ford Kuga test vehicle is placed in the Ford's testing plant.

Scope of the pilot

The pilot aims at enhancing the capabilities of automotive original equipment manufacturers in monitoring the emission levels of vehicles already in operation. By monitoring fleet emission levels, it is possible to suggest corrective actions if necessary to bring emissions back within accepted limits. Ensuring that fleet remains within certification limits throughout their operational lifetime will result in compliance with EU regulations.

Stakeholder/s

- Original equipment manufacturers software engineer
- Powertrain Control Module

Existing infrastructure & assets

- Ford Kuga test vehicle
- Powertrain Control Module
- NOx sensor
- HiFi NOx sensor

Technical goals

- Establishing connectivity with an advanced automotive controller to facilitate immediate access to hybrid vehicle systems and enable the implementation of on-demand diagnostic techniques for identifying propulsion faults.
- Incorporating computer vision technology for exterior inspections to enhance the scope of vehicle condition assessment.
- Creating user-friendly interfaces for diagnostic reporting, allowing seamless integration of feedback from end-users and service technicians through tactile interaction with the vehicle.
- Ensuring the utmost privacy, confidentiality, and security of vehicle-condition data to prevent tampering and granting authorized entities access to authentic information.

Key Results

- Effective monitoring of the fleet's emissions during operation.
- Ensuring that the fleet's emissions remain within designated thresholds.
- Prompt identification of vehicles deviating from regulatory standards.
- Early detection of potential defects or malfunctioning components.
- Timely communication to drivers for necessary repairs at the garage.

Available Data

Data sources available for the project	Sensor measurements, at very high sampling frequencies describe the vehicles' operation and drift correction model parameters.

3.2.2 Future European platforms for the Edge: Meta Operating Systems (RIA)

aerOS

The project aerOS aims at transparently utilising the resources on the edge-to-cloud computing continuum for enabling applications in an effective manner, incorporating multiple services deployed on such a path. The project brings three pilots in the manufacturing domain: Green Manufacturing, Zero-defect Manufacturing and Resilient Flexible Manufacturing

Pilot 1 - Green manufacturing (zero net-energy) and CO2 footprint monitoring

Description

This pilot will experiment Gaia-X and aerOS services to implement edge intelligence services (and analytics) in order to optimise impact and CO_2 footprint of production lines. The implementation of this scenario will take place within the extensive test and demonstration laboratory for Industry 4.0 at the Swiss Smart Factory (Biel, Switzerland).

Scope of the pilot

Data models will be designed to facilitate green manufacturing practices and monitor CO_2 emissions. These models will be intricately linked with the integration of a Digital Product Passport, fostering a systematic transition towards a circular economy. This integration will support activities such as de-manufacturing operations, optimizing reverse logistics infrastructure, and promoting more sustainable product design.

Stakeholder/s

- Production line coordinator
- Salesperson

Existing infrastructure & assets

- Manual Workstation SETAGO
- Smart Conveyor
- PCB THT-Assembly (Automated Production System)
- Melkus C4060 AGV
- Quality control station

Technical goals

- Real-time measuring of CO_2 generated by the assets of the test and demo platform
- Real-time monitoring of CO_2 generated by the assets of the test and demo platform
- Predicting the CO_2-footprint (production) for each individualized produced product

Key Results

- Energy efficiency
- Production line optimization
- Supply chain sustainability
- (Remote) real-time monitoring

Available Data

Data sources available for the project	Drone production line data

Pilot 2 - Automotive Smart Factory Zero Defect Manufacturing

Description

In this pilot, a Zero-Defect Manufacturing (ZDM) approach will be addressed in order to deliver semi-autonomous orchestration via remote tactile human-CMM interaction in dimensional quality control processes. aerOS technological components will be deployed and validated in Innovalia Didactic Factory at AIC – Automotive Intelligence Center (Bilbao, Spain).

Scope of the pilot

The global objective of the pilot is to promote the autonomy level 4 of manufacturing processes (MAL4). At this level, the system operates autonomously and adaptively,
within the defined limits of the system, workers can supervise or intervene in emergency situations.

Stakeholder/s

- Metrologist

Existing infrastructure & assets

- M3MH work platform
- M3-Controller data communication
- INNOVALIA manufacturing line

Technical goals

- Interaction of quality control engine with dimensional equipment, arm robots, or in machine-tool metrology
- Real-time quality control monitoring and error compensation
- Remote tactile low latency human interaction
- Energy efficiency monitoring

Key Results

- Remote tactile operation
- Real-time monitoring and operation for machine error compensation, ensuring the accuracy of dimensional inspection
- Avoidance of errors
- Promote the automation of measurement process

Available Data

Data sources available for the project	Optical measurement system data

Pilot 3 - AGV swarm zero break-down logistics & zero ramp-up safe PLC reconfiguration for lot-size-1 production

Description

This pilot project embodies a genuine Digital Factory, where advanced digital technologies are seamlessly integrated with a Lean approach to logistics and production processes. Within this realm, a real production line harnesses the benefits of digital tools such as Industrial IoT, Cloud computing, Data Analytics, Collaborative Robotics, Virtual Commissioning, as well as Product and Process Digital Twins. The pilot is conducted by partners SIEMENS TechHall (Nuremberg), MADE Competence Centre and POLIMI Industry 4.0 Lab facilities (Milano, Italy).

Scope of the pilot

The first goal is to establish a versatile production system characterized by modularity, efficiency, and adaptability to evolving manufacturing environments. The primary emphasis lies in developing a cyber-physical system that integrates automated guided vehicles (AGVs) and robotic arms alongside decentralized intelligence and communication technologies. This system is bolstered by computational resources known as SIMATIC Industrial EDGE, enabling seamless coordination and optimization within the production environment. The system will enable the identification and categorization of packaging boxes through the utilization of AI technology, leveraging external hardware accelerators to enhance precision and streamline operations for greater efficiency. Additionally, the pilot will utilize the Digital Twin technology to conduct comprehensive analysis of both production processes and products, thereby preventing design errors and accurately predicting final performance outcomes.

Stakeholder/s

Operator

Existing infrastructure & assets

- Three small AGVs

• Larger AGV equipped with a robotic arm • Two mobile robotic arm modules • Oil & Gas manufacturing line
Technical goals
By optimizing AGV routes and implementing a smart decision-making process regarding in-house production or outsourcing, the pilot is poised to achieve significant benefits. These include reduced energy consumption, shorter product lead times, enhanced production line efficiency, minimized idle time, and heightened awareness of production processes. These improvements are anticipated to result in cost reduction, faster time to market, and greater reliability for the company, all attributable to a more efficient and robust production chain.
Key Results
• Optimize AGV travels • Flexible usage of factory assets like a robot arm • Enhance agility and adaptability by using aerOS to seamlessly manage the soft-ware and hard-ware resources needed for the task • Optimize network capabilities to ensure the uninterrupted operation of the AGV, robot arm, and AI vision software • Reduce risk at workplace

Available Data	
Data sources available for the project	Oil & Gas manufacturing line data

4. Opportunities and Challenges in CEI for Manufacturing Industry

An analysis of opportunities and challenges for the full adoption and impact assessment of CEI Continuum technologies in manufacturing has been made through an online survey (Section 4.1) and an interactive, participative workshop held on 25 November (Section 4.2). Lessons learned, guidelines and recommendations will be synthesised in Chapter 5.

4.1 The Online Survey for CEI Continuum in Manufacturing Industry

In order to collect inputs from a broader constituency of experts in the domain, a survey was created and disseminated among our ecosystem.

The survey aimed to gather insights into the opportunities and challenges presented by the Cloud-Edge-IoT (CEI) Continuum in the manufacturing industry. With the increasing adoption of advanced technologies, the focus is on enhancing efficiency, sustainability, and human-centric processes within Industry 4.0 and Industry 5.0 scenarios.

In the domain of advanced manufacturing, we explored key areas such as **Smart Factory Automation**, **Smart Product Lifecycle**, **Smart Supply Chains**, and **Industry 5.0** investigating how CEI technologies can improve production quality, enable predictive maintenance, and enhance supply chain agility. Additionally, it examines the role of these technologies in promoting sustainable manufacturing practices, fostering human-machine collaboration, and building resilience to internal and external disruptions.

The survey included a total of 43 participants, classified into four main categories based on their organizational affiliations. The distribution is as follows:

- **Research Technological Organizations** (RTOs) constitute the majority of participants, representing 58%. This highlights the significant involvement of research-focused institutions in the survey.
- **CEI Providers/Supporters** account for 21%, showcasing the active participation of organizations providing or supporting Circular Economy Initiatives.
- **Manufacturing Companies** represent 14%, reflecting the inclusion of industrial stakeholders within the survey.
- The remaining 7% fall under the category of Others, encompassing participants whose roles do not align with the primary classifications.

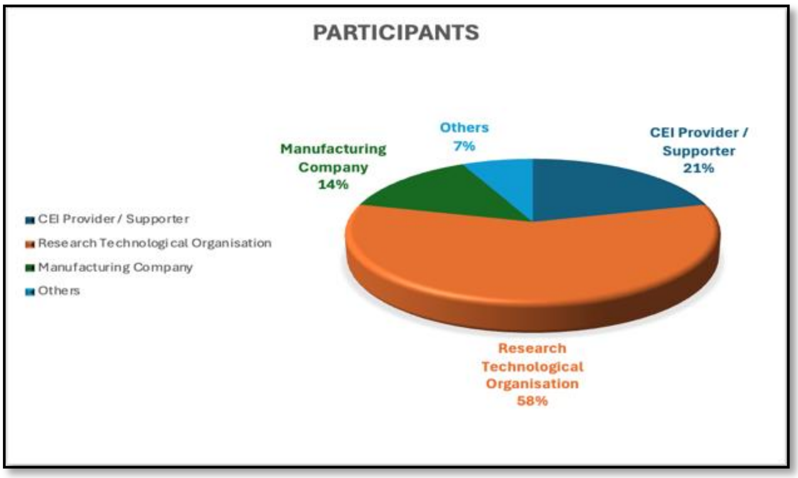


Figure 5 Survey *Participants and Organization types*

Participants came from **17** countries across Europe, demonstrating a broad and diverse geographical representation. The countries include:

- **Western Europe**: Italy, Spain, France, Portugal, Austria, Ireland
- **Northern Europe**: Finland, Denmark, Norway
- **Eastern Europe**: Bulgaria, Romania, Hungary, Slovakia
- **Southern Europe**: Greece, Cyprus

This geographic diversity ensures comprehensive regional perspectives, with notable representation from all over the Europe.

4.1.1 Importance of CEI-enabled advanced applications in Smart Factory Automation

The chart illustrates the distribution of importance assigned to various CEI-enabled advanced applications in Smart Factory Automation by survey participants. The results are presented as percentages, reflecting the relative significance of each factor in the context of advancing automation in manufacturing environments.

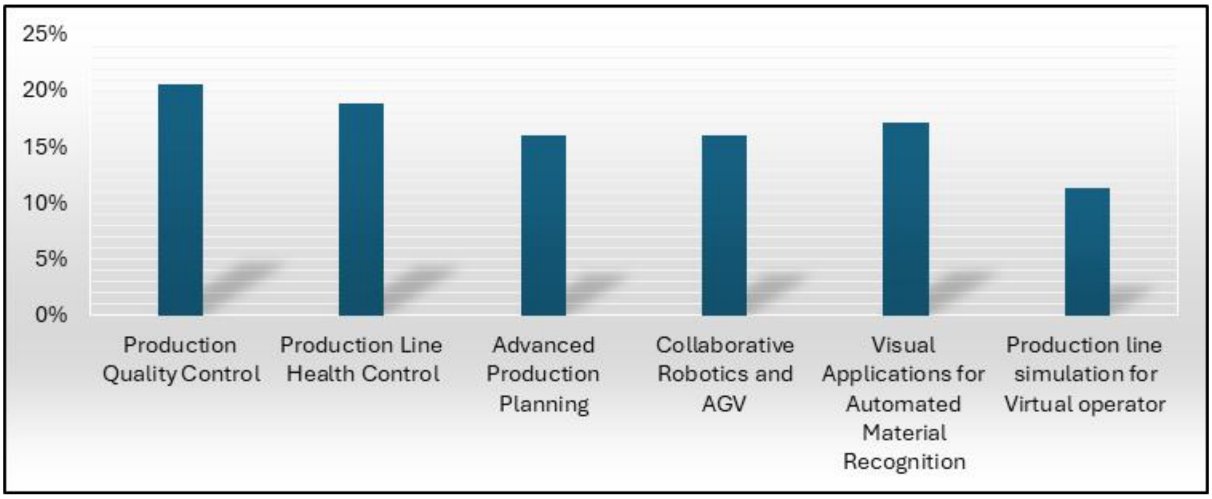


Figure 6 Smart Factory Automation CEI enabled applications

- **Production Quality Control (21%).** Production Quality Control emerges as the most critical factor, with 21% of participants identifying it as a priority. This highlights the industry's focus on maintaining high product standards and reducing defects through automated systems. Quality control in smart factories ensures that end products meet predefined standards, contributing to customer satisfaction and minimizing waste, a key element of sustainable manufacturing.
- **Production Line Health Control (19%).** Ranked second, Production Line Health Control accounts for 19%, emphasizing the need for continuous monitoring and maintenance of manufacturing equipment. This factor underscores the importance of predictive maintenance, which can reduce downtime and operational costs by identifying potential failures before they occur. This aligns with the industry's shift toward proactive, data-driven maintenance strategies.
- **Visual Applications for Automated Material Recognition (17%).** With 17%, Visual Applications for Automated Material Recognition are highlighted as a key factor. This includes the use of AI-powered vision systems to identify and classify materials in real-time, enhancing process efficiency and accuracy. Such applications are crucial in streamlining workflows and supporting advanced automation systems.

- **Advanced Production Planning and Collaborative Robotics and AGV (16% each),** Advanced Production Planning focuses on optimizing manufacturing schedules and resource allocation to improve efficiency and adaptability in production lines. This factor is integral to achieving lean manufacturing goals. Collaborative Robotics and Automated Guided Vehicles (AGVs) highlight the role of human-machine collaboration and autonomous transportation in modern factories. These technologies improve operational flexibility and ensure safer working environments.

- **Production Line Simulation for Virtual Operators (11%).** Lastly, Production Line Simulation for Virtual Operators receives 11% importance. This factor represents the integration of digital twins and virtual models to simulate production processes and train virtual operators. While this is ranked lower, it plays a vital role in testing and optimizing production workflows without disrupting actual operations.

4.1.2 Importance of CEI-enabled advanced applications in Smart Product Lifecycle

The chart showcases the distribution of importance assigned to various factors in the Smart Product Lifecycle, as rated by survey participants. These factors represent key stages and processes in managing products from ideation to end-of-life. The percentages reflect the relative significance of each factor in enhancing product lifecycle management in a smart, technology-driven environment.

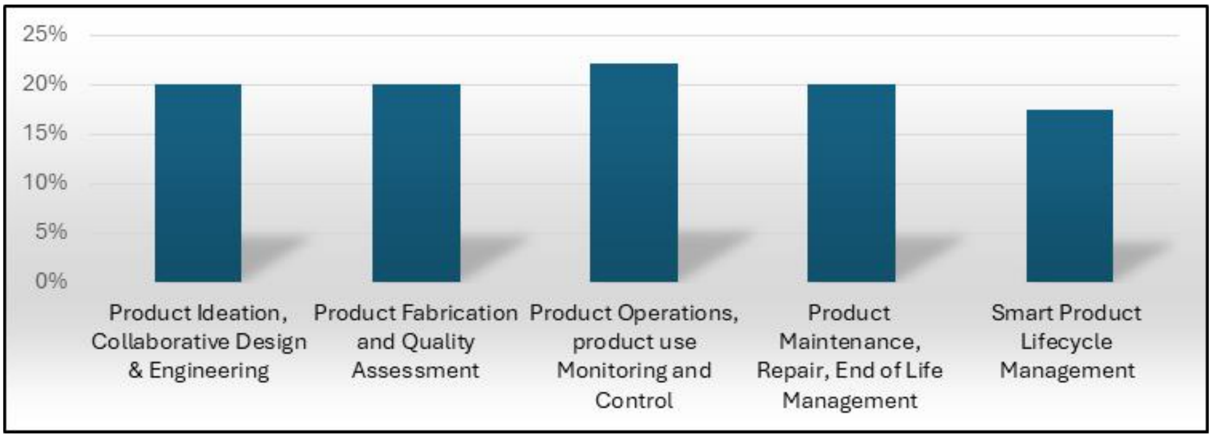


Figure 7 Smart Product Lifecycle CEI-enabled applications

- **Product Operations, Use Monitoring, and Control (22%).** The most critical factor, according to the survey, is Product Operations, Use Monitoring, and Control, which accounts for 22% of the importance. This highlights the industry's emphasis on real-time monitoring and control of product performance. This stage ensures that products operate efficiently and meet user expectations while enabling predictive maintenance and performance optimization through smart technologies.

- **Product Ideation, Collaborative Design & Engineering (20%).** With 20%, this factor underscores the importance of early-stage activities in the product lifecycle. Collaborative design and engineering enable the integration of diverse expertise and advanced tools, fostering innovation and ensuring that products are developed with sustainability and user-centricity in mind.

- **Product Fabrication and Quality Assessment (20%).** Sharing the same importance level as product ideation, Product Fabrication and Quality Assessment emphasizes the need for maintaining high manufacturing standards. This involves ensuring that products meet quality specifications through advanced monitoring and assessment tools, which are integral to delivering reliable and high-performance outputs.

- **Product Maintenance, Repair, and End-of-Life Management (20%).** This factor, also rated at 20%, highlights the significance of sustaining product functionality throughout its lifecycle. Effective maintenance, repair processes, and responsible end-of-life management align with sustainability goals by reducing waste and enabling reuse or recycling of product components.

- **Smart Product Lifecycle Management (18%).** The factor with the least emphasis, at 18%, is Smart Product Lifecycle Management, which integrates all lifecycle stages into a cohesive, data-driven framework. While this receives slightly less focus, its role in ensuring efficient transitions between lifecycle stages and in making data-informed decisions is crucial for long-term product success and sustainability.

4.1.3 Importance of CEI-enabled applications in Smart Supply Chain

The chart provides an analysis of the relative importance of various factors influencing Smart Supply Chain management, as rated by survey participants. These factors encompass key aspects of supply chain operations, from planning to integration, and reflect the priorities for optimizing modern supply chains using smart technologies.

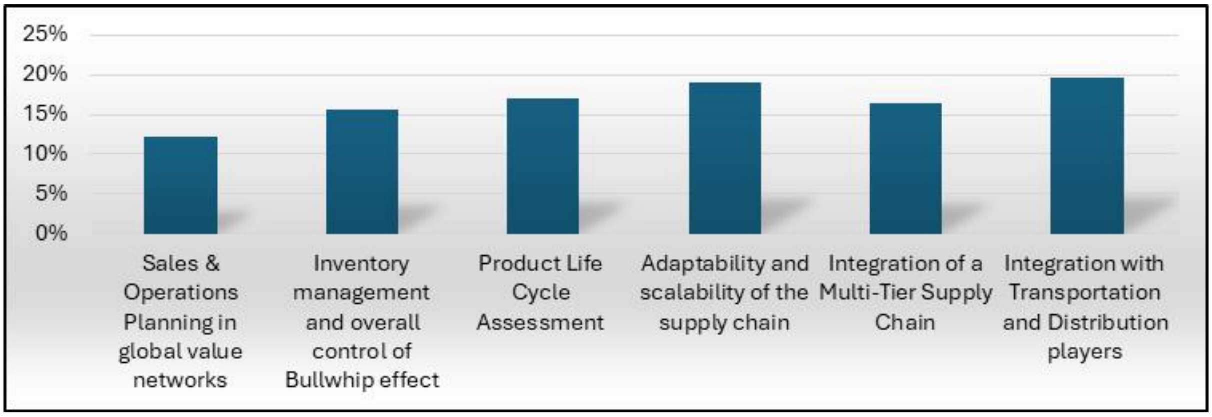


Figure 8 Smart Supply Chain CEI-enabled applications

- **Integration with Transportation and Distribution Players (20%).** Rated as the most important factor, Integration with Transportation and Distribution Players accounts for 20%. This emphasizes the critical role of seamless collaboration with logistics partners in ensuring timely delivery and efficient distribution. Integration at this level enhances supply chain visibility and agility, supporting faster responses to disruptions and demand fluctuations.

- **Adaptability and Scalability of the Supply Chain (19%).** With 19%, this factor highlights the importance of building supply chains that can quickly adapt to changing market conditions and scale operations as needed. The ability to handle dynamic shifts in demand and supply is essential for maintaining competitiveness in global markets.

- **Product Lifecycle Assessment (17%).** At 17%, Product Lifecycle Assessment reflects the emphasis on evaluating the environmental and economic impacts of products throughout their lifecycle. This factor aligns with sustainability goals, ensuring that supply chain decisions consider long-term ecological and cost implications.

- **Inventory Management and Overall Control of the Bullwhip Effect (16%).** This factor, rated at 16%, underscores the need to minimize inefficiencies caused by the bullwhip effect, where small changes in demand can lead to large fluctuations in inventory levels. Effective inventory management ensures optimized stock levels, reducing waste and operational costs while meeting customer needs.

- **Integration of a Multi-Tier Supply Chain (16%).** Also rated at 16%, this factor focuses on the need to coordinate across multiple supply chain tiers. Managing relationships and data across suppliers, manufacturers, and distributors is crucial for creating a cohesive and efficient supply chain.

- **Sales and Operations Planning in Global Value Networks (12%).** At 12%, Sales and Operations Planning in Global Value Networks is ranked as the least important factor. However, it remains significant in aligning production and supply chain operations with global market demands, ensuring efficient resource allocation and strategic decision-making.

4.1.4 Importance of CEI-enabled advanced applications in Industry 5.0

The chart highlights the relative importance assigned to various factors influencing Industry 5.0, as evaluated by survey participants. These factors focus on integrating human-centric approaches, sustainability, and resilience into advanced manufacturing processes. The percentages represent the significance attributed to each factor in driving the objectives of Industry 5.0.

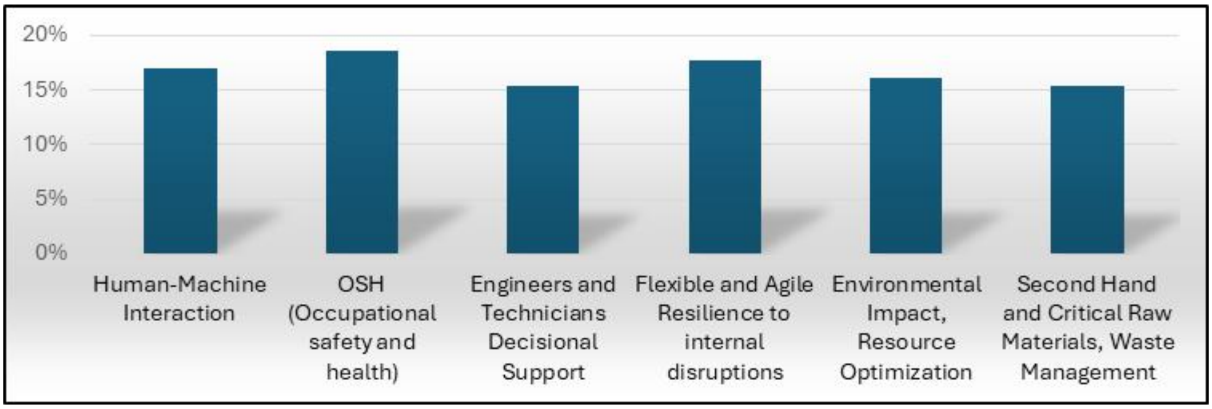


Figure 9 Industry 5.0 CEI-enabled applications

- **Occupational Safety and Health (OSH) (19%).** The most critical factor, accounting for 19%, is Occupational Safety and Health (OSH). This reflects the prioritization of creating safe and healthy workplaces, emphasizing the human-centric philosophy of Industry 5.0. Ensuring worker safety is essential in an environment where humans collaborate closely with advanced technologies.

- **Flexible and Agile Resilience to Internal Disruptions (18%).** Ranked second with 18%, this factor highlights the importance of building resilience within manufacturing processes to adapt to unexpected internal challenges. Flexibility and agility are vital for maintaining productivity and minimizing disruptions in dynamic and complex industrial systems.

- **Human-Machine Interaction (17%).** With 17%, Human-Machine Interaction underscores the significance of seamless collaboration between humans and machines. This factor aligns with Industry 5.0's goal of augmenting human capabilities through intelligent systems, ensuring effective and efficient workflows.

- **Environmental Impact, Resource Optimization (16%).** At 16%, this factor reflects the growing emphasis on minimizing environmental impacts and optimizing resource utilization. Sustainable practices are critical for aligning industrial operations with global sustainability goals, making this a core focus of Industry 5.0.

- **Engineers and Technicians' Decisional Support (15%).** Also at 15%, Decisional Support for Engineers and Technicians highlights the importance of providing real-time data and tools to empower informed decision-making. This ensures enhanced productivity and efficiency, supporting human operators in managing complex systems.

- **Second-Hand and Critical Raw Materials, Waste Management (15%).** Sharing the same percentage, this factor emphasizes the significance of incorporating circular economy principles, including the reuse of raw materials and effective waste management. This aligns with the sustainability focus of Industry 5.0, promoting resource efficiency and reducing environmental footprints.

4.1.5 CEI Technological Viewpoint: Opportunities and Challenges

The following two tables provide a comprehensive overview of the key opportunities and challenges associated with Cloud-Edge-IoT (CEI) technologies in manufacturing, as perceived by the survey participants.

Regarding **Opportunities**:

	Opportunities	Importance
Smart products and Embedded Systems	Enhanced incremental Knowledge Building.	43%
	Feeding insights into the design process from products in use.	43%
IoT and Edge Computing Systems	Real-Time Data Integration including collection and analysis	47%
	Continuous monitoring and enhanced (predictive) maintenance	48%
	Real-time self-improvement tools	40%
Connectivity and Networking Solutions	Customer engagement and experience	36%
	Enabling Next-Generation Applications	38%
	Enhanced Reliability, Redundancy and continuum support	36%
Edge-to-Cloud Continuum Solutions	Dynamical Scalability and Flexibility (long-term agility)	40%
	Enhanced implementation of product analytics and metrics about Sustainability and Compliance	34%
	Enhanced production operational flexibility based on forecasting and optimisation	31%

Figure 10 CEI Continuum opportunities for Manufacturing Industry

IoT and Edge Computing Systems

- **Continuous monitoring and enhanced (predictive) maintenance (48%)**: This is the most critical opportunity, indicating a strong focus on leveraging real-time data for predictive analytics to prevent downtime and improve operational efficiency.

- **Real-Time Data Integration (47%)**: Close in importance, this highlights the value of seamless data collection and analysis for optimizing processes and improving decision-making.

- **Real-time self-improvement tools (40%):** The ability to develop autonomous systems capable of learning and adapting is a notable opportunity for enhancing system resilience and efficiency.

Smart Products and Embedded Systems

- **Enhanced incremental knowledge building (43%)** &

- **Feeding insights into the design process from products in use (43%):** These factors underscore the importance of embedding intelligence in products to provide feedback for continuous improvement and innovation during the design phase.

Edge-to-Cloud Continuum Solutions

- **Dynamical scalability and flexibility (40%):** Long-term agility in scaling operations is a key benefit, enabling businesses to adapt to varying demands with minimal disruption.

Regarding **Challenges**:

	Challenges	Importance
Smart products and Embedded Systems	Higher product costs	28%
	Power Consumption and Energy Efficiency	38%
	Complexity of Embedded Software Development	36%
IoT and Edge Computing Systems	Data Security and Privacy (related to IoT vulnerability)	44%
	Edge/IoT Data Storage Constraints	34%
	Data consistency and Synchronization in production plants	38%
Connectivity and Networking Solutions	Scalability of IoT Networks	41%
	Latency Issues	36%
Edge-to-Cloud Continuum Solutions	Infrastructure initial investment, maintenance and upgrades	41%
	Regulatory and Compliance Challenges	36%
	HPC management of computational resources	28%

Figure 11 CEI Continuum challenges for Manufacturing Industry

IoT and Edge Computing Systems

- **Data Security and Privacy (44%):** This is the most significant challenge, reflecting widespread concerns over vulnerabilities in IoT systems and the need to protect sensitive data from cyber threats.

- **Data consistency and synchronization in production plants (38%):** Ensuring data accuracy and integration across systems remains a critical issue for efficient operations.

- **Edge/IoT Data Storage Constraints (34%):** Data management and storage limitations present barriers to effectively utilizing IoT technologies in large-scale operations.

Connectivity and Networking Solutions

- **Scalability of IoT Networks (41%):** Expanding IoT networks without compromising efficiency or reliability is a key technical challenge for manufacturers.

- **Latency issues (36%):** Delays in data transmission can hinder real-time decision-making, affecting overall system performance.

Edge-to-Cloud Continuum Solutions

- **Infrastructure initial investment, maintenance, and upgrades (41%):** The high cost of implementing and maintaining CEI solutions is a critical hurdle for many organizations.

- **Regulatory and Compliance Challenges (36%):** Navigating the complex landscape of regulations adds another layer of difficulty, particularly in global operations.

4.2 The online interactive Workshop for CEI Continuum in Manufacturing Industry

On 25 November 2024, AIOTI organised an online workshop to present the initial findings of the survey and to validate the responses gathered. The workshop served as an interactive platform for engaging industry experts, researchers, and key stakeholders to discuss the survey results in detail and gather complementary insights. Participants were encouraged to provide feedback and elaborate on critical areas already analyzed through the survey, ensuring a more comprehensive understanding of the opportunities and challenges associated with the Cloud-Edge-IoT (CEI) Continuum.

This collaborative effort aimed to refine the findings, validate key observations, and address any gaps, contributing to a well-rounded analysis of CEI technologies in manufacturing.

- **Organizational Representation.** The workshop was predominantly attended by representatives from Academic and Research Institutions and Research and Technology Organizations (RTOs). This strong representation from research-focused organizations highlights the critical role of innovation and scientific expertise in driving CEI adoption. Contributions from SMEs and industry participants complemented the academic perspective, offering practical insights into real-world applications and challenges.

- **Technological Areas of Interest.** The participants expressed a high level of interest in Edge Computing, IoT, and Artificial Intelligence (AI), reflecting the critical role these technologies play in enabling real-time data processing, automation, and connectivity in manufacturing. Interest in Cloud Computing was comparatively lower, suggesting a shift toward distributed and localized systems over centralized approaches. This trend aligns with the increasing emphasis on decentralized solutions for enhanced efficiency and latency reduction in Industry 4.0 and Industry 5.0 contexts.

- **CEI Adoption in Automation Processes.** The findings revealed that Production Line Simulation for Virtual Operators was perceived as the most impactful business process for CEI adoption. This highlights the value of simulation technologies in optimizing production workflows, training operators, and reducing operational risks. Production Quality Control was also recognized as a key area, emphasizing the importance of maintaining consistent product standards through automated monitoring and quality assurance. On the other hand, areas such as Advanced Production Planning and Production Line Health Control received less attention, suggesting potential gaps in their perceived relevance or awareness of their benefits.

- **Benefits of CEI Technologies in Production Lines.** Participants overwhelmingly identified Improved Product Quality Consistency as the most significant benefit of CEI technologies. This reflects the industry's prioritization of delivering reliable and defect-free products. Additionally, Improved Production Flexibility and Streamlined Workflow Automation were emphasized, highlighting the importance of adaptability and efficiency in modern production environments. Safety improvements, labor cost reduction, and material handling enhancements, though valued, were deemed secondary priorities, suggesting that operational consistency and flexibility take precedence in CEI adoption strategies.

- **Product Lifecycle Priorities for CEI Adoption.** The Maintenance, Repair, and End-of-Life Management stage emerged as the most critical phase for CEI implementation. This reflects a growing recognition of the need for sustainable practices and resource optimization at the end of a product's lifecycle. Activities such as proactive and predictive maintenance, repair efficiency, and recycling logistics were highlighted as essential. In contrast, earlier lifecycle stages, such as product ideation and operations, were given lower priority, indicating that end-of-life considerations are gaining prominence in sustainability-focused manufacturing.

- **Supply Chain Features and Resilience.** The workshop participants emphasized the importance of Inventory Management and Control as a key supply chain feature for CEI adoption. This reflects the critical need to address inefficiencies caused by the bullwhip effect and ensure accurate demand forecasting. Sales and Operations Planning and Multi-Tier Supply Chain Integration were also highlighted as important, showcasing the value of cross-tier coordination and strategic planning. To strengthen supply chain resilience, participants prioritized Rapid Response to Disruptions and Flexibility to Adapt to Demand Fluctuations, underscoring the need for agility and real-time visibility in modern value networks.

- **Pillars of Industry 5.0.** Human Collaboration and Living Lab Implementation was identified as the most essential pillar of Industry 5.0, emphasizing the human-centric nature of this paradigm. This highlights the importance of fostering collaboration between humans and intelligent systems to enhance innovation and operational efficiency. Other pillars, such as occupational safety, resilience to disruptions, and resource optimization, were also recognized but received comparatively less emphasis. This suggests that while sustainability and resilience are integral to Industry 5.0, the human dimension remains central to its success.

- **Enhancing Industrial Capacity in Production Sites.** In production environments, participants identified Human-Machine Interaction and Human-in-the-Loop Systems as critical focus areas for enhancing industrial capacity. These responses underline the importance of integrating advanced technologies with human oversight to achieve seamless collaboration and operational efficiency. Additionally, Human Wellbeing and Ergonomics emerged as a key priority, reflecting the industry's commitment to creating safer and more supportive work environments. Areas such as inclusivity for impaired individuals and resource reallocation during downtime received less attention, indicating potential areas for further exploration.

4.3 Alignment of Survey and Workshop Findings

The findings from the workshop and the survey were largely aligned, reinforcing key priorities and challenges in the adoption of CEI technologies in manufacturing. Both emphasized the critical importance of real-time data integration, predictive maintenance, and quality control as central benefits of CEI adoption.

The workshop participants highlighted these aspects through their focus on Production Quality Consistency and Proactive Maintenance, mirroring the survey's emphasis on real-time monitoring and automation-driven improvements in production and supply chain processes.

Additionally, the alignment on human-centric approaches, such as Human-Machine Interaction and collaborative systems, validates the industry's shift toward Industry 5.0, where human collaboration and wellbeing are integral.

Moreover, both the survey and workshop recognized the need for supply chain agility and resilience, with shared priorities on rapid response to disruptions and flexibility in adapting to demand fluctuations.

The emphasis on sustainability, particularly in end-of-life management and resource optimization, also appeared consistently across both analyses, reflecting a shared understanding of the growing importance of environmentally conscious manufacturing practices.

This alignment between the survey and workshop findings strengthens the validity of the results and highlights key areas for strategic focus in CEI technology implementation.

5. Conclusions and Future Outlook

5.1 Conclusions

The convergence of Cloud, Edge, and IoT (CEI) technologies offers a transformative pathway for addressing the dynamic challenges and opportunities within the European manufacturing sector. Through this document, we have explored the integration of CEI technologies, demonstrating their pivotal role in fostering operational efficiency, enhancing resilience, and achieving sustainability goals across various **industrial and manufacturing scenarios**. This conclusion synthesises the key findings, implications, and future directions for CEI adoption based on a detailed examination of Horizon Europe projects, industry surveys, and stakeholder workshops.

The CEI continuum establishes a seamless integration of cloud and edge computing, complemented by IoT systems, to enable efficient and adaptive information exchange. This capability is essential for the manufacturing sector, which faces increased demand for flexibility, product customisation, and the integration of sustainable practices. By leveraging CEI technologies, manufacturers can achieve significant advantages, including real-time data processing at the edge, predictive maintenance, reduced downtime, enhanced supply chain agility, and improved product quality. These technologies also provide a foundation for the digital transformation encapsulated by Industry 4.0 and Industry 5.0, driving advancements in smart factories, autonomous operations, and human-centric manufacturing.

The survey results and workshop discussions reveal that CEI technologies are instrumental in overcoming **several critical challenges**. For example, manufacturers identified reduced latency, enhanced data security, and optimized energy usage as key benefits of edge computing. Similarly, cloud computing offers scalability and advanced analytics, enabling manufacturers to manage complex production environments. However, the findings also highlight persistent barriers to adoption, such as the high costs of implementation, the complexity of integrating CEI systems, and the need for robust interoperability and standardization frameworks. These challenges must be addressed collaboratively by policymakers, technology providers, and industry leaders to ensure the successful adoption and scaling of CEI solutions.

Moreover, the CEI continuum plays a critical role in advancing **sustainability**. By processing data closer to the source, edge computing minimizes the energy and resources required for data transfer, thereby reducing the carbon footprint of manufacturing operations. These technologies also enable the efficient use of materials, real-time defect detection, and waste reduction, aligning with the European Union's Green Deal and carbon neutrality objectives. The integration of CEI principles fosters a more circular economy, where resource efficiency and sustainability are embedded across the entire product lifecycle, from design to recycling.

The opportunities offered by CEI technologies are complemented by their potential to enhance **human-machine collaboration**. As Industry 5.0 emphasizes a human-centric approach, CEI systems facilitate safer, more inclusive workplaces by augmenting human capabilities with advanced robotics and AI. The development of smart interfaces, human-robot collaboration tools, and adaptive systems ensures that CEI technologies not only improve productivity but also prioritize worker well-being and skill development.

However, achieving the full potential of CEI technologies requires a **coordinated strategy** to address the challenges identified in this report. Interoperability remains a critical issue, as manufacturers seek seamless communication between diverse devices, platforms, and networks. Scalability is another pressing concern, with manufacturers requiring solutions that can handle growing data volumes and processing demands. The lack of standardized protocols for CEI systems further complicates their deployment, emphasizing the need for collaborative efforts in developing and implementing these standards.

The findings also underscore the importance of fostering **innovation ecosystems** to accelerate CEI adoption. Policymakers and stakeholders must promote research and development, pilot programs, and knowledge-sharing initiatives that enable manufacturers to experiment with CEI solutions in real-world settings. Additionally, training and upskilling initiatives are crucial to ensure that the workforce is equipped to navigate the digital transformation enabled by CEI technologies.

In conclusion, the CEI continuum represents a strategic imperative for the European **manufacturing sector**. By addressing the barriers to adoption and leveraging the opportunities identified in this document, manufacturers can position themselves at the forefront of global innovation. CEI technologies offer not only operational benefits but also the potential to achieve broader societal and environmental objectives, including economic resilience, environmental stewardship, and social well-being. As Europe continues to invest in CEI-driven initiatives, a collective commitment to innovation, collaboration, and sustainability will be essential to unlocking the transformative potential of these technologies.

5.2 Future Outlook

We consider the evolution of this white paper in three main future directions.

Manufacturing is evolving from mere automation engineering through Cyber Physical Systems (Industry 4.0) to a more comprehensive and cross-domain ambition including the new role of Humans, the sustainability and circularity of next generation production plants, the resilience and adaptability of the whole manufacturing value network (**Industry 5.0**). **AIOTI Manufacturing working group**, by intensifying its traditional liaisons with Made in Europe and Processes 4 Planet Partnerships in Horizon Europe, will setup new collaboration channels with the Industry 5.0 ecosystem especially with the Industry 5.0 Community of Practice in DG RTD.

Digital Technologies are evolving as well towards a convergence of several different technologies, previously considered walled gardens and silos. Smart Embedded Systems, Internet of Things, Networking Technologies, Data Spaces, Artificial Intelligence (including generative AI) are now a **continuum** dynamically spanning from the edge to the cloud and vice-versa thanks to new solutions for Cybersecurity, Meta Operating Systems and Swarm Intelligence. The Manufacturing Industry represents the most promising sector where to test and experiment such an innovation, owing to the huge amount of data generated in the physical world and the need to real time computations and analysis. Convergence of technologies is also the main enabler for new business models (**servitisation** XaaS Everything as a Service) to make EU Manufacturing Industry more competitive on the global market. **AIOTI Manufacturing working group** will intensify its collaborations with twin communities in Data Technologies, AI and Robotics, in order to promote the CEI continuum adoption in Manufacturing and the development of new business models

SMEs Orientation. Regarding finally the involvement of SMEs, it is quite clear that such technological advancements risk to deepen the digital divide between Large and Small organisations. The more technologies become sophisticated and complicated, the more they can be adopted by very structured organisations and not by small unstructured companies. For this reason, we have now **Digital Innovation Hubs** and **Testing and Experimentation Facilities** aiming at providing SMEs with advanced services for Business acceleration, Ecosystem networking, Skills development and Test before invest. Inside the AIOTI community the SCoDIHNet network aims at creating a network of such DIHs for the benefit of EU SMEs, while the testbed network is a pan-EU distributed facility for test and experimentation. **AIOTI Manufacturing working group** will intensify its relation with TEFs and DIHs in the manufacturing domain, so that to enhance the current capabilities of AIOTI DIHs and Testbeds networks specialised in manufacturing.

ANNEX I: Project Descriptions

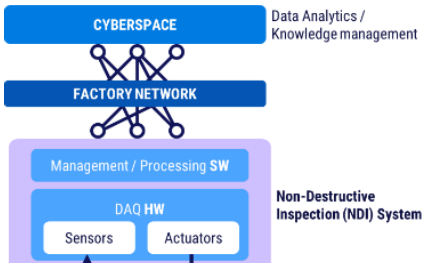
openZDM

Project Description
openZDM is an initiative funded by the European Commission under the Horizon Europe programme. It aims to provide an innovative state-of-the-art integrated open platform that will combine advanced ICT solutions and innovative non-destructive inspection (NDI) systems to support the production network's zero-defect processes. The main objectives of openZDM include the development of an open platform based on RAMI4.0 and AAS, developing and deploying digital twins, defining AI-driven quality assessment modules, developing and integrating NDIs and testing and validating the integrated solution in 5 industrial pilots.
CEI Technologies developed and/or integrated in the Project (is there any official taxonomy of CEI technologies?)
openZDM's goal is the promotion and adoption of the zero defects manufacturing philosophy in 5 industrial pilot cases. To enable this, innovative IoT NDI systems are being designed and deployed in the lines of the openZDM pilots in combination with AI data-driven algorithms. The NDI systems are capable of capturing product-related information. Additionally, using edge computing, the systems perform data processing and preserve their data on databases running on the edge. Furthermore, through communication protocols such as MQTT and HTTP requests communicate raw and processed data to the rest of the openZDM systems. In addition to the NDI systems, the openZDM is composed of an open platform that facilitates access to the openZDM applications. These include high-fidelity digital twins, AI data-driven quality assessment modules and a decision support system for alternative scenario execution. These tools are powered by technologies such as hybrid behavioural models and AI predictive and prescriptive analytics. The openZDM system is deployed in the cloud and on edge computers, enabling seamless access to the solution to pilot personnel inside and outside factory premises. In openZDM AI data-driven algorithms are being developed capable of predictive and prescriptive data analysis, to facilitate proactive quality control. The algorithms are either deployed locally on the pilot premises or in the cloud. In the case of local deployment, they are executed on edge computers. Lastly, they accept data from either legacy systems or NDI IoT systems and their output data is communicated to the rest of the openZDM system similarly to the NDI systems. In terms of taxonomy, the EU is funding several activities towards building a taxonomy at the edge[10]. As detailed in [11] the existing available taxonomy is made of five building blocks, namely integration, brokering, application, orchestration and trust and performance. Core enablers of building blocks are already in use in various parts of the openZDM system. The use of AAS enables traceability and accountability, while the use of Keycloak for authentication and authorisation offers federated authorisation. Lastly, the openZDM platform with its orchestration service provides a synergic orchestration mechanism where all integrated openZDM services and tools work in concert to achieve the desired outcome.
Role of CEI Technologies in Project's architecture

[10] https://eucloudedgeiot.eu/wp-content/uploads/2023/05/V5.eucloudedgeiot.eu-Project-Brochure.pdf
[11] https://eucloudedgeiot.eu/wp-content/uploads/2023/07/D4.3-Toward-an-European-ecosystem-for-the-computing-continuum-Working_v1.1.pdf

The openZDM architecture follows the guidelines detailed by RAMI4.0 and incorporates the AAS in its design. The architecture is a five-layer and three-tier design. The architecture's layers include the external data source and infrastructural layer, the integration layer, the data layer, the service layer and the business layer. The three tiers of the architecture include the authentication and authorization, the logging and monitoring and the data sharing tier. The complete openZDM platform architecture can be seen in **Error! Reference source not found.** Lastly, the platform can support three types of deployment, that include deployment on pilot premises, on the cloud and hybrid.

Fitted on top of the openZDM platform architecture, the openZDM NDIs, are IoT devices inline installed in the openZDM pilot lines. NDIs can perform processing of their captured data at the edge and provide the data to the rest of the openZDM system using the openZDM NDI connector. NDIs are composed of a hardware part and a software part that work combined to extract and analyse features of interest. A high-level architecture of the openZDM NDIs can be seen in **Error! Reference source not found.**



The openZDM NDI architecture.

Pilots and Use Cases using CEI

In openZDM, 4 pilots are using CEI. The EV battery modules manufacturer (APTIV) combines IoT devices and AI algorithms running on the edge for the early detection of welding and aesthetical defects on the battery modules. The steel trailer arms manufacturer (VDLWEW) combines data from IoT devices and legacy systems to feed AI algorithms running on the edge to predict dimensional defects. The automotive assembly pilot (VWAE) utilizes portable IoT NDIs to feed AI algorithms, running on the edge, to predict defects related to gap & flush of the rear-end of the automotive. Lastly, the glass bottle manufacturer (VIDRALA) utilizes an expert system made of a vision-based NDI and an AI algorithm running on the edge to evaluate the wall thickness of glass bottles. In addition, since the openZDM solution is also cloud-deployed seamless and efficient data management from the edge to the cloud is needed. In this context, any data provided by legacy systems and the developed NDI systems are being shared with the cloud using the MQTT communication protocol. On the cloud, dedicated cloud storage services, ensure data integrity and data keeping in case of data loss or corruption on the edge deployed databases.

Selected Pilot(s)

In the APTIV pilot, two innovative IoT NDI systems are deployed and integrated into the openZDM open platform. The NDI systems have the capability of processing their captured data using edge computing and communicating both raw and processed data to the rest of the openZDM system using the MQTT communication protocol. In addition, both NDI systems are coupled with dedicated AI algorithms to detect welding, aesthetic, and positioning defects on the battery modules. The AI algorithms are executed on an edge computer enabling early defect detection. Lastly, NDI data are stored on an edge server, which enables fast data access of historical data from both NDI systems. Lastly, the rest of the openZDM system is also deployed on an edge computer in the manufacturer. This ensures that the entire system has fast access to raw data coming from legacy and NDI systems and data processing conducted by the openZDM applications is conducted closely to the data source in a fast and secure manner.

Opportunities and Challenges for CEI technologies in the Project (to be used for Ch. 4)

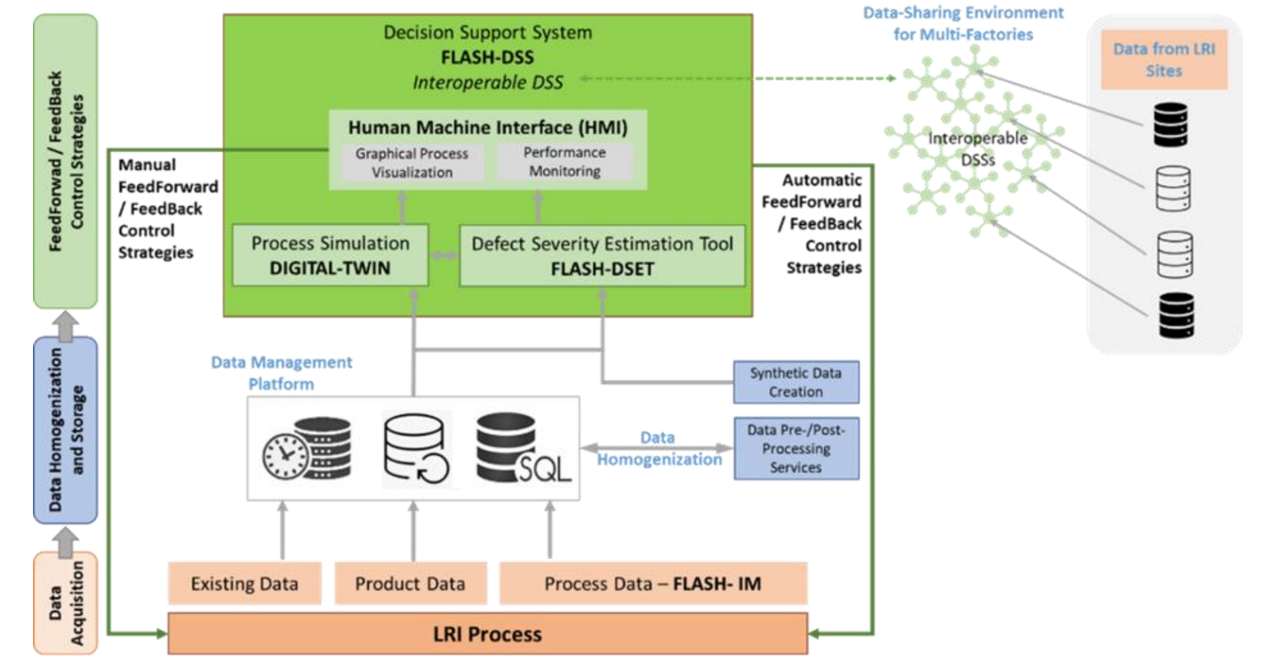
By the end of openZDM, more NDI systems will be deployed on the industrial pilots. Additionally, new software tools will be deployed on the edge in the pilots as well as on the cloud. This deployment will create new opportunities for CEI technologies in the project such as:

- Improved early defect detection and proactive quality control through the use of edge computing and IoT devices that are capable of processing and providing valuable insight from captured data in a fast and secure manner; thus, enhancing the decision-making process,
- Increase in data storage capabilities through cloud storage, which will serve as a backup infrastructure to the edge deployed storage solutions, ensuring that data collected and generated throughout the project will remain available in case of local data loss.

Nevertheless, challenges are also foreseen. Such challenges include: • The processing of point cloud data by an NDI system, which will be deployed in the trailer arms manufacturer to acquire point cloud information of the trailer arms, will be a significant challenge due to the volume of data encapsulated in each point cloud. • Conducting large-scale feedforward simulations by the openZDM software solutions on the edge will also pose a challenge due to the potential computational power required for such executions. However, to combat both challenges, high-performance edge computers will be used to accelerate data processing and AI algorithm execution.

FLASH-COMP

Project Description
FLASH-COMP Flawless and sustainable production of composite parts through a human centred digital approach.
CEI Technologies developed and/or integrated in the Project (is there any official taxonomy of CEI technologies?)
Simulation and modelling (digital twins) covering the material processing level up to manufacturing system: real time monitoring, data collection and AI will be used for physical understanding of complex processes like infusion. Moreover, predictive model-based approaches will be deployed. **Robust and secure industrial real-time communication technologies, and distributed control architectures and standardized equipment protocols:** inter-factory real-time communication approaches will be considered between FLASH-DSS located in different sites; so standardized protocols, safety issues, accessibility, etc. aspects will be taken into account. **Data analytics, artificial intelligence, machine learning and deployment of digital platforms for data management and sharing:** the sharing of the infusion process data between the industrial sites will create a data ecosystem for this manufacturing technology that can boost a sovereign European composite industry.
Role of CEI Technologies in Project's architecture
FLASH-COMP will employ novel, fast and accurate **Inspection and Monitoring techniques (FLASH-IM)** within the most critical manufacturing stages (Pre-Forming and Infusion), to retrieve key process parameters. This data will feed an **AI-based Defect Severity Estimation Tool (FLASH-DSET),** capable of estimating the generation of defects and, in consequence, determining if and what kind of corrective actions should be adopted. Instructions will be linked to **real-time feedforward and feedback (FF/FB) control strategy Decision Support System (FLASH-DSS).** **The solution will increase its knowledge by sharing interoperable and sovereign data among different sites and factories.**



Pilots and Use Cases using CEI (2-3 lines each)

Naval sector: Azimut

Azimut designs and manufactures Yachts (composite structures: 14-50 m in length; metal structures: 50-110 m in length). Use case will be carried out in 3 steps, small scale to analyse further the permeability of fabrics used (Plates of approx. 500mm x 1000 mm); medium scale to analyse some specific complex shape and specific approaches and solution to these items (Objects from 4 to 10 sqm); above all full-scale sample considering or a small hull or a superstructure to evaluate full complexity of a composite part of yachts (Length from 14 m to 20m).

Aeronautical sector: IAI

Wing skin integral structure, 1.2 meter long, that is a representative section of 7m full scale wing skin design. The structure includes wing skin and 3 longitudinal spars all infused in one-shot by resin infusion technology. Currently IAI produces 72 wings per year. This part is for civil use. It is a wing section demonstrator that represents composite wing of Avanti 180 made by Piaggio aircraft.

Selected Pilot(s)

Please see in Annex I.

Opportunities and Challenges for CEI technologies in the Project

Challenges:

Data collected within a production environment is very heterogenous, since frequency can vary from milliseconds (automation data) to hours or days (Laboratory), formats can vary from single (or multiple) data point time series to structured or unstructured data, utilising different communication protocols to acquire the data. Once the data collection is standardised, process data must be checked for validity to avoid error propagations in KPI calculations, or before injecting in AI models, since it would lead to erroneous predictions. Additionally, for benchmarking purposes it is important to standardize the exact process meaning of every descriptive KPI, which is a homogenization from process point of view which will be completed with corresponding naming and labelling, covered by appropriate semantics.

Opportunities:

The smart knowledge will be fed from interoperable and sovereign data sharing between sites and factories. In this way, the composite sector will take advantage of the latest technological innovations to digitalise manufacturing processes towards a more sustainable and competitive composite industry.

ASSIST-IoT

Project Description
ASSIST-IoT aims at design, implementation, and validation of an open, decentralized reference architecture, associated enablers, services and tools, to assist human-centric applications in multiple verticals. Instances of the architecture will be supported by key enablers, like edge/fog computing, (semi-)autonomy, distributed AI, smart devices, interoperability, Distributed Ledger Technology (DLT) atop a smart network infrastructure, with low latency capabilities, allowing execution of context-aware applications with new interaction interfaces (e.g. AR/VR/MR), etc. The proposed solution will integrate AI-based functions transferring intelligence closer to the edge (data sources), including devices. The reference architecture, and developed enablers, will be validated in three realistic pilots: (i) port automation; (ii) smart safety of workers, and (iii) cohesive vehicle monitoring and diagnostics. The proposed approach is focused on the edge-fog-cloud continuum model. However, to simplify the narrative the word "edge" captures all generic situations, in which data processing takes place in the appropriate location within the IoT ecosystem. This location is as close as possible to sensing/actuating. This means that the "edge node" is the one that was specifically selected, within the continuum, to perform given function(s).

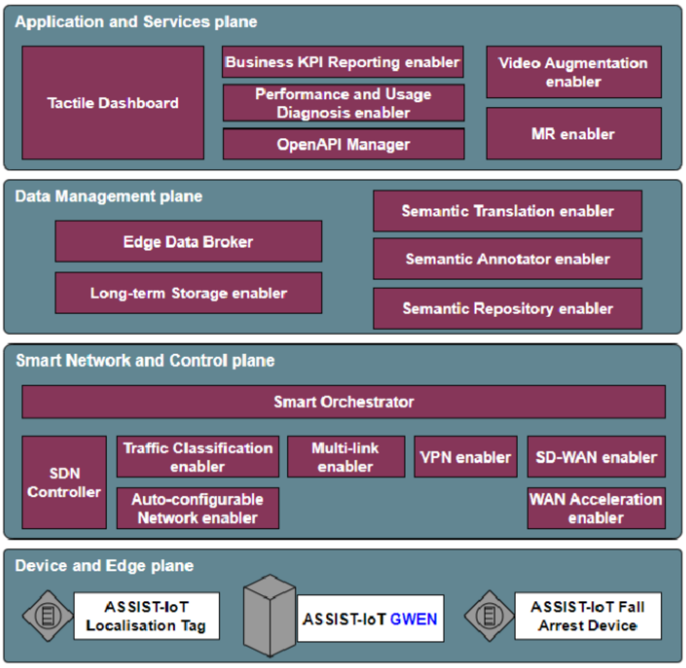
CEI Technologies developed and/or integrated in the Project (is there any official taxonomy of CEI technologies?)

The ASSIST-IoT project aims at designing, implementing, and validating an open, decentralized, reference Next Generation IoT (NG-IoT) architecture, with its corresponding enablers, services, and tools for assisting human-centric applications within multiple verticals.

The design principles of the ASSIST-IoT RA are:

- The split of the different functionalities of the architecture into micro-applications
- The instantiation of the former into containers
- The introduction of the enablers abstraction
- The orchestration of these enablers considering small Kubernetes footprint

Role of CEI Technologies in Project's architecture



Microservices: ASSIST-IoT leverages concepts from microservices-based architectures, in which an overall system (in this case, the RA) is divided into services that communicate among them leveraging their own, well-defined API.

Containerisation: ASSIST-IoT proposes the use of containers as the standard unit that packages the code and dependencies needed for a micro-application to work. This choice is motivated by several factors. Firstly, it is about lightness. Containers can virtualise at the OS level, and then multiple containers can be running over the OS kernel directly. Hence, containers are far more lightweight than VMs, they can be deployed much faster, and use a fraction of the memory. This is critical as the available computing resources might be scarce. Secondly, containers are very flexible and can be installed over several host OSs and CPU architectures, facilitating the execution of workloads over different types of equipment. Lastly, maturity is also key. Most development teams know how to work around them, having their DevOps processes prepared to embrace them.

Enablers abstraction: an enabler is a collection of software (and possibly hardware) components - running on computation nodes - that work together to deliver a specific functionality of a system. ASSIST-IoT enablers are not atomic but presented as a set of interconnected components, bound together in a single package. In particular, an enabler component is an artifact that can be viewed as an internal part of an enabler that performs some action necessary to deliver the functionality of an enabler as a whole.

Kubernetes: Kubernetes is strongly recommended as the main technology for containers' orchestration, and thus, for enablers orchestration. The main motivation for choosing this option lies in it being the de facto standard in current trend towards Cloud-Native implementations in contrast to other alternatives, as well as the evolution of Kubernetes distributions with lower memory footprint to cope with the constraints posed by edge-oriented ecosystems.

Pilots and Use Cases using CEI

Port automation: The pilot aims to showcase in the Malta Freeport Terminal the benefits of ASSIST-IoT, easing the utilization of complex industrial processes and equipment in the maritime industry while addressing yard congestion.

Smart safety of workers: The primary aim of this pilot is to ensure safe and healthy working conditions on construction sites. However, due to the dynamic and unpredictable nature of these environments, achieving this goal poses significant challenges.

Cohesive vehicle monitoring and diagnostics: The pilot will enhance the capabilities of automotive original equipment manufacturers to monitor the emission levels of vehicles which are already in operation.

Selected Pilot(s)

Please see in Annex I.

Opportunities and Challenges for CEI technologies in the Project

Microservices

Microservices architecture offers significant opportunities for software systems, characterized by loosely-coupled internal services that can be maintained, deployed, and scaled independently. Unlike monolithic architectures, microservices eliminate the need for communication middleware, enhancing simplicity and reducing potential points of failure. This architectural approach promotes flexibility, allowing for the seamless addition of new services and minimizing the impact of errors within individual services on the overall system. Additionally, microservices support the use of diverse programming languages, enabling teams to leverage different technologies for specific tasks.

However, the adoption of microservices also poses challenges, including managing the complexity of distributed systems, ensuring effective service discovery and communication, and addressing issues related to data consistency and transaction management.

Containerization

Containerization presents several advantages over traditional virtual machines (VMs), including lightweight deployment, rapid deployment times, and ease of execution. Containers are praised for their security features, providing isolation and minimizing attack surfaces, although Unikernels and VMs offer similar advantages by incorporating the OS kernel. Serverless platforms, particularly those adapted to edge computing, offer scalability and cost-effectiveness but may pose challenges in setting up and managing complex services.

Overall, while containerization remains widely adopted and recognized as a secure virtualization technology, alternative approaches such as Unikernels and serverless platforms show promise in edge-oriented ecosystems. However, the technical complexity and expertise required for their implementation may present adoption barriers that need to be addressed.

Enablers abstraction

Opportunities stemming from enablers include the facilitation of modular architecture, interoperability enhancement, acceleration of development processes, and scalability improvements. However, several challenges accompany the utilization of enablers, such as managing complexity, addressing security and privacy concerns, optimizing resource allocation, and establishing standardization and governance frameworks.

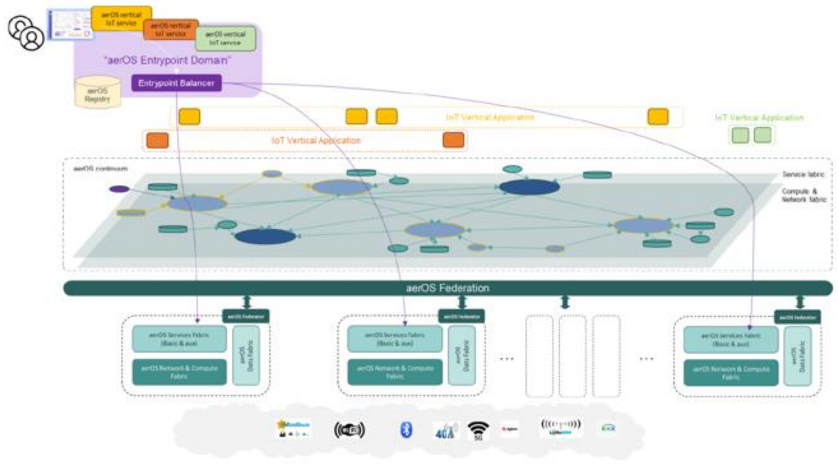
Kubernetes

Kubernetes offers a range of capabilities that enhance operational efficiency and reliability. It automates the rollout and rollback processes, ensuring seamless deployment while monitoring workload health to pre-

emptively address potential issues. Additionally, Kubernetes conducts regular health checks on deployed services and restarts failed containers as necessary. Furthermore, it dynamically scales services based on resource utilization, optimizing resource allocation. However, despite its numerous advantages, implementing and managing Kubernetes can present challenges, including complexity in configuration and maintenance, resource overheads, and the need for specialized expertise. Nonetheless, the benefits it brings to the table outweigh these challenges, making Kubernetes a compelling choice for container orchestration in modern IT landscapes.

ACCORDION and DECENTER

Project Description
The IoT ecosystem is a dynamic aggregation of resources, e.g., sensors, actuators, processing/storage, populating edges of current infrastructures, e.g., edge computing with local/ad-hoc clouds, fog computing, far edge and federated approaches. AI (with explainability) and real-time processing may require high computing power close to events and, sometimes, distributed across Infrastructure Elements. EU funded projects, like ACCORDION and DECENTER, already address continuum challenges, by associating edge computing with 5G, and by realising Fog Computing platform. In such a distributed data and compute scenario, the so-called *network compute fabric*, the network should host computing intertwined with communication for the highest level of efficiency, to support heterogeneous systems, ranging from simple terminals to performance-sensitive robots and augmented reality nodes. However, edge meta operating systems require flexibility to serve any dynamic combination of Infrastructure Elements, providing globally orchestrated services, for example, policy services specifying behaviour; data governance; or even cognitive services. Examples of current and extended state of the art edge meta operating systems are: Thin Edge, ROS for robotic environments, EOS for virtualised telco networks, or VirtuOS for the cloud. *Breakthrough:* aerOS will continue developments leading toward achieving IoT edge-cloud continuum, by integrating relevant technologies, elements of connectivity, IoT, AI, data autonomy and cybersecurity. The proposed meta operating system will support distribution and data sharing across the IoT edge-cloud continuum and will enable orchestration of resources and services, by providing mechanisms for data processing and application of intelligence, in particular, close to where the data is produced.
CEI Technologies developed and/or integrated in the Project (is there any official taxonomy of CEI technologies?)
The aerOS project aims at designing a Meta-OS approach, based on open source components, for efficient resource provisioning and services orchestration on heterogeneous nodes across the IoT-edge-cloud continuum. For that purpose, It leverages the following concepts: • Federation • Orchestration • Data Fabric
Role of CEI Technologies in Project's architecture
Federation Federation plays a crucial part in harnessing the collective strengths and resources across different domains, enabling collaboration, sharing of resources, distribution of workloads, and seamless interoperability among multiple aerOS domains within the IoT-Edge-Cloud ecosystem. **Orchestration** Orchestration plays a central role in overseeing and coordinating the deployment and execution of containerized workloads across diverse domains. By leveraging the capabilities provided by federation, aerOS orchestration facilitates cross-domain communication to synchronize activities and share resources across multiple administrative domains, extending from the edge to the cloud. **Data Fabric** Every aerOS domain incorporates an aerOS Data Fabric enabler component, empowering any interested consumer within the domain, whether it's the high-level orchestrator, the trust manager, or an AI decision support component, to request data and seamlessly receive it.



Pilots and Use Cases using CEI

The aerOS Data-Driven Cognitive Production Lines pilot is divided into three clearly differentiated scenarios:

- **Green manufacturing (zero net-energy) and CO2 footprint monitoring:** It involves testing Gaia-X and aerOS services to introduce edge intelligence services (including analytics), aiming to enhance the efficiency of production lines and reduce their environmental impact, particularly in terms of CO2 emissions.
- **Automotive smart factory zero defect manufacturing:** A zero defect manufacturing approach ensuring robustness and stability of the process, deploying inline quality control among the manufacturing workflow.
- **AGV swarm zero break-down logistics & zero ramp-up safe PLC reconfiguration for lot-size-1 production:** The business process incorporates the process of specific information with context information about what needs to be done, which is then fed to the edge-cloud continuum by means of industrial edge apps (pub/sub schemas) to feed aerOS.

Selected Pilot(s)

Please see in Annex I.

Opportunities and Challenges for CEI technologies in the Project

Federation

Federation within aerOS aims to seamlessly integrate compute and network, service, and data fabrics, enabling efficient resource utilization and information sharing across domains. Opportunities include optimized resource allocation, enhanced collaboration through data exchange, and a unified user interface. Establishing defined rules, protocols, and standards for access control, security, and interoperability is crucial for successful federation. Moreover, securing federated environments against unauthorized access and ensuring data privacy are critical challenges. Lastly, it is critical to overcome interoperability challenges that involves addressing differences in technology stacks, data formats, and communication protocols to ensure smooth data exchange and service integration.

Orchestration

Orchestration within aerOS, empowered by federation capabilities and the integration of the aerOS Data Fabric, offers significant opportunities for efficient cross-domain coordination and resource utilization. It enables seamless communication and resource sharing across diverse administrative domains, facilitating dynamic workload placement and optimization. However, challenges such as cross-domain communication, resource allocation, data consistency, and security must be addressed. On the one hand, Overcoming interoperability issues and ensuring seamless integration between disparate systems and protocols requires robust communication mechanisms and standardized interfaces. Furthermore, optimizing resource allocation and workload placement across the entire aerOS ecosystem requires sophisticated algorithms and decision-making processes. Moreover Ensuring that data remains synchronized and up-to-date across distributed environments requires robust synchronization mechanisms and data management strategies. Finally, securing cross-domain communication and ensuring compliance with regulatory requirements are paramount concerns for orchestration.

Data Fabric

The Data Fabric presents a transformative approach to data management, enabling seamless access, contextual representation, and efficient task execution across diverse administrative domains. Opportunities include enhanced data accessibility, contextual representation, and improved task execution efficiency. However, several challenges must be addressed, including data consistency, interoperability, scalability, and security. Overcoming these challenges requires robust mechanisms for data synchronization, standardization of protocols, scalability strategies, and implementation of stringent security measures.

ANNEX II: The Survey "CEI Continuum adoption in manufacturing Industry"

- ### The Manufacturing Industry Viewpoint

Starting from the projects mentioned in **Section 2.1** (Green, flexible and advanced manufacturing AND Advanced digital technologies for Manufacturing 2021 and 2022 topics) and the CEI adoption industrial pilots mentioned in **Section 3.1** (Zero Defect Manufacturing, Agile Manufacturing, Sustainable and Circular Manufacturing), we have identified two main industrial scenarios where the adoption of CEI technologies is expected to benefit more manufacturing industry:

- A current **Industry 4.0** scenario articulated in **Smart Factory Automation**, **Smart Product Lifecycle** and **Smart Supply Chain** reference processes and
- A more advanced **Industry 5.0** scenario focussing on **Human Centricity**, **Resilience** and **Sustainability** (Circular) reference processes.

For both scenarios, we are elaborating an online survey and a conclusive interactive workshop, where AIOTI for Smart Manufacturing stakeholders can express their opinion about opportunities and challenges for CEI technologies adoption in Industry 4.0 and Industry 5.0 scenarios.

1) **Smart Factory Automation** processes are analysed regarding the adoption of CEI technologies in the production plants during the fabrication of goods. Evaluate from 1 to 5 the importance of CEI technologies in the following fields:

   - Production Quality control: incremental knowledge Root Cause Analysis for Achieving Zero-Defect Manufacturing.
   - Production Line Health control: automatic fault diagnosis with line self-reconfiguration and Predictive/Prescriptive Maintenance.
   - Advanced Production Planning (predictive Sales & Operation planning including raw material supply, reactive production route configuration, predictive order due data quotation, etc.) and production line Scheduling (optimal line scheduling, material flows tracking, etc.).
   - Collaborative robotics and AGV for production line management and internal storages optimisation.
   - Visual Applications for Automated Material Recognition and Tracking in the Internal Supply Chain.
   - Production line simulation for Virtual operator training and Virtual Commissioning including VR and AR.
   - Other Smart Factory Automation Industry 4.0 business processes.

2) **Smart Product Lifecycle** processes are analysed regarding the adoption of CEI technologies along the whole product lifecycle from cradle to grave and in circular economy. Evaluate from 1 to 5 the importance of CEI technologies in the following fields:

   - Product Ideation, Collaborative Design & Engineering.
   - Product Fabrication and Quality Assessment.
   - Product Operations, product use Monitoring and Control.
   - Product Maintenance, Repair, End of Life Management and Circular Economy
   - Smart Product Lifecycle Management with a focus on Sustainability and Compliance
   - Other Smart Product Lifecycle Industry 4.0 business processes.

3) **Smart Supply Chain** processes are analysed regarding the adoption of CEI technologies in the supply and distribution global networks. Evaluate from 1 to 5 the importance of CEI technologies in the following fields:

- Sales & Operations Planning in global value networks.
- Inventory management and overall control of Bullwhip effect.
- Product Life Cycle Assessment and Carbon Footprint Estimation along the value chain
- Adaptability and scalability of the supply chain.
- Integration of a Multi-Tier Supply Chain for complex products (collaboration and communication across Supply Chain partners).
- Integration with Transportation and Distribution players (including Real-Time tracking and visibility of goods).
- Other Smart Supply Chain Industry 4.0 business processes.

4) **Industry 5.0** processes are analysed regarding the adoption of CEI technologies in production plants, along the product lifecycle and through the whole value chain.

- Human-Machine Interaction blending efficiently the machine activity and the human activity (both at shop-floor and non-shop-floor levels)
- OSH (Occupational Safety and Health) including workers wellbeing, Inclusiveness, ergonomics, non-discrimination, etc.
- Engineers and Technicians Decisional Support, Digital assistants and DSS
- Advanced Tacit/Explicit KMS (Knowledge Management Systems) based on LLM
- Human Collaboration, Living Lab innovation and Consumers' Empowerment.
- Flexible and Agile Resilience to internal disruptions in the production site.
- Proactive and Agile Resilience to external disruptions in the market and value chain.
- Environmental Impact, Resource Optimization, Energy Management, LCA
- Second Hand and Critical Raw Materials, Waste Management, Industrial Symbiosis and Circular Production.
- Other Factory, Product, Supply Chain Industry 5.0 business processes.

o The CEI Technological Viewpoint

Starting from the projects mentioned in **Section 2.2** (Meta Operating Systems, Cognitive Cloud, Swarm Intelligence applied to Manufacturing for Horizon EU 2021 and 2022 topics) and the use cases mentioned in **Section 3.2** (Cloud Computing and Edge-to-Cloud Continuum), we have identified three main scenarios: Smart and Embedded System, IoT and Edge Computing, Cloud and HPC infrastructure.

Evaluate from 1 to 5 the importance of the following technological opportunities ang challenges for CEI technologies in the following fields:

Smart products and Embedded Systems

Opportunities:

- Enhanced incremental Knowledge Building. Incremental knowledge is closely linked to the monitoring and analysis of data collected by smart products and embedded systems, often directly during their use.
- Feeding insights into the design process from products in use. Continuous monitoring of products and feedback into the design process primarily relate to smart products and embedded systems that collect data during use.
- Mass product customization. Mass customisation links to the configurability of embedded systems and the flexibility of smart products to satisfy high variability requirements and maintain at the same time high volumes of products.

Challenges:

- Higher product costs (and therefore prices) for implementation and maintenance for CEI integration. Higher costs for implementation and maintenance are directly related to the complexity of smart products and embedded systems exploiting CEI technologies.
- Power Consumption and Energy Efficiency. Smart products and embedded systems often operate in environments with limited power resources, such as battery-powered devices or situations where energy efficiency is crucial.
- Complexity of Embedded Software Development. Limited hardware resources and high specialisation for software development staff make the field complex.

IoT and Edge Computing Systems

Opportunities:

- Real-Time Data Integration including collection and analysis. Integration of IoT systems, often operating at the edge, to gather and begin processing data, minimizing latency.
- Continuous monitoring and enhanced (predictive) maintenance. Continuous monitoring can rely on IoT and edge computing systems that collect and analyse data in real-time.
- Real-time self-improvement tools. Efficient implementation of self-healing/self-configuration/self-protection/etc. tools based on richer information collected from IoT and real-time elaborated.

Challenges:

- Data Security and Privacy (related to IoT vulnerability). Data security and privacy is a crucial barrier in IoT and edge computing systems, where device vulnerabilities can expose the entire system to risks (e.g. in the context of Smart Factory Automation).
- Edge/IoT Data Storage Constraints. Edge devices/IoT devices often have limited memory and processing capabilities.
- Data consistency and Synchronization in production plants. Data fluxes generated by IoT devices installed in manufacturing production environments do not always align with CIM integration principles. This discrepancy introduces complexity in synchronizing data with automation systems, such as material tracking systems.

Connectivity and Networking Solutions

Opportunities:

- Customer engagement and experience. These are closely tied to interactions with smart products, which can be configured and monitored to enhance the user experience.
- Enabling Next-Generation Applications. CEI is crucial for enabling next-generation applications, such as smart manufacturing, connected vehicles and intelligent retail.
- Enhanced Reliability, redundancy and continuum support. CEI technologies allow distributing computing and networking resources across the edge and cloud. Moreover, workloads can be dynamically balanced between the edge and the cloud based on real-time needs.

Challenges:

- Scalability of IoT Networks. A strongly growing number of devices with varying latency, bandwidth, and reliability requirements necessitates a robust infrastructure and careful planning.
- System Interoperability and standardisation/Integration issues (platform diversity and standardisation). They require connectivity solutions and standardisation of communication platforms among various devices.
- Latency Issues. They are critical issues in connectivity and networking solutions, which must ensure timely and stable communications.

Edge-to-Cloud Continuum Solutions

Opportunities:

- Dynamic Scalability and Flexibility (long-term agility). Scalability and flexibility are achieved through architectures that allow extending or reducing computing and storage capacities between the edge and the cloud (e.g. on demand allocation).
- Enhanced implementation of product analytics and metrics about Sustainability and Compliance. Analytics and metrics related to product sustainability and compliance often require a combination of data collected at the edge and analysed in the cloud.
- Enhanced production operational flexibility based on forecasting and optimisation (e.g. RCA, reactive production route configuration, minimisation of lead times, etc.). Operational optimisation and forecasting require data integration and analysis from both the edge and the cloud, enabling rapid and flexible responses to changes.

Challenges:

- Infrastructure initial investment, maintenance and upgrades. The complexity of implementing edge-to-cloud solutions includes managing associated costs (hardware, software licenses, and possibly specialised edge computing platforms).
- Regulatory and Compliance Challenges They require data and operational integration that often involves the entire edge-to-cloud continuum.
- HPC management of computational resources. HPC is typically available in the cloud. Moving data between edge devices (such as sensors, IoT devices, or mobile devices) and the cloud so as to implement advanced technologies (e.g. LLM) can introduce substantial latency.

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About AIOTI

AIOTI is the multi-stakeholder platform for stimulating AI, IoT and Edge Continuum Innovation in Europe, bringing together small and large companies, academia, researchers, policy makers, end-users and representatives of society in an end-to-end approach. We strive to leverage, share and promote best practices in the AI, IoT and Edge Continuum ecosystems, be a one-stop point of information to our members while proactively addressing key issues and roadblocks for economic growth, acceptance and adoption of the AI, IoT and Edge Continuum Innovation in society. AIOTI contributions go beyond technology and address horizontal elements across application domains, such as matchmaking and stimulating cooperation by creating joint research roadmaps, defining policies and driving the convergence of standards and interoperability.