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Foresights and Recommendations of Digital Manufacturing Platforms for a Digital Europe – Second iteration

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Abbreviations and acronyms

TERMS, ABBREVIATIONS AND ACRONYMS	
AI	Artificial Intelligence
AQ	Answer Question
AAS	Asset Administration Shell
B2B	Business-To-Business
CC	Competence Center
CE	Circular Economy
CF	Connected Factories
CSA	Coordination and Support Actions
DIGITAL	Digital Europe Programme
DFA	Digital Factory Alliance for Digital Manufacturing Platforms
DGA	Data Governance Act
DIH	Digital Innovation Hub
DMP	Digital Manufacturing Platform
DT	Digital Transformation
EC	European Commission
EDIH	European Digital Innovation Hub
EU	European Union
HE	Horizon Europe Programme
HPC	High Performance Computing
ICT	Information and Communication Technology
IDSA	International Data Space
IDSA	International Data Spaces Association
IT	Information Technology
MPFQ	Materials, Processes, Functions and Quality
OEE	Overall Equipment Effectiveness
OT	Operation Technology
PPP	Public Private Partnership
SME	Small Medium Enterprise
TEF	Testing and Experimentation Facility

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Executive Summary

Digital Manufacturing Platforms (DMP) are implementing the Digital Transformation of Manufacturing Industry, enabling products to become smarter, processes to become more efficient and platforms to become open and interoperable.

In 2018-2020 H2020 program, DMPs are mostly developed by 6 Innovation Actions in DT-ICT-07 that are supported by Connected Factories 2 CSA (CF2). In addition, many other projects develop DMPs with different targets and foci, as for instance DT-ICT-03 Digital Innovation Hub projects on AI, Digital Twins, Human-Robot interaction and DT-ICT-08 projects about Cybersecurity applied to Manufacturing.

The CF2 WP3 *Cases: from industrial state-of-the art to demonstrators and pilot lines* focused on industrial cases and how they are demonstrating the benefits of DMPs in realistic industrial environments. The deliverable D3.5 summarises conclusions of the Task 3.4, *Portfolio analysis and recommendations*, giving an outlook on the challenges industry will have to face in the future.

The main objective of Task 3.4 was to analyse the portfolio of platforms, use cases and demonstrations resulting from the work carried out in the CF2 (in particular, in tasks T3.1, T3.2, T3.3, T2.3 and T2.4) and to detect the areas in which the implementation of the news technologies is more widespread. It also aimed to identify the challenges that will have to be addressed with future initiatives. The approach has been to dive into Digital Europe challenges and identify new scenarios and key lines of evolution of digital platforms towards increased levels of intelligence and autonomy to provide key recommendations, scenarios and motivate future lines of research.

The first iteration of the "Foresights and Recommendations of Digital Manufacturing Platforms for a Digital Europe", D3.3, described the activities performed and workshops organised by CF2 with respect to uses cases and demonstrators in the first 18 months of the project. This second iteration of the report, D3.5, in a similar way, describes the contributions of the different workshops and activities carried out in the second period of CF2 to sum up the future foresights and recommendations. In addition, the report D3.5 sums up the recommendation from a large number of associated projects, clusters and events that CF2 has been supporting and being involved in.

In particular, the analysis of CF2 pathways and their validation in DMP industrial cases allowed the identification of foresights and recommendations regarding Circular Economy, Data Spaces and AI in manufacturing. In addition, foresights and recommendations have been formulated for cross-cutting aspects, in particular, for standardisation. Recommendations and observations regarding the implementation of the pathways have been also collected from the national and regional workshops.

Altogether, the foresights and recommendations have been formulated together with the ecosystem of digital manufacturing platform projects and ecosystems associated with ConnectedFactories 2.

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1 Introduction

1.1 Aims and objectives

The ConnectedFactories 2 project establishes a structured overview of available and upcoming technological approaches and best practices with regard to the digitalisation of manufacturing. The project identifies present and future needs, as well as challenges, of the manufacturing industries.
In particular, the project

- explores **pathways** to the digital integration and interoperability of manufacturing systems and processes and the benefits this will bring.
- creates **insights into important cross-cutting factors and key enablers**.
- associates **projects and project results, use cases and demonstrators** to the pathways and the cross-cutting factors.

The objective of WP3 is to dive into the Industry 4.0 related research and innovation projects founded by the Commission to collect and catalogue the main practical results of those projects. The Task 3.4, *Portfolio analysis and recommendations*, provides an outlook on the challenges industry will have to face in the future.

The deliverables D3.3 and D3.5 "*Foresights and Recommendations of Digital Manufacturing Platforms for a Digital Europe*" report the main recommendations and observations collected from projects and project results, use cases and demonstrators associated to the different pathways explored and the important cross-cutting factors identified.

This second iteration reports the contributions of the different workshops and activities carried out in the scope of the CF2 to support the analysis of future foresights and recommendations in the second period of the project.

1.2 Outline of the document

The document is structured in five main sections. The first section introduces the overall concept and scope of the deliverable.

Section 2 presents the Foresights and Recommendations from CF2 Pathways and Cross-Cutting aspects. The analysis of CF2 pathways and their validation in DMP industrial cases allowed the identification of foresights and recommendations related to Circular Economy, Data Spaces and AI for Manufacturing. Regarding the Cross-Cutting aspects, foresights and recommendations have been collected from the DMP cluster working group for standardisation.

Section 3 reports the foresights and recommendations collected from the National Regional workshops, related to:

- Cybersecurity
- Added Value Business Models
- Interoperability and Standardisation
- Industrial Agreement and Legal Aspects
- Humans in Manufacturing and Human Factors

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- Circular Economy
- Autonomous Smart Factories and Hyperconnected Factories
- Collaborative Product-Service Factories
- Data Spaces

The section 4 discusses the foresights and recommendations from the ecosystem of digital manufacturing platform projects and collected during the interactive workshops organized. Participants were asked to analyse the following aspects from the perspective of their project:

- Added value - impact - value proposition (addressing manufacturing challenges)
- Significant innovations and achievements associated to digital challenges + Significance of the results for SMEs
- Key exploitable results
- Gaps and challenges regarding digital technologies for manufacturing that should still be addressed in future work

Finally, section 5 provides the final conclusions.

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2 Foresights and Recommendations from CF2 Pathways and Cross-Cutting aspects

The analysis of CF2 pathways and their validation in DMP industrial cases allowed us to identify foresights and recommendations about circularity, data spaces and artificial intelligence in manufacturing.

2.1 Foresights and Recommendations from Circular Economy pathway

The Circular Economy pathway rises to highlight the importance of the Circular Economy (CE) paradigm for the sustainable development of the manufacturing sector. It is a maturity assessment model which allows companies to estimate their position into the CE paradigm, considering the levels and the dimensions depicted in Figure 1. This is one of the CF2 developed pathways. For further information pls consult Deliverable 2.5.

The starting point in CE pathway is a company and its value chain in which, the environmental regulations are met, but CE and sustainability viewpoints are not considered as strategic advantages. The next step for many companies is start piloting in order to minimise the inputs of energy and materials, however often the drives is strengthening the brand image. A crucial step towards more sustainable manufacturing is Systemic Materials Management where multisource product lifecycle data is exploited systematically for resource efficiency and circularity gains. Further, at next level the environmental, social and economic pillars of sustainability are explored in collaboration with value chains. This network level activity is required to truly take advantage of circular economy. The most advanced phase is circularity, where the company and its embedded value chains are re-structured for closed (=cross-sectoral) loops. Here, the data flows and (federated) data spaces are one of the crucial enablers for emphasizing the positive sustainability impacts.

For further information about CE pathway consult Deliverable 2.5 and the video published at the EFFRA portal[3]. Other (strongly interlinked) pathways show important milestones on the way to realize a collaborative product service or data spaces factories.

[3] Link to video: https://www.effra.eu/news/connectedfactories-final-event-presentations-and-recordings-available

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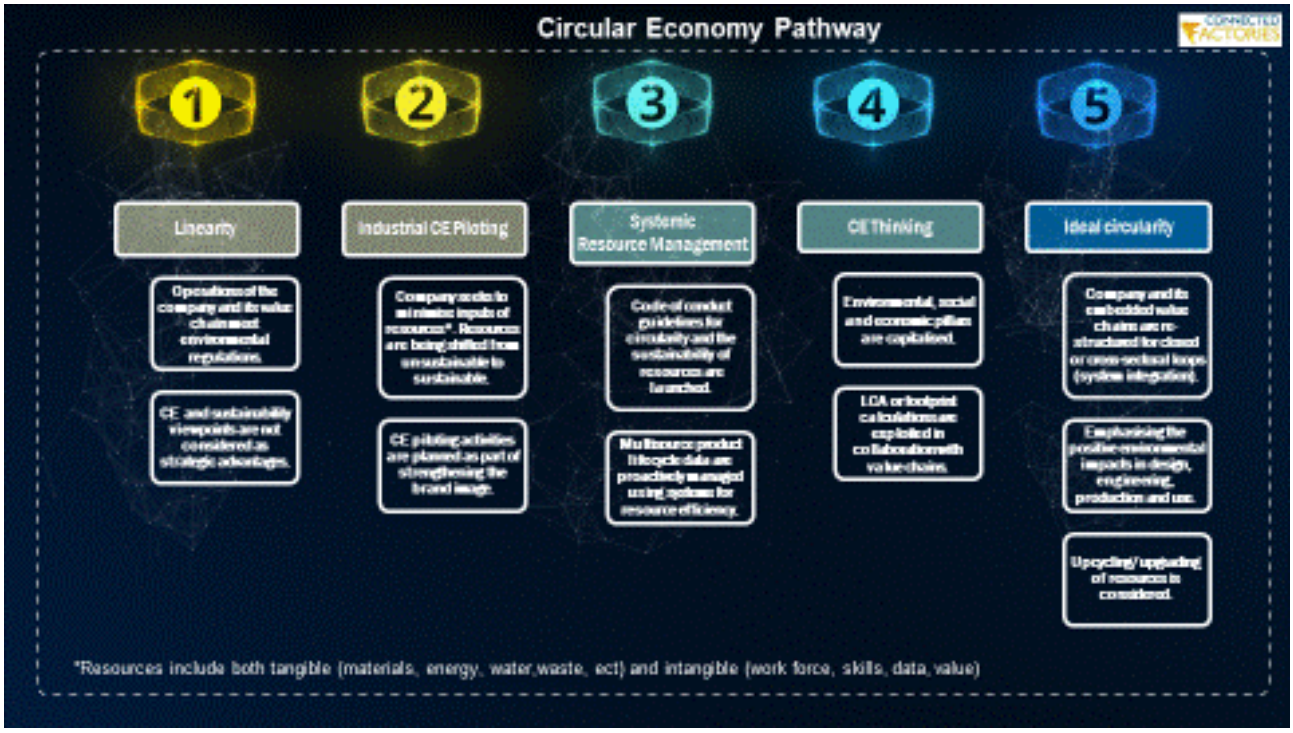


Figure 1. Circular Economy Pathway

Digital platforms enabling circular manufacturing are piloted in variety of industrial sectors (from ICT-07 cluster projects the CE focus had especially the following: European Connected Factory Platform for Agile Manufacturing (EFPF), An Advanced Circular and Agile Manufacturing Ecosystem based on rapid reconfigurable manufacturing process and individualized consumer preferences (KYKLOS) and Digital Platform for Circular Economy in Cross-sectorial Sustainable Value Networks (DigiPrime).

From the CE pathway community of cases, the following **foresights and recommendations** for circular manufacturing systems arise. First, the shift towards greener value chains requires the use of recycled materials and green energy, along with focusing on resource-efficient, demand-driven production and circular value networks. Moreover, sustainable industrial production carefully considers material use and re-uses and repurposes waste streams as materials. Collaborative incentives throughout the value chain are needed for companies to actively consider sustainable materials, durability and reparability. Then, the close connection with Industry 5.0 approach is apparent. However, due to production and consumption often taking place in different countries, manufacturing value chains may need to be reorganised to facilitate reuse and remanufacturing, and product lifetimes can be extended by upgradeability. Excellence in manufacturing enables the production of future green products with positive environmental handprint. In line with this, European manufacturing industry has the potential to be forerunner and grasp the opportunities of CE.

2.2 Foresights and Recommendations from Data Spaces pathway

The CF2 Data Spaces Pathway (Figure 2) is made by crossing six Data Technology enablers (Data Management, Data Protection, Data Processing, Data Analytics, Data Visualisation and Data Sharing) versus a five-level maturity model (No Data Control, Data Silos, Data Bridges, Data

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Interoperability and Data Valorisation). Information of the development is available on the deliverable 2.6.
The video of the DS pathway is available HERE.

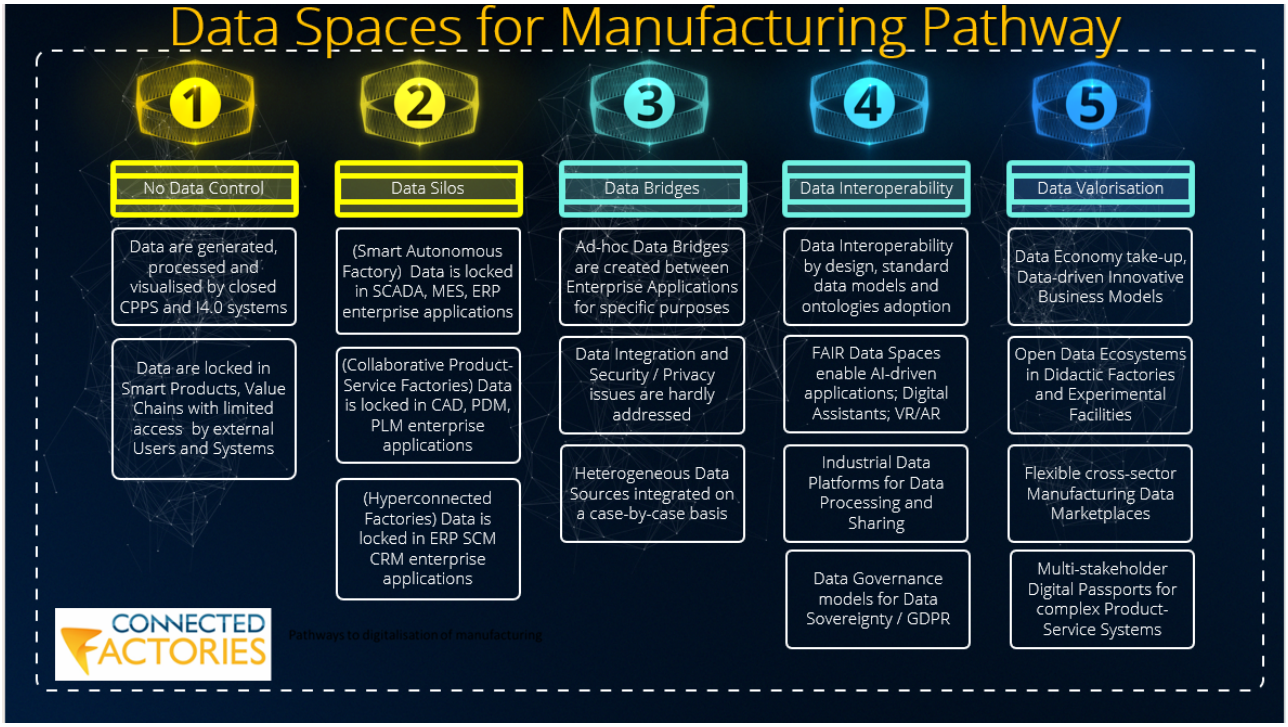


Figure 2. Data Spaces pathway

The foresights and recommendations from CF2 DS pathway validation are to be directed to the "DS for Manufacturing" deployment call in Digital Europe. The five main CF2 recommendations to the Data Space 4.0 preparatory CSA in "DS for Manufacturing" started on October 1st, 2022, have been presented during the Manufacturing Conference 2022 at the end of September 2022

- **Do not underestimate the DATA dimension in your I4.0 projects**. A Data Space is not just a software Digital Platform, but it is also composed by FAIR (Findable Accessible Interoperable Reusable) high value Datasets, accompanied by the proper legal and industry agreements between the involved stakeholders (Platform Economy to enable Data Economy)
- **Embryonic Data Spaces do exist (Success Stories Value Networks)**. Several projects have recently started aiming at implementing the three main DS business models (open data, data marketplaces, data ecosystems) in the three main CF1 Grand Scenarios of Smart Autonomous, Collaborative Product Service and Hyperconnected Factories of the Future
- **Use Data Quality pipelines for sustainable and trustworthy AI systems**. In the case Data Spaces are feeding smart intelligent AI-based applications, particular attention must be paid on the Quality of the input data (especially when synthetically generated). Quality-oriented Data Pipelines methods, tools and templates need to be developed and made available
- **Assess your maturity for fully exploiting Data Economy (Servitisation)**. Data Economy needs to be better exploited in the Manufacturing Industry, especially when associated to advanced new business models related to servitisation and MaaS Manufacturing as a Service (e.g diagnosis and maintenance, sustainability ESG assessment, circular data spaces)

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- **Join the DATA SP4CE 4.0 Ecosystem and fly Data Spaces with us!** This was the final recommendation for Data Space Practitioners and now the project is up and running as well as its community and ecosystem.

2.3 Foresights and Recommendations from AI for Manufacturing pathway

The CF2 AI for Manufacturing pathway (Figure 3) considers the Manufacturing Autonomy Levels of the Industrie 4.0 initiative, by identifying five levels of decisional autonomy in the interaction between humans and AI systems in manufacturing.

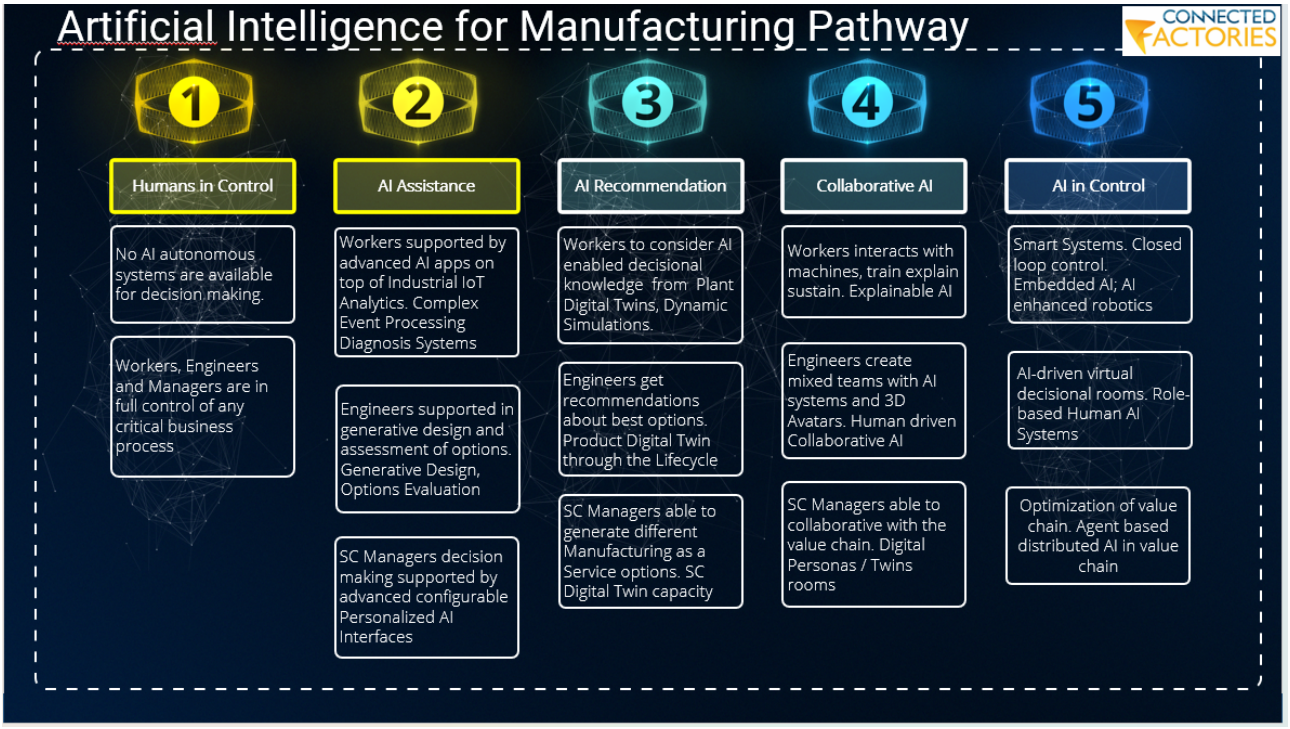


Figure 3. The AI for Manufacturing Pathway

On June 13th, 2022, in Brussels, a specific event for discussing the AI pathway has been held at the presence of several projects' representatives of the DMP ecosystem. As reported in Deliverable 2.6 the final sli.do interactive session was centred on the consideration of the obstacles and barriers preventing manufacturing companies (SMEs) to adopt AI. Seven aspects were identified:

- **Data Availability** (Quality, Synthetic Data, Data Space)
- **Skills and Competencies** (new roles, up- / re- skilling, DIHs
- **Trust Building** (solution providers, solution users, DIHs)
- **Business Benefits** - Best practices, success stories and common agreed KPIs
- **Data Sharing** motivation and incentives
- **Security and Confidentiality** (IPR protection, Data Sovereignty)
- **AI Solutions' Complexity** (costs, efforts)

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The collected foresights and recommendations have been reported and discussed with the AI4Manufacturing cluster (8 RIAs and 1 CSA, STAR and XMANAI projects in particular) and with the I4MS community (AI REGIO and KITT4SME AI DIH for Manufacturing H2020 Innovation Actions).

Conclusions will be made available to the new started Horizon Europe projects in HORIZON-CL4-2021-TWIN-TRANSITION-01-07 "Artificial Intelligence for sustainable, agile manufacturing" in collaboration with the AI, Data and Robotics Partnership, and in particular the Circular TwAIn, s-x-AIPI and AIDEAS Innovation Actions.

2.4 Foresights and Recommendations from Cross-Cutting aspects

Beyond what has been reported D1.4, we analyze here the foresights and recommendations from the cross-cutting aspects.

2.4.1 Foresights and Recommendations from WG1 standardisation

As presented in the CF2 final event in the section 'Cross-Cutting aspects - main take-aways and observations', the main recommendations regarding standardisation are (Figure 4):

- **Practical advice:** It is advised that project consortia carry out a comprehensive gap analysis with regard to current standardization needs as early as the application phase.
- **Support action** is needed to address challenges regarding membership, fees, and involvement possibilities for projects in SDOs.
- Provide better promotion of official **guidance** to research projects, including information on how standardization can be addressed in an appropriate/useful manner in the respective project tasks.
- It is **suggested** that upcoming projects focusing on the development of an I4.0 or SM compliant reference architecture follow the latest developments of the SM Meta-model
- **Broken consistency** of concept digital factory framework and asset administration shell for industrial applications.
- **Support action:** There should be a central contact person at EU level to liaise and make a recommendation to existing committees at EU level.
- **Practical advice:** Brief revisions and updates should be made periodically in the project.
- **Practical advice:** It is recommended to estimate the time needed for committee work very accurately before joining a working group and developing the standard.

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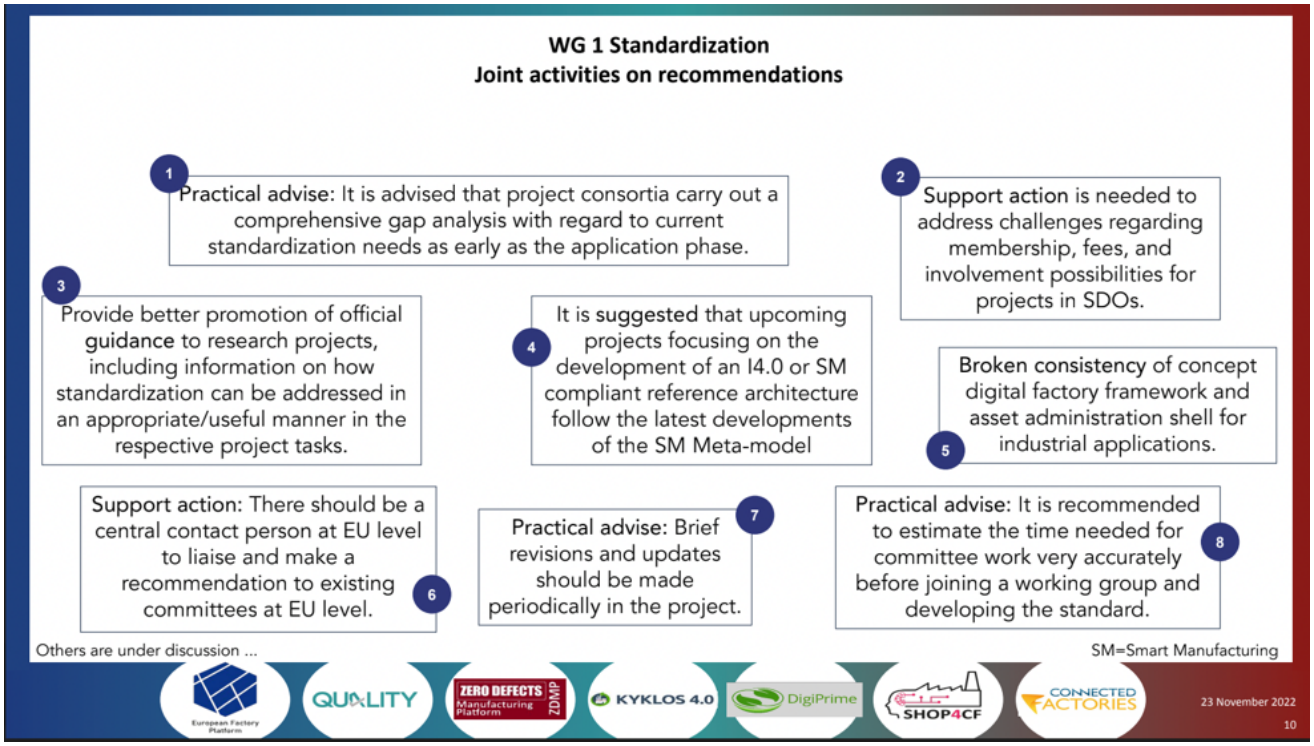


Figure 4 WG1 Standardization Recommendations

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3 Foresights and Recommendations from National Regional workshops

The section reports the main recommendations and observations regarding from the national and regional workshops. The workshops addressed the pathways as well as cross-cutting aspect.

3.1 Cybersecurity

The four workshops addressing cybersecurity produced the following results:

- Feedback regarding the cybersecurity pathway structure itself:
  - The "*Software Integrity"* component of Level 4 should rather refer to "*Platform Integrity"* such that conceptually the component is closer to the hardware and corresponding firmware that might be integrated to improve cybersecurity
  - The linearity of the pathway in real life is not obvious and it is difficult to define clear priorities. Cybersecurity consists of multiple small components. We must try to move forward in parallel on all subjects rather than focusing on a single brick and improving bringing that brick into the state-of-the-art.
  - Setting "*Penetration testing*" at Level 1 seems unrealistic, since systematically operating this type of tests is beyond the scope and technical sophistication of SMEs at such level. Instead audit mechanisms could be set up in place.
- Companies often do not know how to begin a plan for cybersecurity. The structured approach proposed by CF2 was a valued alternative to set up such a plan, including different aspects of relevance for improving cybersecurity components of SMEs.
- Larger companies, e.g. Picanol Group, only started to elaborate such plans after they experienced cyber-attacks. The implementation of their plan is still on-going showing the intricacies of the process. Moreover, this successful use-case was highly valued and appreciated by participants.
- Cybersecurity is not only about technology and not all risks can be addressed with limited budgets. Hence, a risk-based cybersecurity strategy should be set up before cyber-attacks are experienced.
- The draft cybersecurity pathway attracted a lot of attention, and inquiries about when a finalised version was expected.

3.2 Added Value Business Models

Four workshops addressing this topic were organized during the second iteration of National/Regional workshops. It is worth noting that as a topic, specific technologies and fields guide the development of business models. The main transferable results obtained include:

- Regarding business models applied to the *data economy*, the general impression is that this is still an R&D topic. However, participants are aware that it will reach them soon enough. Most agree on the value of data and that soon data is going to become a central part of their businesses. Thus, at the data economy the present customer - supplier roles of manufacturing value networks may change, i.e. relationships are more equal if all partners are both data users and owners. Furthermore, new actors and business models regarding the data management emerge.
- A need for additional information (high level-business related) was identified, particularly in the context of *data economy*.

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- The transition to business models and product-service systems for *circular economy* in the EU industry is an ongoing process that has already begun and continues in diverse national networks and communities.
- Digitalization, sustainability, and circularity: business models for circular economy are narrower and move in the limits of ecology and economic sustainability. Hence, it is important specify that differences between them two exists, and which are those differences, since they reflect on the business models.

3.3 Interoperability and Standardisation

Five workshops were organized dealing with this topic. The main transferable results include:

- It was identified that typically OT and IOT devices are designed to complete a task. However, no standards are specified for: no embedded security, live update mechanisms to guarantee availability and resilience, security standard or compliance, etc.
- In the context of *data economy*, it was identified that the interest in using data from others sources/partners/institutions/organizations/etc. highlighted the need to standardize and set rules regarding the quality of data.
- The benefits of using standards and interoperable technologies in the conception of the *data spaces* was highlighted. Workshop-participants work for different customers with different data sharing systems, and that is very inefficient. Finding common tools that can be interoperable would be a major improvement for the improvement of productivity.
- Several interoperability challenges were identified during the workshops. Specifically[9],
    - Interoperability between proprietary solutions;
    - Interoperability between sectors: cross-sectorial reference architectures;
    - Cloud-IOT interoperability: Edge, fog, cloud;
    - Data interoperability: B2B data exchange, Data integrity: Facilitate storage in common repositories;
    - Semantic interoperability: AAS;
    - HMI-SCADA interoperability: interoperability of real-time process control and visualization software with larger number of devices;
    - Interoperability for the implementation of a digital twin: Data exchange between physical and virtual assets.
- The correct technical interpretation of standards is of vital importance for the success of the technologies that they norm and the standards themselves.
- AAS is a well-accepted international standard that is gradually becoming one of the branding solutions for digital twins, answering and guaranteeing different inquiries regarding interoperability, reliability, etc.
- National colouring, i.e. different countries utilizing different non-compatible standards, should be prevented. Global work is the major priority now.
- Standards and norms should facilitate the interaction between technologies and markets. Standards should aim at international acceptance and specify pathways to compatibility.
- It is essential to achieve common solutions (as e.g. AAS standard and its submodels) especially for sematic interoperability, even if specific technologies or standards change. This type of approach towards semantic definitions is also key to achieve cross-interoperability also on global level.

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- Tools and trainings are currently available as open source. Moreover, these are not abstract but practical, e.g. concrete problems that may be adapted to specific user-case, which may also be tried it out with individual product.
- Companies as a whole need to join and grow, self-assess, etc. A simple and interesting hands-on starting point may be the digitalization of products and services, in compliance with standards, e.g. article numbers to URL.
- The FabOS project provides interesting basis for the practical implementation of standards in a digital twins set up. FabOS middleware provides the necessary framework to establish interoperability between by different users and adopt AAS concepts including submodels, recipes, integration of devices, etc. This should provide SMEs stock-up container in a low-threshold manner.
- Open-source standards: Their operation of such global standards as digital twin should be fast but also practice oriented. Following challenges were discussed in this concern: e.g. paywall, user association, without royalty fee, as user time advantage, accessibility given, all standards freely accessible and accompanying software.
- The Digital Product Passport constitutes an opportunity for the AAS as an interoperability tool and paradigm for the recently promoted European Green Deal.
- There is a need for integration of *solo* actors and stakeholders, such that the contribution to overall interoperability and standardisation efforts can be follow a coherent strategy.
- It is fundamental to consider the scaling of the proposed measures and technologies. It is not enough to test in demonstrations that cannot clearly transfer into industrial settings, neither for technical nor financial reasons.
- An interesting future perspective may be given by the integration of blockchain, which may help identifying white spots, and complement interoperability particularly in the field of digital twins.

3.4 Industrial Agreement and Legal Aspects

This topic was addressed by one workshop focused mainly on the issue data spaces. In this context, the legal aspects related to sovereignty of data, processes, and value and supply chains for the manufacturing process were comprehensively discussed.

A relevant outcome is that, from a legal perspective, it should be feasible and guaranteed that efficiency may be increased within a supply chain in industry, even if between manufacturers of a product and producers of the required raw materials many different suppliers exist. In this context, a fundamental aspect to facilitate the legal safeguards to achieve that increase in efficiency depends on the existence of suitable and robust standards.

3.5 Humans in Manufacturing and Human Factors

The cross-cutting factor Humans in Manufacturing and the pathway Human Factors were touched in four and three workshops correspondingly. Since both topics are very closely related, the transferable results are presented together in the following:

- There is an increasing focus on human-centred aspects of digitalisation, particularly considering the Industry 5.0 concept, which places humans at the centre. One aspect of

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human-centricity are digital assistance systems. Digital assistance systems are increasingly becoming mainstream and encompass a broad range of different devices, e.g. cobots, exo-skeletons, HoloLens, etc.

- Given the increasing labour shortage, digital assistance systems not only support workers and improves quality and production processes but might also embrace employer branding.
- Design thinking approaches are important to address possible barriers and add to successful technology implementations. By doing so, job profiles can be designed to take into consideration needs of employees at an early stage.
- Current technologies enable manufacturing processes at paces in which humans cannot cope with. Therefore, a rise sick leaves it is expected. Hence, effective, and complementary ways of putting humans (back) in the centre of the manufacturing process need to be sought out, designed and tested.
- Co-determination, i.e. closer collaboration and synergies between employers and employees, proved to be successful in the past. Before the pandemic, regular meetings where organised on the shopfloor where information was exchanged between different shift groups. An organisational culture based on trust and open communication is essential for the adaptation and acceptance of new technology developments being rapidly implemented in the European manufacturing landscape.
- Shift the paradigm of "*humas adapting to new manufacturing technologies*", to "*technologies facilitating the job of humas in manufacturing*". An example reviewed was a use case from the automotive industry where the chassis of the car was turned by 90 degrees so that it was not necessary for the workers to work above their head[10].
- A clear understanding of the differences between clerical worker and shopfloor workers should be made. Shopfloor workers often do not have the time to read emails and do not use devices such as tablets for operational reasons as simple as oily hands. The challenge is understanding how digitalization can help and be effectively incorporated into shopfloor activities, instead of just implementing fancy tools. Moreover, industry workers are not coding experts. Effective communication and techniques to improve acceptance of new technologies, e.g. co-creation, can be very meaningful in incorporating digitalization.
- Employees want to communicate to each other. There is clear feedback from various companies that workers do not solely want to use devices like mobile phones to exchange information, but they would like to communicate with colleagues and exchange views, experience etc. For some of the participants this is also an expression of appreciation. Young workers embrace these devices better than older ones.
- Participants highlighted situations in which company workers could not adapt to the incorporation of digital technologies, e.g. tablets, and measures to improve their acceptance. In a specific company workers averaged 50 years of age and received tablets for processing their orders. Nevertheless, 85% of them refused to use the tablets because they were afraid of being monitored. Consequently, every department someone was nominated to show the added value of these devices, offered help, including recommendations on how to improve shopfloor processes. This led to a rethinking of the usage of these tablets as most workers realized their improved working situation and productivity[11]. An important conclusion was that technological progress needs to function in a dialogue, this addresses fears of workers and clerical workers likewise.

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- Innovative shopfloor design is necessary. Human-centred design focuses on human needs. If there are fears, communication needs that are needed but not used, we need a design process where technology can provide solutions. Human-oriented technology design is important and can provide solutions. This implies that these design-features should be considered at early stages.
- Techniques to improve acceptance are essential. This involves recognizing once the new innovative technologies may underperform as a mean to create trust with workers in the shopfloor. Moreover, if trustworthiness is imbedded in the corporate culture, it is easier to implement new technologies because workers trust the technologies, systems, and handling of data.

3.6 Circular Economy

One workshop addressed the topic of Circular Economy (CE) during the second iteration, thus the first version of CE pathway was used. Its main results include:

- The Circular Economy pathway was mostly understandable. However, the pathway could greatly benefit from considering that CE is not created (nor possible) by individual companies. It rather requires collaboration in ecosystem and value-creating networks. The pathway should reflect these facts. This comment was considered and the second (published) version of CE pathway was developed in order to emphasize the network approach.
- The current perspective for CE is dominated by a product-wise perspective. Conversely, life cycle or value-chain perspectives would be easier to be implemented and understood. As mentioned above this was already considered during the development work.
- Radical innovation and complete rethink are needed to create realistic new circular offerings.
- The transition towards CE should be based on customer and consumer requirements.
- Investments made in Stages 1-3 of the pathway may hinder progress towards Stages 4 or 5. This shows a lack of compatibility between Stages.
- As a whole, the Circular Economy pathway may also need to be clarified and synchronized with other frameworks for sustainable transition such as the Paris Agreement[12].

The recommendations for Circular Economy in manufacturing were discussed also at Foresight and Recommendations workshops (autumn 2022). The conclusions from that workshop could be summarized as follows:

- Development of future platform-enabled circular economy options i.e. different R-strategies for resource upgrade
- Interoperability and compliance for 'full-traceability' of value chains within and outside Europe, Digital Product Passport (DPP) as one possible solution
- Novel expert profiles integrating technical skills (IA / Algorithms / data analytics) and CE business views within manufacturing organisations, manufacturing as a service one potential
- Enabling interaction between citizens and consumers with the platforms, enhancing towards circular economy conscious behaviors.

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3.7 Autonomous Smart Factories and Hyperconnected Factories

The Autonomous Smart Factories pathway was addressed in four workshops by three CF2 Partners while the Hyperconnected Factories in two workshops. The main outcomes of both pathways include:

- Companies are aware of the level of smartness and data connectivity in their factories, and they are in principle convinced on the benefits Industry 4.0 digital technologies could bring to them. The Autonomous Smart Factories pathway description was clear and helped them to position themselves in the proposed landscape without any difficulty. Additional discussion with the companies might be needed for depicting the required skills (e.g. multi-stakeholders' teams) and/or barriers that need to be overcome to progress through different phases of the Pathway.
- All SMEs understand the importance of digitalisation, but in many cases the scope of digitalisation is too big. It's easy to focus on the state-of-the-art digital technologies, but for many (possibly most) companies, focusing on the fundamentals is more important.
- Environmental data (as opposed to process data) is increasingly important to help companies meet their regulatory targets around energy use, emissions, and noise. This is often missed from manufacturing digitalisation discussions.
- For SMEs, leadership and guidance is critically important. C-level executives of a company will have many responsibilities, and understanding digitalisation is a critical pre-requisite for effective implementation of digital solutions in a business.
- Data showed very clearly that access to funding and creating business models is the largest hurdle for SME digitalisation. Many digitalisation technologies have benefits which are hard to quantify, which makes business cases difficult.
- SMEs are also wary of digitalisation solutions that involve buying into proprietary or non-standard frameworks. They often lack the skills or financial resources to be able to transition from one standard to another. Open, commonly adopted standards are seen as extremely valuable.
- Conversely, SME technology providers are incentivised to conform to open interoperable standards to encourage adoption of their technologies, as SME-technology providers are perceived as "less stable" than larger companies, and at risk of going out of business.
- Pathways were perceived as extremely useful and interesting tools, and their application to the challenges of creating business cases was particularly emphasized.
- SMEs will often focus on the lower levels of a pathway, and thus the names of some pathways may exclude them from consideration by SMEs. An SME wants a "*connected factory*", not a "*hyperconnected factory*" (nor do they know that hyperconnected means) for example.
- The draft cybersecurity pathway attracted a lot of attention, and inquiries about when a finalised version was expected.
- The importance of inspiring cases and examples cannot be emphasised enough.
- SMEs are also wary of digitalisation without existing proven implementations they can understand and relate to their own business.

3.8 Collaborative Product-Service Factories

Two workshops dealing with this topic were held during the second iteration. The main outcomes include:

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- The pathway is heavily dependent on the specific industrial and manufacturing field for its implementation. It is relevant for its understanding to improve its scalability and generalization.
- There are difficulties in funding new and suitable partners to transit from linear value chains to collaboration in ecosystems. For example, recycling actors are moving towards a much more strategic role, new type of player that fills a very important role for many business models.
- New types of collaborations outside the traditional value chains are needed, e.g. in recycling, upgrading, etc. This extends to building up new types of customer engagement, i.e. from transaction to relationship.

3.9 Data Spaces

Four workshops organized by three different partners dealt with the new pathway on Data Spaces. The outcomes of these workshops include:

- A gap of knowledge exists in the community, which leads into a need for communication and dissemination of the most basic information, e.g. what are data spaces? Why do we need them and how can a company/organization/administration benefit about it?
- Moreover, it is important to adapt the communication, especially when explaining to non-IT people. This includes simplifying the message to essential and understandable terms. Similarly, it is important to create a culture of data sharing that includes the main concepts around it.
- Mobilizing the sectoral associations and encourage them to manage or administrate data spaces would be really an intelligent move, as they would guarantee the impartiality and transparentness
- The legal consideration of developing and implementing data spaces-related services is a big concern for companies, although not crucial for initial incursions since most companies exploring data spaced initially would develop infrastructure with current collaborators[13].
- It is crucial to define new job profiles, specifying the required skills to implement and maintain data spaces. Also specifying a certified training program to achieve those skills. Both for the development and maintenance of components and for the operation of the data spaces within the verticals. Training and skills development must be a priority to be able to adopt a data-driven paradigm. A large need for data-skilled workers was identified.
- The topics of data sharing and data spaces are very interesting for [Austrian] companies as many of them are highly specialized in their fields and would, therefore, directly profit from exchanging more information within their supplier networks in trustworthy ways. Examples of functioning data spaces are still quite rare [in Austria], which is why collaboration with European partners was chosen as the means of delivering the right content to the interested target group[14].
- The importance of data handling and the preparation of reliable data sets, e.g. for usage of digital twins (e.g. collection, cleaning, integration, and grouping), need professional data experts/analysers who are the key to reach good result. This further highlights the importance of developing suitable skills before the implementation of such digitalization technologies in manufacturing.

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4 Foresights and Recommendations from DMP ecosystem

With the objective of collecting foresights and recommendations to be addressed in the Digital Europe Programme and Horizon Europe Programme, CF2 project organized an interactive workshop "ConnectedFactories Foresight & Recommendations workshop" on 19th October, 2022**.**

Participants were asked to analyse the following aspects from the perspective of their project:

1. Added value - impact - value proposition (addressing manufacturing challenges)
2. Significant innovations and achievements associated to digital challenges + Significance of the results for SMEs
3. Key exploitable results
4. Gaps and challenges regarding digital technologies for manufacturing that should still be addressed in future work

Attendees were the representatives of the ecosystem of digital manufacturing platforms associated to CF2. In the following sections the results are presented for each project.

4.1 Foresights and Recommendations from the QU4LITY Project

4.1.1 QU4LITY overview

Qu4lity is the biggest European project dedicated to Autonomous Qu4lity and Zero-Defect Manufacturing (ZDM) in the Industry 4.0. Qu4lity demonstrates, in a realistic, measurable and replicable way an open, certifiable and highly standardised, SME-friendly and transformative shared data-driven ZDM product and service model for Factory 4.0 through 14 pilot lines.

Qu4lity also demonstrates how European industry can build unique and highly tailored ZDM strategies and competitive advantages through an orchestrated open platform ecosystem, ZDM atomized components and digital enablers across all phases of product and process lifecycle. The main goal is to build an autonomous quality model to meet the Industry 4.0 ZDM challenges.

QU4LITY project develops:

- Reference architecture and blueprints: Reference architecture, vocabularies, open data models, standards, best practices, SDOs/SSOs contribution, clustering activities, …
- Digital enablers and Equipment solutions: digital enablers, ZDM platforms and equipment solutions, patents in autonomous manufacturing asset & control, autonomous digital twin MBSE platforms.
- A Pan-European innovation ecosystem clustering activities (DMP Cluster, OPEN DEI Cluster, 4ZDM Cluster, Connected Factories) and the Digital Factory Alliance (DFA)

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Figure 5. The Qu4lity solutions

4.1.2 QU4LITY: identified challenges and recommendations

Main challenges identified in the QU4LITY project are depicted in the following picture:

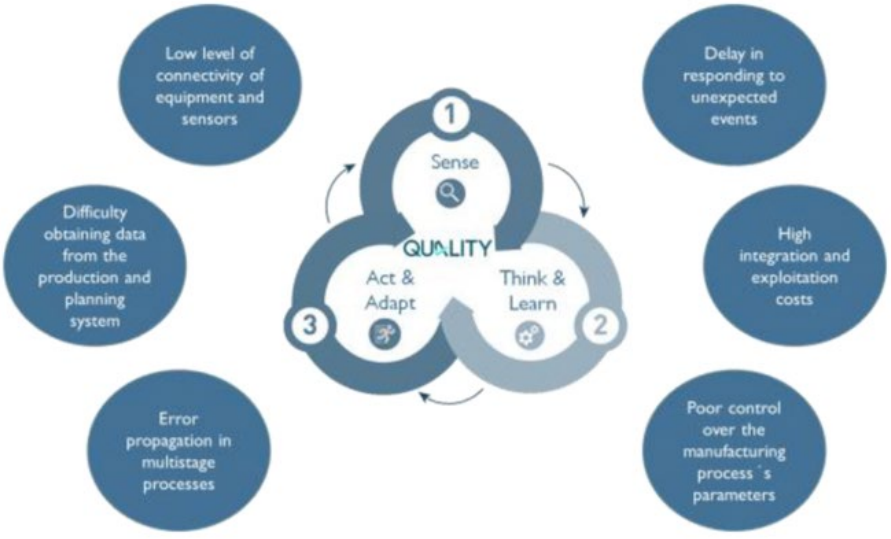


Figure 6. The main challenges

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Thus, the future development work should focus on:

- Further improvement and pervasive use of Sovereign Digital Service Infrastructures toward Manufacturing Data Spaces (for ZDM and circularity);
- Further DFA services to increase preparedness of EU SMEs toward adoption and full exploitation of new-coming digital technologies and data economy.

4.2 Foresights and Recommendations from the SHOP4CF Project

4.2.1 SHOP4CF overview

The **SHOP4CF** (Smart Human Oriented Platform for Connected Factories) project aims to create a unique infrastructure for the convenient deployment of human-centric industrial applications. SHOP4CF believes that people should not be replaced by automated process but can gain new relevance through usage of their individual abilities within the factory. Therefore, new technologies need to be human-centric.

In SHOP4CF, 20 partners develop a comprehensive software platform that hosts a wide range of different software modules (referred to as components) that cover a broad spectrum of industrial requirements and functionalities in the context of modern, flexible, and data-rich manufacturing. Human centricity is one of the key objectives, as the project aims at finding the right balance between automation and human tasks in industrial work.

Therefore, all components considered in the SHOP4CF software platform aim at the mutual complementation of human labour and machines to improve the working conditions by:

- Automating monotonous/laborious work,
- Developing worker's skills,
- Making human-robot collaborations safe,
- Increasing human productivity through smart assistance.

Key aspects of innovation in SHOP4CF are:

- Ensuring interoperability of heterogeneous SW components and existing legacy software via the development of a future proof reference architecture;
- Kick starting a new way of offering and selling software functionality (components) via an online marketplace:
- Focus on the human aspect in terms of acceptance, concerns, and missing knowledge to improve adoption.
- Platform to facilitate the path to Industry 5.0

4.2.2 SHOP4CF: identified challenges and recommendations

SHOP4CF recognises several main challenges regarding digital technologies for manufacturing and works on overcoming them.

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So far, mostly large companies could afford new digital technologies. The SHOP4CF marketplace, components and tools, lower the market entry barriers for small companies offering innovative products and services.

By offering this technology through the marketplace, it is made easy for the industry to discover and test these novel solutions and gain a competitive advantage supporting them in reaching to international customer base and establishing new value chains, clear licensing model reducing the legal overhead, large number of compatible components and services and, finally, affordable remuneration plans the European companies, especially small ones, have increased chances of successfully operating on the international market.

By providing many modern training tools, including MOOCs and AR and VR technologies, SHOP4CF supports acquiring new skills to overcome missing knowledge or needed profiles, making integration of digital technologies in SMEs difficult or even impossible. Offering different technological solutions is often not enough, but also the necessary support needs to be provided and this is planned in SHOP4CF through the developed marketplace.

To summarize, gaps and challenges regarding digital technologies for manufacturing that should still be addressed in future work are:

- To make available the state-of-the-art digital technologies to SMEs (mostly only large companies can afford)
- Integration of digital technologies in SMEs difficult or impossible due to the missing IT knowledge
- Ensure that there is not only the opportunity to buy, but also the necessary support is provided (steep learning curve at the beginning!)
- Standards / availability of usable data models: Lots of reinvention of the wheel is taking place, especially by SMEs for any development work
- Challenges regarding validation of robotic safety (for collaborative applications in factories), especially with flexible processes that are changing and that require updates to risk assessment and validation measurements. Is there a way to do this virtually without the downtime/expertise/hassle required for a measurement?
- Challenges regarding the three areas of functional safety, AI, and cybersecurity: No standards available yet, lots of uncertainty, more experiments and approaches needed in order to be able to establish best practices, which would be a first step towards meaningful standards
- More experiences and evaluations of human factors side of increasing digitalization (especially collaborative robotics) on workers (long term effects) needed to ensure the human-centric goals are being achieved.

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4.3 Foresights and Recommendations from the DIMOFAC Project

4.3.1 DIMOFAC overview

The digitalisation of industry is transforming the existing manufacturing ecosystems and forever changing the production line. The EU-funded **DIMOFAC** (Digital Intelligent MOdular FACtories) project will develop solutions for a permanent production transformation, amelioration and adaptation that will reduce the time of production lines.

To achieve this, it will integrate Plug-and-Produce modules in a 'Closed-Loop Lifecycle Management System'.

DIMOFAC solution is built upon three digital innovations:

- AAS: use of **standards** (AAS as a de-facto standard) to exchange the data between different modules
- DIMOFAC **Digital Platform**: use of a specialised middleware (software) that allows easy deployment of AAS models, and assist the industrial end user to realise the notion of PnP modules and assist in orchestrating them
- **Digital Twins**: to model and simulate processes, to make predictions, to visualise data

4.3.2 DIMOFAC: identified challenges and recommendations

Main challenges identified are:

- Training the existing workforce to use the new technologies
- Support the start-up stages to overcome initial reluctance due to lack of knowledge and too many aspects to integrate, so that industrials does not know how to start
- Reassure and support manufacturers to better embrace innovative Industry 4.0 technologies through test-before-invest approach
- Creating positive image about the manufacturing industry in the new generation so that they are open to join manufacturing domain
- Use of standardisation and healthy collaborations

4.4 Foresights and Recommendations from the 4ZDM Cluster

4.4.1 4ZDM overview

4ZDM cluster gathers several related projects, identifies common interests and synergies, and creates collaborative spaces under the zero-defect manufacturing concept. Through the dissemination of research results developed within industrial cases, it identifies commercial & business opportunities around ZDM. The cluster is paving the way towards an efficient transfer that will allow increase industrial impact. Finally, in the longer term, 4ZDM will aim at the definition of a ZDM vision, paradigm and system architecture.

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The cluster aims to share technological approaches and results for common applications and processes, and is planning to contribute to a common ZDM system architecture, to a European ZDM paradigm and even to international standards on ZDM.

The cluster Value Proposition is based on the following outcomes:

- Reference architecture, blueprints, standards, vocabularies, ... to build ZDM digital platforms.
- Digital enablers and machine enhancements.
- Digital Factory Alliance (https://digitalfactoryalliance.eu/) providing Knowledge, Digital solutions, Innovation Ecosystem and Business network.

The significant innovations can be summarized under the following topics:

- Bridge building among past-running-new ZDM EC-funded projects.
- Generation of a ZDM relevant community, aware of last developments and technology achievements.
- Sensitiveness for ZDM-technology transfer towards industries and sectors (identifying the ZDM industrial needs/challenges)
- Adaptation and evolution of ZDM paradigm to new waves (digital transition, green transition)
- Generation of paradigm, whitepapers, roadmaps, books in ZDM framework.
- Lobby activity in front of EC to keep opportunities for ZDM in future programmes/topics.

4.4.2 4ZDM cluster identified challenges and recommendations

ZDM is in constant/dynamic evolution (digital, green, zero-waste, zero-X, DTI...). It welcomes all digital technologies that help reduce time/costs, increase productivity/quality, improve sustainability/circularity along lifecycle approach.
Gaps and challenges regarding digital technologies for manufacturing that should still be addressed in future work are as follows:

Increasing Demand for Mass Customization, Personalization and Small Batch

- Zero defect manufacturing systems able to prevent the generation of defects based on integration of process, product and context data, applicable to small batch productions.
- Development of dynamic quality control systems, operating under adaptable thresholds and alarm triggering mechanisms.
- Capability of adjusting target quality-productivity trade-offs depending on the market conditions. Zero defect manufacturing during system ramp-ups in the transition to new production.

Pressure on Efficiency in Delivering Complex, Multi-material Products

- Robust design approaches for non-conventional processes and systems taking into account non-ideal parts, able to anticipate and compensate for product variations already in the design phase.
- Integrated and data-driven product process, and system modeling and analysis tools, able to facilitate understanding of quality bottlenecks and quantitatively predict the effect of quality improvement actions on the service level of defect-free parts. System engineering and control tools for optimized quality and logistics control solutions, at system level.

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Pressure to Deliver Zero Waste and Improve the Social and Environmental Performance of EU Industries

- Solutions for remanufacturing, repairing and reworking defects in-line, thus avoiding non-value-adding energy-intensive processes on already defective parts.
- Quality assurance plans for manufacturing systems that are tolerant to the reuse of recovered materials and components as secondary raw materials, from a circular economy perspective.
- New robotics and ICT solutions in support of accelerated human learning and of robot-assisted manual operations.

New Service-oriented Businesses and Globally Efficient Manufacturing Ecosystems

- New generation of service-oriented plug-and-inspect sensors, to be selected and integrated into production lines based on their capability to perform the required inspection tasks.
- New quality assurance methods to capture implicit product requirements in emerging region-dependent markets, supporting the delivery of the needed product functionalities at the required quality levels.
- New cross-plant quality information systems to support product traceability and planning coordination in adaptive and multi-stakeholder value chains.

Integrated Approach to Quality Control, Production Logistics and Maintenance Policies

- Improved condition-based and opportunistic maintenance methods, correlating the machine degradation states to the workpiece quality able to reduce the impact of maintenance actions on the achievement of production targets.
- In line, 100% product, process and resource inspection and data-gathering systems.
- New modular control system architectures for intelligent machining and adaptation of process plans for dynamic workload allocation to compensate for machine degradation.

Research priorities are:

Increasing Demand for Mass Customization, Personalization and Small Batch

- Cyber-physical systems able to adapt process plans, parameters and production routings to reduce defects.
- Profile monitoring tools, supporting zero defect manufacturing in small batch productions.
- Defect monitoring in complex manufacturing systems.
- Dynamic control of quality targets during production.

Pressure on Efficiency in Delivering Complex, Multi-material Products

- Tolerance-oriented assembly methods enabled by on-line optimal part matching algorithms.
- Part variation modeling methods and tools to predict the output quality.
- Learning and diagnosis methods for complex multi-material products.
- Predictive quality planning methods to anticipate quality issues during the system
- design stage.
- Development of cost-effective in-line geometric product inspection technologies.
- New multi-level, multi-scale, integrated process/system modeling and analytics.

Pressure to Deliver Zero Waste and Improve the Social and Environmental Performance of EU Industries

- Combining additive & subtractive processes and surface treatments for in-line product repair and remanufacturing.
- Development of manufacturing processes and systems for the reuse of secondary raw materials.
- Development of highly automated demanufacturing and remanufacturing technologies.
- Development of robotics and ICT solutions to support complex manufacturing tasks.

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New Service-oriented Businesses and Globally Efficient Manufacturing Ecosystems

- Design and implementation of plug-and-inspect sensors for on-demand inspection.
- Cloud-based quality information systems for traceability and planning coordination in
- the value chains.
- Quality assurance strategies and solutions for supporting frugal innovation in emerging
- strategic markets with region-dependent requirements.
- Manufacturing strategies and business models for zero defect and zero waste
- manufacturing systems.

Integrated Approach to Quality Control, Production Logistics and Maintenance Policies

- Model-based, opportunistic maintenance solutions, integrating maintenance, quality and inventory control decisions.
- Protocols and standards for data collection and integration – including product quality, process conditions and part logistics.
- Development of next-generation machine control systems for adapting process plans according to shop-floor resources.
- Integrated machine, fixture, tool and workpiece models for quality and resource deterioration prediction.
- Integration capabilities in production equipment of intelligent, autonomous, and self-adaptive devices for process degradation monitoring.
- In-process sensors for machine footprint diagnostics supporting decision making in both quality control and maintenance planning.
- Formalized data structures and interaction mechanisms between maintenance, quality and production logistics departments.

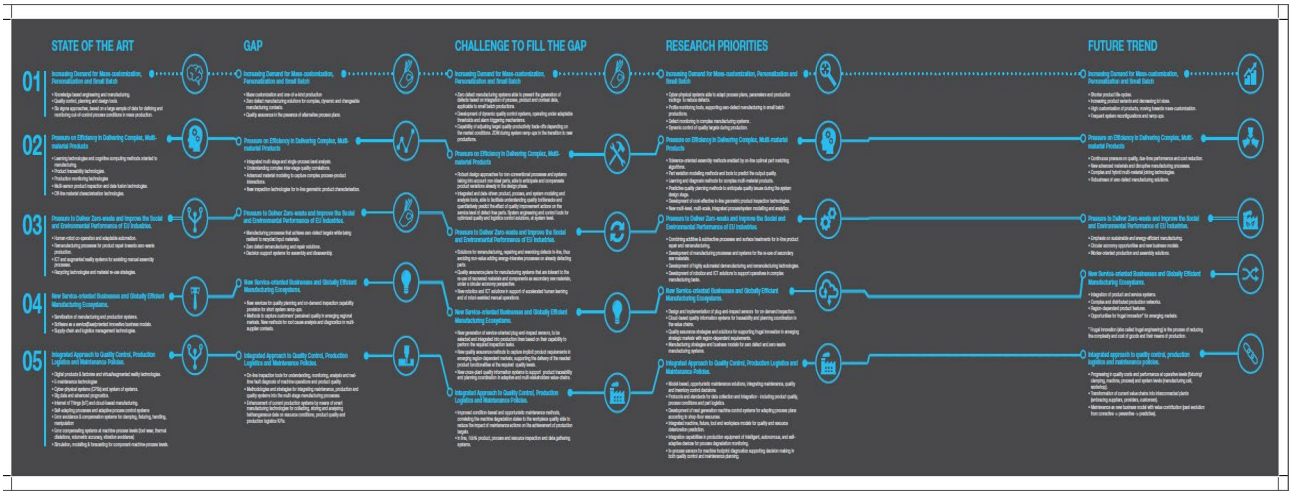


Figure 7. The 4ZDM gap and challenges

4.5 Foresights and Recommendations from the ForeSee Cluster

4.5.1 ForeSee overview

The **ForeSee** cluster (www.foresee-cluster.eu) consists of 11 EU funded H2020 and HE research projects (PROPHESY, PROGRAMS, SERENA, UPTIME, Z BREAK, Level Up, COALA, MAS 4 AI, RECLAIM and OpenZdM). Research and technology partners together with industrial end users

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have been working collaboratively to develop and deploy solutions that advance technologies and practices in industry towards more efficient, sustainable, human centric and resilient factories.

The ForeSee cluster thematics are:

1. Predictive Maintenance,
2. Predictive Quality,
3. Predictive Analytics,
4. Predictive Energy,
5. Skills and Competencies and
6. Standards.



Figure 8. ForeSee cluster thematics

The ForeSee cluster focuses on

- Introducing predictive operations paradigm in the manufacturing industry
- Skills requirements and development for the future factory
- Contribution to the future research agenda
- Development of roadmap for predictive technologies adoption
- Enhance European industry innovation capacity
- Joint communication and dissemination activities
- Joint standardization considerations

4.5.2 ForeSee: identified challenges and recommendations

The main exploitation result is the ForeSee cluster white paper on *"Predictive maintenance technologies for production systems. A roadmap to development and implementation*."

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Figure 9. ForeSee White Paper

The White Paper provides a roadmap to predictive maintenance solutions in manufacturing, merging the knowledge of the six H2020 projects and discusses the skills requirements for enabling predictive maintenance in manufacturing.

ForeSee identified the following gaps:

- Complexity of implementing and interpreting AI
- Skill gap in the manufacturing workforce
- Quantity and quality of data for accurate AI solutions
- Capital investment for required infrastructure
- Mindset

4.6 Foresights and Recommendations from the XMANAI Project

4.6.1 XMANAI overview

The EU-funded **XMANAI** project will focus on explainable AI, a concept that contradicts the idea of the 'black box' in machine learning, where even the designers cannot explain why the AI reaches at a specific decision. XMANAI will carve out a 'human-centric', trustful approach that will be tested in real-life manufacturing cases. The aim is to transform the manufacturing value chain with 'glass box' models that are explainable to a 'human in the loop' and produce value-based explanations.

XMANAI aims at placing the indisputable power of Explainable AI at the service of manufacturing and human progress, carving out a "human-centric", trustful approach that is respectful of European values and principles, and adopting the mentality that "our AI is only as good as we are".
XMANAI, demonstrated in 4 real-life manufacturing cases, will help the manufacturing value chain to shift towards the amplifying AI era by coupling (hybrid and graph) AI ""glass box"" models that are explainable to a ""human-in-the-loop"" and produce value-based explanations, with complex AI assets (data and models) management-sharing-security technologies to multiply the latent data value in a trusted manner, and targeted manufacturing apps to solve concrete manufacturing problems with high impact."

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4.6.2 XMANAI: identified challenges and recommendations

In order to enable fair, accountable and transparent machine learning and deep learning applications, XMANAI shall make AI models for manufacturing more explainable by design during the pre-modelling, modelling and post-modelling phases.
Across the three XAI perspectives, different AI models always need to be trained and validated while detecting and mitigating bias in training datasets..
However, currently European society is not providing enough meaningful data for the development of AI. This is an indisputable requirement to create insightful AI pipelines less prone to errors.

Main recommendations from the project are:

- Spread the glass-box approach in digital technologies implementation to overcome manufacturing companies' initial reluctance due to black-box effect
- Improve AI flexibility to adapt to different manufacturing needs while ensuring a smooth IT integration
- Support new business models based on digital transformation in predictive maintenance for production systems
- Promote standardisation of data and platform interoperability techniques to help establish a comprehensive digital ecosystem

4.7 Foresights and Recommendations from the AI-PROFICIENT Project

4.7.1 AI-PROFICIENT overview

The manufacturing and process industry can benefit from artificial intelligence (AI) technologies. By combining human knowledge with AI capabilities, **AI-PROFICIENT** project will develop proactive control strategies to improve manufacturing processes in terms of production efficiency, quality and maintenance. The overall goal is to increase the positive impact of AI technology on the manufacturing process as a whole, while keeping the human in a central position, assuming supervisory (human-on-the-loop) and executive (human-in-command) roles. By identifying the effective means for human-machine interaction, the project will assist Europe's manufacturing and process industry to improve production planning and execution.

The added value of the project is as follows:

- Investigate disruptive technological solutions by introducing AI for the implementation of optimized strategies in the frame of agile production and predictive maintenance, to face challenges of adaptability, agility and resilience of Cyber Physical Production System
- Place the human at the center of the implementation (considering ethical aspects - relation to operational actor) and at the center of the service design (ethics by design)
- AI-based improvements in e.g. production, quality, machine control and use of material

4.7.2 AI-PROFICIENT: identified challenges and recommendations

AI-PROFICIENT identified the following needs:

- **Integration of AI technologies:**
  - Enable plant level automated operation
  - Achieve decision making detached from the operator's experience

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  - Support human interaction (operator) – integrate to service/UC pipelines
  - Establish AI as enabler for solution development
- **Data-driven predictive AI-analytics to develop maintenance Strategy**
- **Anomaly detection for:**
  - Early prevention of faulty Product characteristics
  - Early detection of process failure to minimize loss of raw material and avoid energy consumption
- **Real-time decision-making and advanced edge deployments**:
  - Addressing monitoring quality, meeting customer delivery dates, and more → Immediate decisions making
  - Streaming analytics and real-time prediction services → act immediately prevent undesirable consequences
  - Ability to deploy predictive models on the edge devices → critical to enable smart manufacturing applications
- **Data quality**:
  - Access to clean, meaningful, high-quality data
  - This can be a challenge in manufacturing
- **Correlation between Data and Physics**:
  - Descriptive and predictive correlations of data → design and operation of manufacturing systems
  - Laws of physics to be implicit in the data → sufficient to produce relationships and operating laws
- **Self-Capabilities**:
  - Incorporate artificial intelligence techniques → high level of autonomy → adaptability and resilience.
  - Applicable to Component, Machine and Production System levels → Self-Aware, Self-Predict, Self-Compare, Self-Maintain, Self-Organize
- **Sustainability instrumentation**:
  - Systematic deployment in manufacturing systems → collecting environmental data
  - To be encouraged → processing by artificial intelligence algorithms

4.8 Foresights and Recommendations from the CAPRI Project

4.8.1 CAPRI overview

CAPRI (Cognitive Automation Platform for European Process Industry digital transformation) brings cognitive solutions to the Process Industry by developing, testing and experimenting an innovative Cognitive Automation Platform towards the Digital Transformation. To this end, CAPRI enables cognitive tools that provide existing process industries flexibility of operation, improving the performance across different indicators and state of the art quality control of its products and intermediate flows.
The main added value provided by the project is the Digital transformation of Process Industry (Steel billets & bars, Asphalt minerals, Pharma industry chemical) and Manufacturing companies through cognitive solutions applied at Different automation levels.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

4.8.2 CAPRI: identified needs and challenges

Gaps and challenges identified by CAPRI regarding digital technologies for manufacturing that should still be addressed in future work are:

- Interoperability of IT infrastructures
- Mutual lack of knowledge among manufacturing sector experts and IT/Data experts
- Unavailability of real time data with enough quality
- Proper identification of relevant end users
- User acceptance of the technical solutions (change of status quo)
- Training of new digital skills
- Open collaboration

4.9 Foresights and Recommendations from the DigiPrime Project

Digital technology plays a big role in our transition to a circular economy, which aims to make optimum use of resources within industries. Investing in innovation is good for the protection of the environment, and it also contributes to Europe's competitiveness. The EU-funded DigiPrime (Digital Platform for Circular Economy in Cross-Sectorial Sustainable Value Networks) project will develop the concept of a circular economy digital platform in order to create circular business models based on the data-enhanced recovery and reuse of functions and materials.

4.9.1 DigiPrime overview

The EU-funded DigiPrime (Digital Platform for Circular Economy in Cross-Sectorial Sustainable Value Networks) project will develop the concept of a circular economy digital platform in order to create circular business models based on the data-enhanced recovery and reuse of functions and materials. The project will develop a new concept of Circular Economy digital platform overcoming current information asymmetry among value chain stakeholders, in order to unlock new circular business models based on the data-enhanced recovery and reuse of functions and materials from high value-added post-use products with across-sectorial approach. The project addresses the following challenges:

- Product data and knowledge is not exchanged among manufacturers and de- and remanufacturers, as well as among sectors leading to unlocked cross-sectorial material re-use opportunities.
- Lack of certification protocols for secure reused materials and components transfer among sectors.
- Poor acceptability of products embedding recycled materials by end-customers

4.9.2 DigiPrime: identified challenges and recommendations

The DigiPrime recommendations for future R&D and remaining challenges are:

- Digital Product Passport (DPP) compliance of the developed digital platform;
- Integration of upstream value-chain phases (core resource gathering and pre-processing, material supply) in the developed platform.
- Integration among platforms, e.g. Circular Economy and Energy Management platforms.
- Integration of the concept of 'Manufacturing as a Service'.

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- Integration of platforms services with the eco-innovation indicators in order to support companies in the implementation of the eco-innovation action plan.
- Reward schema and specific strategies for involving citizens and consumers in the interaction with these platforms, towards circular economy conscious behaviors.
- Specific training programs aiming at facilitating the adoption of digital platforms and the related tools within factory operations (recycling and remanufacturing in particular).
- Support uptake of emerging platform-enabled circular economy business cases in emerging sectors, i.e. batteries, textiles and composite/techno-polymers.
- Support development of future platform-enabled circular economy options. i.e. remanufacturing for function upgrade. Smart product remanufacturing for cross-sectorial re-use by reprogramming or by installing new or modified software modules.

4.10 Foresights and Recommendations from the KYKLOS 4.0 Project

4.10.1 KYKLOS 4.0 overview

In **KYKLOS 4.0** (An Advanced Circular and Agile Manufacturing Ecosystem based on rapid reconfigurable manufacturing process and individualized consumer preferences) aims to develop an innovative Circular Manufacturing ecosystem based on novel CPS and AI based technologies, enhanced with novel production mechanisms and algorithms, targeting on personalised products with extended life cycle and promoting energy efficient and low material consumption intra-factory production processes, resulting reduced greenhouse gas emissions and air pollutants.

Key benefits of the project, as they are formed until this point, are summarized below:

- Incorporate a set of components that support the production, post-production, and assembly phases, by modernizing the functionalities of shop floors in the adoption of Circular Manufacturing principles
- Identify processes not performing optimally and recommend further improvement
- Address several business-related and technical challenges towards building a Circular Economy
- Accelerate businesses' digital transition to boost their advancement and recovery
- Enable continuous monitoring of the Circular Manufacturing implementation within the organizations to early react and improve the Circular Economy related metrics.

4.10.2 KYKLOS 4.0: identified challenges and recommendations

KYKLOS 4.0 recommendations for future R&D and remaining challenges are:

- Digital technologies cannot be made for dummies since the knowledge require to understand and digitalize the manufacturing business is specific for each business
- The required effort for the deployment and adaptation of the digital solutions to the industry is still and potentially will always be high, due to the high relationship of the manufacturing process to the actual business.
- Lack of required expert profiles in IA / Algorithms / data analytics / CE within manufacturing organisations (Expensive resources)
- Consultancy should be in house – increasing overall costs

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- Expert knowledge on CE business models / manufacturing business is Required for the transition to CE, the adaptation of the manufacturing businesses to this new CE models / resource monitoring and control is not always so evidence

4.11 Foresights and Recommendations from the AI REGIO Project

4.11.1 AI REGIO overview

The EU-funded AI REGIO project addresses policy, technology and business barriers to support creation and sustainable growth of AI-focused Digital Innovation Hubs (AI DIHs) to support European manufacturing SMEs in their digital transformation. It will build a one-stop-shop platform that enables access to resources for AI-based solutions in efficient and sustainable manufacturing, with particular emphasis on resources that can lower the AI adoption barriers for SMEs.
AI REGIO aims to consolidate the collaboration in the pan-European network of Digital Innovation Hubs (DIHs) by enhancing the offering of regional DIHs to manufacturing SMEs on three levels:

- **Better coordination of regional smart specialisation strategies** (Policy Impact): AI REGIO will foster closer cooperation across European regions, EU and non-EU countries to make sure innovations can scale to European and global marketplaces, building up on the Four Motors for Europe movement and the I4MS Community and Platform.
- **Enhancing knowledge transfer across the network of DIHs** (Technological Impact): AI REGIO will build on Digital Manufacturing Platforms from previous EU-funded projects such as BEinCPPS, MIDIH, L4MS and AI4EU and help to integrate these into Digital Innovation Hubs offerings. These Digital Manufacturing Platforms will in turn benefit from present Digital Innovation Hubs services regarding their business and social impact challenges. Present AI-enabled technological assets will further be extended.
- **Upgrade the offering of DIHs by AI-driven applications** (Business Impact): DIHs and SMEs participating in AI REGIO will jointly conduct 30 AI-driven regional application experiments focused on the adoption of AI technologies by SMEs, considering skills development, as well as privacy and sovereignty preservation.

The AIREGIO network of DIH will have a strong impact in the competitiveness of SMEs manufacturers, through easing their efforts for successfully adopting AI. In particular, the project will provide SMEs with access to resources that confront the main challenges of AI adoption, including organizational and process reengineering issues, but also reliable, secure, safe and human centric technological solutions. The potential impact on SMEs could be exponential, as recent studies reveal that organization which start the AI adoption in the right foot and see benefits, expect to have much more benefits in the future. In practice, the AI REGIO platforms and related support services will enable SME manufacturers to optimize their logistics operations, to improve operational parameters like OEE (Overall Equipment Efficiency) based on AI-based predictive maintenance and quality management, as well as to eliminate laborious and error prone processes based on the deployment of robots and their collaboration in human-robot (co-bot) use cases. AI REGIO employs a holistic approach to AI adoption for SMEs

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4.11.2 AI REGIO: identified challenges and recommendations

As an external contributor to the DMP cluster, AI REGIO (I4MS Phase IV project focussing on DIHs for Manufacturing and SMEs Digital Transformation) can formulate the following foresights and recommendations to be taken into account by e.g. the I4MS2.0 projects to be funded in HEP calls.

- **Data4AI Pipelines.** It is necessary to address the data challenges in future DMP projects, especially when they are referred to advanced and potentially sensitive AI applications. In AI REGIO this has been implemented by Data Pipelines in the APACHE Streampipes development studio and deployed for several industrial cases (including those selected for the FSTP two waves open calls). The issue of no-code / low-code synthetic data generation for AI is a new R&I frontier which could be addressed by the Data community and applied to manufacturing as well. In particular, certified quality synthetic datasets are absolutely necessary for diagnosis / maintenance applications (reproducing malfunctions and accidents difficult to demonstrate in real plants) and for applications involving human factors (TEchnology and REgulatory SAndboxes TERESA)

- **AI for Manufacturing toolkit.** Several projects are addressing the "AI for Manufacturing" challenges. The role of AI REGIO Innovation Action is not just to develop new AI assets and models, but to systematise the bulk of knowledge regarding the "AI for Manufacturing" domain in some sort of "toolkit", this way easing and favouring its access by DIHs and SMEs. In order to do that, a strong collaboration with AI4Europe is recommended, regarding the AI Catalogue and its Manufacturing vertical, the centralised AI4Europe experimental facility of ACUMOS-based AI pipelines experiments and its marketplace (Design Studio and its components), the creation of a network of interoperable distributed local-regional AI playground facilities to ease the testing and experimentation of AI applications requiring multiplicity and high decentralisation of data to be analysed (e.g. in federated learning and AI TEF for Manufacturing facilities).

- **Human-AI collaboration.** An essential aspect of Manufacturing Automation Level 4 (see CF2 AI for Manufacturing pathway) is to properly model the behaviour of not just physical artefacts (Digital Twins of Manufacturing components, of Products – the so called Digital Product Passports -) but also of human beings (Digital Personae) and to insert them in virtual simulated workspaces and working situations. Such simulated environments (including also 3D Avatars and Metaverse facilities) could be very useful to simulate complex situations (Human assisting Machines vs. Machines assisting humans) and to address unexpected, unknown situations also by means of synthetic data and scenarios generation tools.

- **Data Spaces for Manufacturing.** Last foresight and recommendation from AI REGIO concerns "Data Spaces for Manufacturing" and the coming DEP third call for Dynamic Assets Management and Agile Value Networks in Manufacturing (JAN 24th 2023). In the AI REGIO project we have developed a threefold business model to rule the business impact of Data Spaces to Manufacturing Industry.
  - **Open Data business models**, open both from the supply and the demand side. In order not to contrast legitimate requirements for privacy and confidentiality, this business model can be fruitfully applied to "test before invest" Didactic Factories and to increase the contribution of Manufacturing Industry to open Innovation Models, and Living Labs

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- **Data Marketplaces business models**, open from the demand but closed from the supply side, in order not to conflict with legitimate arguments about competition from many manufacturing and ICT companies. Platform Economy principles have to be considered (and modelled by Skt Gallen BM Navigator for instance) as well as Data Sovereignty architectures and DMPs
- **Trusted Data Networks business models**, closed both from the demand and the supply side but with lower entry barriers for SMEs and Startups willing to implement cross-domain and cross-sector industrial value chains. In this case, beyond the Technical and the Business aspects, the recommendation is not to underestimate the need for legal multi-stakeholders Industry Agreements to be created and put in place.

4.12 Foresights and Recommendations from the EFPF Project

4.12.1 EFPF overview

EFPF is a federated smart factory ecosystem and a digital platform that interlinks different stakeholders of the digital manufacturing domain. The EFPF platform enable users to utilise innovative functionalities, experiment with disruptive approaches and develop custom solutions to maximise connectivity, interoperability and efficiency across the supply chain

EFPF enables users to leverage Industry4.0, data analytic and IoT solutions available in the EFPF ecosystem through a unified interface and Single-Sign-On functionality. The goal is to foster a pan-European platform ecosystem that enables the transition from "analogue-first" mass production to "digital twins" and batch-size-one manufacturing.

To this end, the federated EFPF ecosystem is established by linking industrial platforms and open-source tools from project partners. At the heart of the EFPF ecosystem is the Data Spine, an interoperability mechanism that supports secure and interoperable data exchange, service calls and API integrations across multiple systems and platforms.

To support users in creating their software applications and services, an open Software Development Kit (SDK) and a development environment (Studio) have been created. The EFPF Marketplace Framework uses the Data Spine to connect the marketplaces of multiple platforms in the EFPF ecosystem. It provides a unified interface that allows users to search across multiple marketplaces for their business and technology needs.

4.12.2 EFPF: identified challenges and recommendations

Gaps and challenges regarding digital technologies for manufacturing include:

- Standardisation of data and platform interoperability techniques to help establish a digital ecosystem of digital systems and platforms
- Introducing more ease of use of blockchain technologies to facilitate their application in different scenarios
- Human centric (more explainable, trustworthy) AI to facilitate understanding and adoption of AI solutions in critical decision-making processes

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Future work in the context of EFPF project can include:

- Enhancing Data Spine to semantic and Intelligent Data Spine so that the interoperability gap (at data model, serve and platform levels) can be address in a more automated approach.

5 Conclusions

While there is a great recognition that digital technologies and platforms help reduce time and costs, increase productivity and quality, improve sustainability and circularity in manufacturing, there are still many barriers that hinder their adoption. This report gives an overview of the barriers and challenges associated with the development and adoption of digital technologies and platforms, and associated cross-cutting aspects. In addition, recommendations to future development topics are given. The analysis is based on the results of several projects, working groups, workshops and use cases, as well as on the ConnectedFactories pathways.

As a summary, many projects and initiatives identified tough technical challenges in e.g. interoperability, standardization, data quality and availability, architectures and availability of tools. However, many barriers are non-technological, such as **lack of resources** and **expertise** in companies who want to approach the digital transformation process, or the **need of human centric** (more explainable, trustworthy) technology to facilitate understanding and adoption of digital solutions in critical decision-making processes. Also, legal aspects are a big concern for many companies. The need for best practices and success stories, including business and regulatory aspects, were called for.

The recommendation for future investments in the area of Circular Economy, Data Spaces and AI in manufacturing, including cross-cutting issues, are various and well documented in the report. To name only few, activities are needed to

- accelerate the shift towards greener value chains that requires the use of recycled materials and green energy, along with focusing on resource-efficient, demand-driven production and circular value networks,
- highlight the business benefits of adopting green and digital technologies
- improve the quality and availability of data, which requires a change of mindset in lot of companies, scared of adopting new solutions (Open Source in particular) to share data among third parties in digital value chains.
- invest in standardisation and interoperability
- support SMEs in the adoption of digital technologies and platforms as well as of circular approaches
- strengthen human-centric approach and development of skills

Finally, the collaborative approach is highly appreciated, which is even more evident when addressing circular business models and data sharing in value chains. Inspiring use cases and success stories and structured approaches (such as the CF2 pathways) are valued. These should be continued and highlighted also in the future.

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