D5.1 Collaborative Intelligence and Industry 5.0

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Table of Contents

Figures

Executive Summary

Task 5.1 in AI REGIO aims to provide a modelling and simulation playground for Industry 5.0 and Human-AI Collaborative Intelligence scenario (the AI REGIO Industry 5.0 Platform inside the AI REGIO "AI for Manufacturing" Architecture). Such I5.0 models will be suitable to support orchestration of human-centered processes in terms of process management and Human-AI interaction assessment, enabling comparison of different technological solutions and selection according to client needs. As part of this task, an orchestration and enactment service will be defined to support the design of operational and interaction workflows, and the configuration of specific applications and services.

The goal of the present deliverable is to drive all the developments to be performed within the task 5.1. To reach this goal, the document starts to analyze Industry 5.0 and Collaborative Intelligence concepts, also leveraging a set of motivational scenarios oriented to the new Industry 5.0 paradigm. The main findings of this preliminary analysis include the motivations to go beyond the technology-centred view of Industry 4.0, more focused on digitalization and AI-driven technologies. Industry 5.0 focuses on principles such as social fairness, resilience, sustainability, and the need to enforce awareness on societal challenges such as the ageing workforce and mass customization. Other significant findings of the analysis work are the definition and objectives of the new Industry 5.0's paradigm.

This analysis is then compared with a study on ongoing initiatives related to Industry 5.0, useful to define an appropriate proposition of architecture. A main outcome of this study is a list of research and technical gaps on Industry 5.0, mapped with challenges and enabling technologies to overcome them. In particular, the list of the enabling technologies includes human-centric solutions and human-machine-interaction technologies that interconnect and combine the strengths of humans and machines and real time based digital twins solutions to model the workers at the centre of the manufacturing processes. This study mainly focuses on the latter, with the overall aim to implement a digital twin compliant with the Industry 5.0 paradigm. Moreover, the D5.1 document reports a classification of past and ongoing EU projects focused on Industry 5.0 in order to provide confirmation of such research and technological gaps.

Based on the results of the state of the art, a conceptual model for Human-AI interaction in Industry 5.0 is conceived and designed, which is focused to orchestrate, monitor, and simulate the human-centred processes. The AI REGIO Industry 5.0 model is based on the Digital Twin (DT) which is becoming a consolidate technology to simulate the physical industrial asset performance, thus allowing to predict failures or investigate problems. Specifically, the DT represents a virtual and faithful mirror of the physical process that allows to monitor the process parameters, to compare them with any analytic models, and to supply in real-time specific variations of parameters to keep the process always in optimal conditions. The AI REGIO Industry5.0 model can be adopted as a reference architecture for a platform that promotes harmonization and orchestration between machines and the human factors, especially considering the cognitive and physical workload related to manufacturing operations.

At a second stage of the project, the partners involved within the task 5.1 will work to provide an implementation adhering to the proposed conceptual model's specifications, and this implementation will also be validated within a real case study, thus allowing to demonstrate the correctness of the overall proposed approach.

Abbreviations

Abbreviation	Explanation
OME	Observable Manufacturing Element
LOD	Linked Open Data
SWT	Semantic Web Technologies

1 Introduction

1.1 Scope of the Deliverable

The goal of the present deliverable is driving all the developments to be performed within the task 5.1 throughout the entire project.

In particular, the scope is to provide a conceptual model for a platform managing Human-AI interaction in Industry 5.0 contexts, where the platform is mainly exploited to orchestrate, monitor, and simulate the human-centred processes. In order to reach this goal, the work will also provide, as an intermediate result, an analysis of the fundamentals related with the concepts of Industry 5.0 and of Collaborative Intelligence, also leveraging the definition of a set of motivational scenarios oriented to the new Industry paradigm.

Based on the design of the conceived conceptual model, a roadmap for future actions within AI REGIO should be developed and proposed. Indeed, the design of the conceptual model represents the main step of a roadmap which will continue, at a second stage of the project starting at M10, with the implementation of an AI REGIO Industry 5.0 platform having its root in the conceptual model previously defined.

1.2 Impact and target audience

The target audience of the herein proposed conceptual model are manufacturing SMEs interested to extend their Industry 4.0 processes towards a collaborative intelligence paradigm between humans and AI-based autonomous systems.

Specifically, this conceptual model can be taken into account by SMEs as a reference architecture of a platform for Industry 5.0 adoption that include methods and tools to promote harmonization of human and technological skills and strengths, and this harmonization brings in turn a mutual benefit for SMEs and SMEs workers.

1.3 Dependencies in AI REGIO

The task 5.1 is interacting with several AI REGIO work-packages and tasks:

- **WP2 - *Beyond REQUIREMENTS: AI DIH Digital Transformation from scenarios to business cases.***
  The Industry 5.0 Platform represents one of the five AI REGIO Key Exploitable Assets in WP4 and WP5. As for all other assets, its technological requirements have been elicited through an analysis process performed within the WP2 (D2.3 and D2.5).

- **WP4 - *Beyond PLATFORMS: AI DIH Open Platforms and DIH Platform.***
  The Industry 5.0 platform is closely interrelated with Data4AI and AI4Manufacturing platforms

- **WP5 - *Beyond INDUSTRY 4.0: AI DIH Industry 5.0 and Data Sharing Spaces.***
  A pillar of the AI REGIO industry 5.0 platform is an Industry 5.0 data space conceived in collaboration with the other tasks of WP5, including the data models, data sovereignty contracts, data cleansing, and life cycle management.

- **WP6 - *Beyond EXPERIMENTS: AI DIH regional facilities from demos to regional champions.***

  The AI REGIO Industry 5.0 platform will be evaluated and assessed within some AI REGIO experiments more oriented to Industry 5.0.

- **WP7 - Beyond IMPACT: AI DIH exploitable assets from technological to regulatory sandboxes.**

  One or more Digital Factories belonging to the AI REGIO Digital Factories network (task 7.2) will be selected on the basis of the willingness to support Industry 5.0, in order to adapt the principles of this paradigm. In this context, in addition, the AI REGIO Industry 5.0 platform will be tested and evaluated also in the TERESA (T7.1) experimentations.

1.4 Structure of the Document

The document is structured as follows.

Chapter 2 (Background and Motivation) illustrates how the EU Manufacturing Industry market (and especially SMEs) needs a human-centric, resilient and sustainable revolution to be competitive in the global market, especially recovering from the pandemics.

Chapter 3 (**Fundamentals of Industry 5.0**) reviews the fundamentals related to the concepts of Industry 5.0 and Collaborative Intelligence, by focusing on the historical background of Industry 5.0 (Section 3.1), on a classification of ongoing EU projects from an Industry 5.0 perspective (Section 3.2), and on a report from the EC about the enabling technologies for a concrete realization of the Industry 5.0 concept (Section 3.3).

Chapter 4 (AI REGIO I5.0 Platform Specification) proposes a conceptual model of a platform for Human-AI interaction within Industry 5.0 scenarios, where the platform is mainly focused on orchestrating, monitoring, and simulating human-centred processes. The requirements of the platform are elicited, leveraging a set of motivational scenarios oriented to Industry 5.0 (Section 4.2).

Chapter 5 (**AI REGIO I5.0 Collaborative Intelligence Model**) elaborates more on the core module of the I5.0 Platform: the implementation of a Collaborative Intelligence cross-models interoperability framework (Section 5.1). In addition to the main components of the platform, Section 5.2 presents a representation of the main aspects related to Industry 5.0 and Collaborative Intelligence within a knowledge graph (Section 5.2.2), thus contributing to a better definition of the concept of Industry 5.0 and collaborative Intelligence.

Finally, **Chapter 6** draws the conclusions, summarizing the main outcomes and future steps which will be conducted at a second iteration of T5.1.

2 Background and Motivation

2.1 Beyond Industry 4.0

While the push of Industry 4.0 is still active to increase the flexibility and efficiency of the production processes, a new paradigm is already emerging on the horizon into the manufacturing scope. But which are the motivations behind a further paradigm shift that goes beyond Industry 4.0 (I4.0)?

First, Industry 4.0 is a technology-centred and technology-driven paradigm. Thus it is more focused on digitalization and AI-driven technologies and less on other relevant principles such as social fairness and sustainability[1]. In addition, despite various studies are analyzing the link between new digital technologies and human factors[2], their interrelations and the sociotechnical impact deriving from these interrelations have insufficiently addressed. Moreover, a recent US research study involving 1,500 industrial companies demonstrated the relevance of these interrelations by showing that the biggest performance improvements come when humans and machines work together[3], enhancing each other's strengths (Collaborative intelligence: humans and AI are joining forces).

Another motivation to go beyond Industry 4.0 is the need to enforce awareness on societal challenges by repositioning Industry 4.0 in the scope of megatrends[4]. In particular, some significant examples of such challenges are the ageing workforce, the mass customization, the global knowledge society, and the dynamic technology and innovation.

At the same time going beyond Industry 4.0 has to address the need to increase the power of individuals. An example of this tendency is a manifest of the Japanese Society 5.0[5] that states that "every individual… can live safe and secured comfortable and healthy life and … can realize his/her desired lifestyle". Finally, it should be considered that AI must be used in the service of humanity and not the other way around, as many fear it might happen.

To address these criticalities of the Industry 4.0 model, Institutions and Policy makers are starting to shift their attention towards human-centered design and ethical and responsible innovation in the Factories of the Future. To go in these directions, some initiatives are ongoing and are all brought back to the umbrella term of Industry 5.0.

Industry 5.0 aims at complementing the Industry 4.0 paradigm to allow the industry workers to return to the center of all the production processes (perhaps not to perform them in person - for that there are technologies - but to be the real beneficiary through eventually an augmentation of capability.

To create the conditions of this paradigm shift, the cooperation between machines and human beings will be better exploited by combining their diverging strengths while removing their weak points. This synergistic collaboration will enable humans and machines to coordinate with each-other to perform a specific activity[6]. It should be noted that machines taken into account in this interaction can be both physical machines (e.g., robots) and digital components (e.g., AI algorithms), also considering that the relationship human-digital machine is completely different from human-robot interaction where physicality is part of the collaboration. Furthermore, while the physical machine has traditionally been

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[1] https://op.europa.eu/en/publication-detail/-/publication/468a892a-5097-11eb-b59f-01aa75ed71a1/
[2] https://beyond4-0.eu/; https://empower-project.eu/
[3] Wilson, H. J., & Daugherty, P. R. (2018). Collaborative intelligence: humans and AI are joining forces. Harvard Business Review. https://hbr.org/2018/07/collaborative-intelligence-humans-and-ai-are-joining-forces
[4] https://ec.europa.eu/assets/epsc/pages/espas/chapter1.html
[5] https://www.keidanren.or.jp/en/policy/2016/029_outline.pdf
[6] https://www.mdpi.com/2071-1050/11/16/4371

designed to relieve worker fatigue by performing dangerous, dust, and dull activities, virtual machines are designed to extend and complement human cognitive abilities. However, these machines still do not have the ability to design and imagine, while human has the ability to abstract and solve problems. From this point of view, it can be said that man and machine are complementary and for this reason, it is essential to identify approaches to ensure their coexistence and collaboration.

Industry 5.0 is also defined as an 'Age of Augmentation' where the human and machine reconcile and work in perfect symbiosis with one another[7]. The relevance of this topic is also demonstrated by the fact that the EU created the Directorate-General for Research and Innovation (DG RTD) of I5.0[8]. In this regard, this organization already produced a document[1] above where the paradigm-shift towards Industry 5.0 is based on three core elements: sustainability, resilience, and human-centricity (Figure 1). Sustainability has been a flagship of European policy for a long time and, in particular, it represents the core of the Green Deal, signed in December 2019 where it is stated that Europe must do transition to a sustainable economy. The concept of resilience, got popular due to pandemic crisis of covid-19, has been identified as one of the essential features that an enterprise must show to be competitive in the international scenario. Last but not least, human-centricity means that from digital transition both companies and workers should gain and innovative solutions must be thought to bring advantages to workers. The herein presented study focuses mainly on the third core.

On the other hand, it should be noted that Deep learning and other AI technologies has helped to solve many critical problems (e.g., in computer vision, natural language processing, and speech recognition). However, as these technologies evolve and move from hype peak to its trough of disillusionment, it is becoming clear that it is missing some fundamental key-features such the interaction with human.

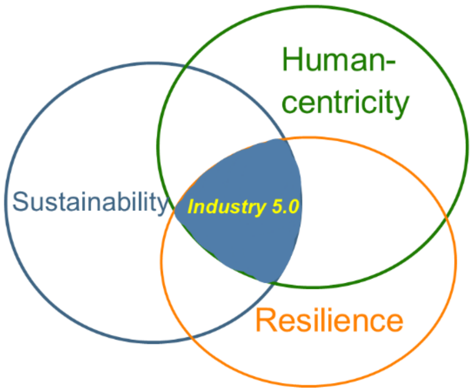

Figure 1. The core elements of the paradigm-shift towards Industry 5.0[1]

2.2 Human-centricity in Industry 5.0

One of the most important transitions that characterize the Industry 5.0 model is the shift of attention from technology-driven progress to a human-centric approach. The European Union is already pushing towards a human-centric approach by adopting several of its key policies. One relevant example of these policies is the General Data Protection Regulation (GDPR) to preserve the rights of individuals to protect their personal data protection. Another example is the White Paper on

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[7] https://www.mdpi.com/2076-3417/10/12/4182

[8] https://ec.europa.eu/info/research-and-innovation/industrial-research-and-innovation/industry-50_en

Artificial Intelligence that provides AI regulation for the users of certain categories of AI technologies. Despite the significant improvements resulting from the adoption of these policies, in many specific fields there is still place for progress regarding the human-centric approach. Specifically, in order to ensure that both industrial companies and workers benefit from the digital transition, it is essential rethinking and redesigning business models to put workers at the centre of the factory. In this regard, Industry 5.0 aims to realize a synergistic collaboration between humans and machines, through which humans and machines can enhance each other's complementary strengths. Thus, humans can enhance creativity, teamwork, and social skills, while machines can enhance human capabilities such as speed, precision, and scalability.

Moreover, in the Industry 5.0's context, all employees should be put in conditions to continuously align their skills and competencies to the changing requirements of this transition process (reskilling) and also to create new competencies and abilities (upskilling). This need can be supported by means of a continuous training path, which starts within courses offered by academic programs and continues in the real workplace. In this regard, the training path can be driven by the growing paradigm of the Didactic Factory, which is specifically linked to manufacturing education. Its major scope is to align manufacturing training and teaching to the need of an increasingly complex scenario in industry. Under these conditions, traditional workplace must evolve into a life-long learning educational place, bringing several advantages. In particular, it can promote a continuous training environment inside the factory, and can also lead to beneficial results outside the factory by making effective a process of knowledge transfer based on a two-way channel, which includes: factory-to-classroom and academia-to-industry communication paths. In this regard, a stronger cooperation is needed between enterprises on the one hand, and education and training institutions on the other, where companies are well placed to determine the skills gaps and forecast the skills needs for the near future.

2.3 Sustainability in Industry 5.0

Sustainability is placed at the center of a European Union policy based on the acceleration of both the green and digital transition. In fact, in the United Nations 2030 Agenda, which represents the general strategic reference in terms of sustainability, the latter is analyzed within an integrated vision of the different dimensions of the development, where sustainability is only one of these dimensions.

To regenerate the production models in a sustainable way and to take urgent action to combat climate change and its impact on society and the planet, the EU assigns a fundamental role to industry, defining it as a potential "resilient provider of prosperity" in the report on Industry 5.0[1] above. In this report, the EU sees industry as one of the main engines of a new development based on total respect for the planet and for work, recognizing its ability to achieve social objectives and new paradigms for production that place the well-being of the worker at the center of the production process.

A boost to the green transition will come from the European Green Deal, with which Europe aims to make the economy more sustainable and ecological, using new technologies to modify production processes so that they have a lower environmental impact. For this, renewable energy sources and materials reused must be used more paired with the waste reduction to allow future generations to maintain natural resources.

2.4 Resilience in Industry 5.0

Resilience of a manufacturing company is its capability to optimally cope with unforeseen events, not only linked with the pandemics, but also changes in the supply chain, new orders, sudden changes in customer needs. The technologies that can ensure the resilience of the manufacturing system and that therefore need to be explored within the Industry 5.0 model include a wide range of cases[9].

First of all, we need to consider the technologies that allow operators to intervene on processes without being physically present; these solutions can mainly be related to collaboration, such as design and engineering remotely shared, or collaborative robotics. Furthermore, with a view to the need of social distancing, it will be also important to explore the technologies for remote commissioning and maintenance activities. For example, companies can take advantage of the digital twin, thanks to which the tests can be remotely or even virtually guided. Finally, It will be also essential to strengthen the cyber security policies of the industries, thus allowing to avoid any interruptions in production caused by external tampering.

[9] https://www.fabbricaintelligente.it/blog/dal-cfi-una-proposta-di-politica-industriale-produrre-un-paese-resiliente/

3 Analysis of fundamentals for I5.0

Since the concept of Industry 5.0 is quite new and its bases are still being founded, it can be interesting to take a step back and examine its fundamentals, by analyzing which concepts are being focused on and which are the trends the industry seems to have been following. In this regard, this chapter reviews the fundamentals related to the concepts of Industry 5.0 and Collaborative Intelligence.

This analysis is then mapped with a study on background of these topics. Another outcome of this study is a list of research and technical gaps on these topics, paired with challenges and enabling technologies to overcome these gaps. These outcomes will be then exploited to conceive and design a new conceptual model for a platform for Human-AI interaction in Industry 5.0, focused to orchestrate, monitor, and simulate the human-centred processes.

3.1 Historical background on Industry 5.0

According to Web of Science, Industry 5.0 is a relatively recent topic, with only a few contributions over the recent years, although with increasing interest, from one article in 2016 up to seventeen articles in 2020 in journals belonging to various areas, from Biology journals, Sustainability, conferences on Complex Systems, workshops of the International Federation of Automatic Control (IFAC), etc.

To summarize, it appears that Industry 5.0 idea was born under the push of two different aspects: on the one hand, the recognition of the drawbacks of the current Industry 4.0 technology centered extreme automation, and, on the other hand, the forecasted disruptive changes in Biology and Bio-engineering which will affect not only the manufacturers' production systems, but the whole society.

Then Industry 5.0 research focused on exploitation of the novel Artificial Intelligence technologies aiming at enhanced human-machine interaction to augment both the human and the AI decision-making processes. This context stimulated, in parallel, the need for novel innovation management approaches and enhanced digital platforms. In the following sections, we give a summary of the most relevant articles, collected with the Keyword search "Industry 5.0" from the Web of Science multiple database search engine.

3.1.1 From 2016 to 2018: the idea of Industry 5.0 appears

Discussion on Industry 5.0 has started in the 2016 article by Sachsenmeier[10], depicting the future industrial paradigm shift, namely, Industry 5.0, stemming from the impact of novel engineered biological systems, able to process information, manipulate chemicals, fabricate materials and structures, with important social and economic implications on humanity, such as level of bio-engineering control on biological systems, especially if human embryos or living humans are involved.

[10] https://www.sciencedirect.com/science/article/pii/S2095809916309493

In 2018, Ozdemir and Hekim[11], in OMICS, a Journal of Integrative Biology, started from the on-going discussion on the dangers of the so-called Industry 4.0 revolution, which, based on Internet of Things and Big Data, aiming at extreme automation to achieve the vision of the Smart Factory, presents critical vulnerabilities, such as possible failures or hacking of the highly integrated systems involved.

The related extreme systems' connectivity also creates new social and political power structures, which, if left unchecked, might lead to authoritarian governance.

To tackle these systemic risks, the authors propose the Industry 5.0 paradigm, that can democratize knowledge co-production from Big Data and IoT, building on the new concept of symmetrical innovation. Industry 5.0 has a three dimensional symmetry in innovation ecosystem design: 1) a built-in safe exit strategy in case of demise of the digital knowledge networks; 2) equal emphasis on acceleration and deceleration of innovation if diminishing returns are apparent; 3) next generation social science and humanities (SSH) research for global governance of emerging technologies.

3.1.2 2019: Industry 5.0: Beyond Industry 4.0 with focus on human-machine interaction

In 2019 Industry 5.0 starts to be seen as a novel vision for manufacturers with a focus on enhanced human-machine interaction.

In 2019, Nahavandi[6] above depicts Industry 5.0 as the new approach that can be adopted by manufacturers to increase productivity without removing human workers from the industry, approach based on advanced brain-machines interfaces and artificial intelligence. The article discusses key features and concerns of the proposed Industry 5.0 approach where robots are intertwined with the human brain and work as a collaborator instead of competitor.

In 2019 again, Salaken[12] investigate, as an interesting step towards Industry 5.0, an empathy controlled robot, capable of behavior changes depending on the emotional state of an operator's voice. The article addresses new approaches that can be adopted in the design of mobile robots to reduce costs, power consumption and computational load, on the basis of the separation of computational resources (on-board or cloud) if the algorithms are addressing functional or experiential needs.

Another interesting contribution in the area of human-machine interaction is, in 2019 again, a research[13] which, on the basis of a field research in a manufacturing plant, evidenced a set of possible positive and negative attributes linked to the working environment, in a way to identify a set of considerations/guidelines for deployment of robot technologies in industry.

3.1.3 2020: Collaborative robots and systems for Industry 5.0

In 2020 the focus on collaborative robots and systems is still a major market driver for Industry 5.0, although there is still some uncertainty in the scope and definition of the Industry 5.0 concept. Some contributions deals with the parallel needs of new innovation management methodologies and digital platforms to provide appropriate tools for the new Industry 5.0 implementation. Javaid and Haleem[14] have studied what differentiates Industry 4.0 from Industry 5.0 and have identified 17 critical

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[11] https://www.liebertpub.com/doi/full/10.1089/omi.2017.0194
[12] https://dl.acm.org/doi/abs/10.1145/3313991.3314018
[13] https://ieeexplore.ieee.org/document/8673139
[14] https://www.worldscientific.com/doi/abs/10.1142/S2424862220500141?journalCode=jiim

components of the latter, evidencing how intelligent machines can now solve real problems with the help of human critical thinking.

Sha et al.[15] present the first results of a business model transformation from Industry 4.0 to Industry 5.0 project on a European SME, which produces 3D printers, with a single case study design. The business model transition aims at sustainable business models targeting also human, social and environmental aspects.

Longo et al.[7] above define the emerging Industry 5.0 as a new revolutionary wave of 'Age of Augmentation', when human and machine will work in perfect symbiosis. Recently, human-centric design of Cyber-Physical Production Systems (CPPS) and 'Operator 4,0' have emerged as novel concepts that raise ethical questions on the impact of technology on workers and society. The authors propose a new Value Sensitive Design (VSD) approach as a principled framework enabling human-machine symbiosis in the Factory of the Future.

Massaro and Galiano[16] have reviewed Industry 4.0 technologies and applied image vision and AI methodologies for auto-adaptive quality check of pasta production, in the vision of Industry 5.0, discussing the results of the use case as well. The use of the so called Industry 5.0 is limited to prediction of pasta defects, most likely to provide automatic pasta check, but no strong interaction with the operator is evidenced. He et al.[17], recognizing the importance of Industrial Internet of Things (IIoT) technologies while manufacturers are moving towards Industry 5.0, propose a blockchain-based software for status monitoring of industrial systems and embedded devices, called BoSmoS.

Aslam et al.[18] propose a novel innovation management framework called Absolute Innovation Management (AIM) to make innovation more understandable, implementable and part of the organization's daily routine, in order to pave the implementation of the new future paradigms such as Industry 5.0. To make innovation more human-centered, the proposed AIM framework links innovation management with corporate strategy buy adopting innovation management as a strategy, via design thinking.

From a different point of view, Gorodetsky et al.[19] recognize the need for advanced digital platforms for adaptive management of enterprises within the upcoming era of Industry 5.0. The authors, aware of the limitation of existing digital platforms, with their centralized and hierarchical management style, consider the concept of digital ecosystems as open, distributed self-organizing 'systems of systems' of smart devices capable of decision making with coordination and automatic conflict resolution.

The authors also propose classification of the services provided by these advanced digital platforms and their functions. Finally, Erwin Rauch[20] highlights that Industry 4.0 has been dealt by production science for almost ten years, and many challenges have been encountered in this context to achieve the vision of intelligent and self-optimizing factories. Industry 4.0 started as a technology driven innovation, while now the future level, called by the author Industry 4.0+, will be based on data-driven innovation, with two possible research directions: the introduction of Artificial Intelligence in manufacturing systems and the use of nature as inspiration for Biological Transformation.

[15] https://hrcak.srce.hr/239013
[16] https://www.tandfonline.com/doi/full/10.1080/21693277.2020.1749180
[17] https://ieeexplore.ieee.org/abstract/document/8869742
[18] https://www.mdpi.com/2078-2489/11/2/124
[19] https://link.springer.com/chapter/10.1007/978-3-030-32258-8_4
[20] https://link.springer.com/chapter/10.1007/978-3-030-50794-7_18

3.1.4 2021: Human-centric and Human-Cyber Physical Systems

Although 2021 has just started, two interesting contributions can be found on Web of Science, in the same research stream of the previous year 2020.

The first one investigates the aviation sector: Carayannis et al.[21], on the basis of an important case study, have tried to identify which are optimal solutions for implementing the novel human-centric logic of Industry 5.0. Aiming at this, knowledge circulation, dialogue between sub-systems and the ability to adapt technologies and corporate strategies to the environment, with the users as first stakeholders, appear to be necessary practices in knowledge-based innovation and decision-making processes.

The second one is an application case: Chen et al.[22] propose an intelligent and semi-autonomous human-cyber-physical system (HCPS) to operate future wind turbines in the context of the novel Industry 5.0 (I5.0) technologies. As the complexity of the next-gen wind turbines is increasing, Artificial Intelligence (AI) is needed for their efficient and effective operation and maintenance. The proposal is to evolve the Industry 4.0 digital twin, seen previously as an aid to human decision process, to the proposed I5.0 digital twin, used for training the AI via machine learning. Human intelligence is then raised to a supervisory level, in which high-level human decisions, made with a human-machine interface, can break the autonomous behavior of the machine, if needed.

3.2 Classification of ongoing projects from an Industry 5.0 perspective

Even though Industry 5.0 is a relatively new concept, some early academic writing describing the main features of this notion exists. In general terms, the situation shows up an uncertain scenario that is awaiting to be defined and explored. To do so, Industry 5.0 goes beyond the production of goods and services to reach a wider purpose constituted by three core elements: human-centricity, sustainability, and resilience.

The human-centrical vision of the ecosystem takes the emergent technologic advances and puts them under the service of human needs and interests. Instead of focusing the industry evolution on these technological advances, these advances will be used to adapt the production process to the needs of the worker. On the sustainability pillar of action, Industry 5.0 is going to lead the evolution in coordination with respect for the planetary boundaries. It will link the recycle, reuse and repurpose of natural resources with the actual industry, making way for reducing energy consumption and greenhouse emissions while avoiding the degradation of the actual natural resources. Finally, on the side of Industry 5.0, there is resilience.

This core element refers to the need to develop an upper degree of robustness in industrial production. In terms of uncertain scenarios or highly disruptive changes, resilience is going to ensure the industry remains strong and solid.

In this section, a list of ongoing EU projects and initiatives involved in the Industry 5.0 paradigm are presented and analysed. Each project is introduced under a common format of study (a synoptic representation based on a table) to define the basis of a future classification and extraction of patterns. In the context of this study, it is important to consider the possibility that a project points to

[21] https://link.springer.com/article/10.1007%2Fs13132-021-00763-4

[22] https://www.mdpi.com/2071-1050/13/2/561

a specific pillar of Industry 5.0 but also achieves important results in the others thanks to its outcomes. In this regard, the

Table 1 presents a classification of ongoing projects (selected through the Community Research and Development Information Service (CORDIS) search engine) based on their gradual contribution to each pillar based on the objective and description of each project. For each entry in the table, the contribution to an Industry 5.0 core can present two colours: a darker colour, representing the main objectives of each project, or a lighter one, representing the objectives achieved as an outcome of the main concerns of a project

Table 1: Projects classification under the Industry 5.0

		Industry 5.0 Core Elements		
Project	**TOPIC**	**Human-Centricity**	**Sustainability**	**Resilience**
SOMATCH	ICT-2014-1	X		X
A4BLUE	FOF-2016	X	X	
MANUWORK	FOF-2016	X		
Factory2Fit	FOF-04-2016	X		X
HUMAN	FOF-04-2016	X		X
INCLUSIVE	FOF-04-2016	X		
MANUWORK	FOF-2016	X		
ACTPHAST 4.0	ICT-30-2017			X
PLATOON	DT-ICT-11-2019		X	
BD4OPEM	DT-ICT-11-2019		X	X
HUBCAP	DT-ICT-01-2019	X		
Change2Twin	I4MS Phase IV		X	X
I4MSTs	I4MS Phase IV			X
DIH-World	I4MS Phase IV			X
VOJEXT	I4MS Phase IV	X		X
DIGITbrain	I4MS Phase IV		X	X
PULSATE	I4MS Phase IV			X
Better Factory	I4MS Phase IV		X	
KITT4SME	I4MS Phase IV	X	X	X

As outlined in the table, the three core elements of Industry 5.0 can be individually found in Industry 4.0 projects. Indeed, a significant number of projects of Industry 4.0 projects, addresses one of more of these elements (sustainability, reliability, human centricity). Nevertheless, most Industry 4.0 projects focus on optimizing these aspects individually rather than combining them to achieve massive personalization with end-users / customer involvement which is one of the promises of Industry 5.0. Furthermore, the human centric nature of Industry 4.0 project was mostly about making manufacturing processes human centred based on improvements in the workplace and the production processes. Industry 5.0 targets mass personalization and human centricity by involvement both workers and customers in the end-to-end loop of the production process.

Introducing a more deeply analysis focused on each pillar of the industry 5.0, the classification seen in

Table 1 seems to present an evolving scenario which moves according to the needs and concerns of the SMEs:

- The human-centricity core demonstrates a strong trend started in 2016.
- The situation of 2020 gives way to the search for resilience by SMEs and Europe. And, on the other hand, European climate policies[23] urge projects to seek solutions to these problems. Given the circumstances, this pillar of Industry 5.0 seems to be waiting to be exploited again.
- On the sustainability part of Industry 5.0, more projects seem to show up especially over 2020. As it was previously introduced, it is easy to foresee a rapid increase in this subject of study since the world, especially Europe, is positioning in favor of a necessary change in how society interacts with the enviroment.
- Finally, in terms of the resilience core of the action, it can be seen how the vast majority of projects can be easily classified under its category. Since almost all the projects target the SMEs and DIH as their stakeholders, being able to adapt and overcome disruptive changes or uncertain scenarios becomes an almost necessary quality of their R&D investments.

3.3 Enabling technologies for a concrete realization of the Industry 5.0 concept

The main goal of this section is to investigate/explore Industry 5.0 enabling technologies that a manufacturing company should adopt to implement the Industry 5.0 concept (and which are the enabling technologies for this paradigm shift), of course according to its core business.

In particular, this section aims to address the following research questions, by collecting, analyzing and synthesizing some of the major contributions on the themes of the Industry 5.0 and Collaborative Intelligence:

- Q1. Which are the enabling technologies that can help to realize Industry 5.0?

At the beginning of this document, Industry 5.0 is defined as the evolution (not revolution) of Industry 4.0 with the help of well-known AI-driven technologies, now human-centred.

At European level, the concept of Industry 5.0, its enabling technologies and possible challenges were discussed on July 2020 by a group of Europe's technology leaders. In their final report ("Enabling Technologies for Industry 5.0"[24]) they concluded that there are 6 main groups of technologies supporting the concept of Industry 5.0:

1. **Human-centric solutions and human-machine-interaction** technologies that interconnect and combine the strengths of humans and machines. Multi-lingual speech approaches, human intention prediction, cobots (collaborative robots) or augmented reality are some examples of these technologies.
2. **Bio-inspired technologies and smart materials** allowing embedded intelligence (such as sensors) and enhanced features while being recyclable or coming from carbon-neutral bioplastics, biopolymers or other bio-fibre materials.

[23] European climate policies: European Commission; Energy, Climate change, Environment policies [Source]
[24] https://op.europa.eu/en/publication-detail/-/publication/8e5de100-2a1c-11eb-9d7e-01aa75ed71a1/

3. **Real time based digital twins and simulation** to model entire systems related with manufacturing aspects, for instance virtual simulation, multi-scale dynamic modelling or cyber-physical systems.
4. **Cyber safe data transmission, storage, and analysis technologies** that are able to handle data and system's interoperability. The common European Manufacturing Data Space initiative[25] will be essential to advance these technologies related to data acquisition, data management, data curation and data governance while at the same time maintain privacy and sovereignty.
5. **Artificial Intelligence** e.g. to detect causalities in complex, dynamic systems, leading to actionable intelligence. Some technologies included in this group are: causality-based artificial intelligence, swarm intelligence, informed deep learning or brain-machine interfaces.
6. **Technologies for energy efficiency and trustworthy autonomy** as the above-named technologies will require large amounts of energy. Some examples are the seamless integration of renewables directly into the manufacturing processes, or low energy approaches for data transmission and data analytics.

Furthermore, these technologies range from physical to virtual world (Figure 2).

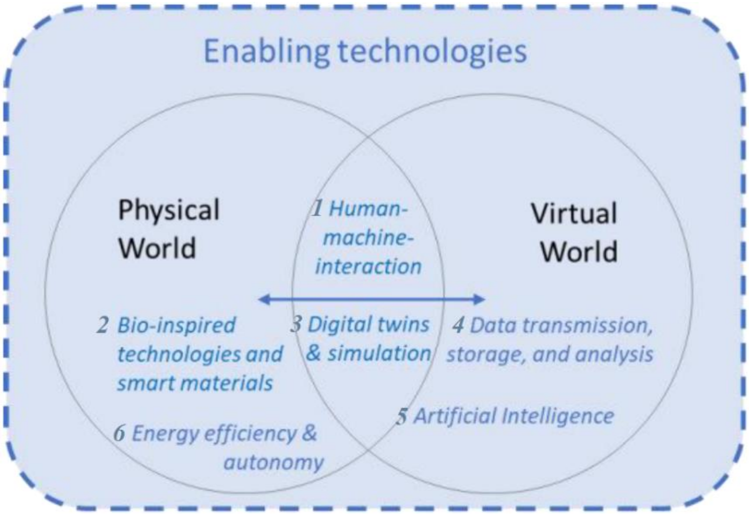

Figure 2 Enabling Technologies for Industry 5.0[26].

From a manufacturing point of view, Made in Europe Partnership[27] establishes that the use of AI, Data & Robotics technologies will be crucial for its sector. The use of these technologies will enhance the manufacturing sector through AI-enabled, adaptable, resilient factories and supply networks; advanced robotics solutions and human-robot collaboration in factories; data-driven business models and data-sharing solutions for manufacturing industries[28]. Specifically they select as key technologies, among others, the following:

- Data analytics, artificial intelligence, machine learning and deployment of digital platforms for data management and sharing

[25] https://ec.europa.eu/info/sites/info/files/communication-european-strategy-data-19feb2020_en.pdf
[26] https://op.europa.eu/en/publication-detail/-/publication/8e5de100-2a1c-11eb-9d7e-01aa75ed71a1
[27] Made in Europe partnership is the private public effort among European commission and European Factories of the Future Research Association (EFFRA)
[28] https://cloud.effra.eu/index.php/s/1Ye3n1FiBoyZJFX

- Simulation and modelling (digital twins) covering the material processing level up to manufacturing system, and factory and value network level from design until recycling.
- Intelligent and autonomous handling, robotics, assembly and logistic technologies.

In this scenario looks like the main enabling technologies related with Industry 5.0 are AI technologies (included data management) focused on human-machine collaboration. Even more, all Data Analytics processes, Machine Learning algorithms and, in general, the deployment of digital manufacturing platforms are essential to provide services that support manufacturing in a broad sense.

An interesting perspective of the Industry 5.0 enabling technologies derives from taking into account the last Gartner's Hype Cycle for AI (Figure 3), by analyzing the technologies to be adopted in next 5 years together with a qualitative alignment or matching related to Industry 5.0 concept (Table 2).

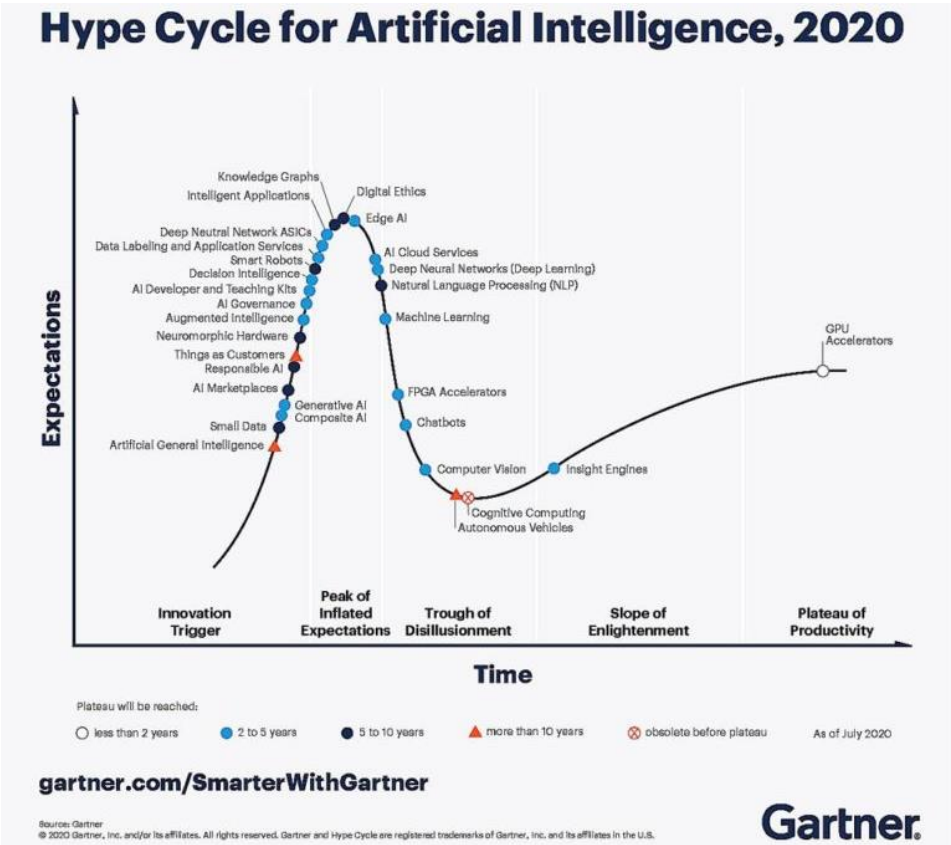

Figure 3 Gartner's Hype Cycle for Artificial Intelligence, 2020[29].

Table 2 Emerging AI technologies in the direction of Industry 5.0

AI Technologies	Plateau will be reached	Short definition/description	Industry 5.0 matching
GPU accelerators	less than 2 years	Hardware acceleration	Low

[29] https://www.gartner.com/smarterwithgartner/2-megatrends-dominate-the-gartner-hype-cycle-for-artificial-intelligence-2020/

Composite AI	2 to 5 years	Combined application of different AI techniques to improve learning efficiency, increase the level of "common sense," and ultimately to much more efficiently solve a wider range of business problems.	High
Generative AI	2 to 5 years	Various machine learning (ML) methods that learn a representation of artifacts from the data and generate brand-new, completely original, realistic artifacts that preserve a likeness to the training data, not repeat it	High
Augmented Intelligence	2 to 5 years	A design pattern for a human-centered partnership model of people and artificial intelligence (AI) working together to enhance cognitive performance, including learning, decision making and new experiences.	High
AI Governance	2 to 5 years	Legal framework for ensuring that machine learning (ML) technologies are well researched and developed with the goal of helping humanity navigate the adoption of AI systems fairly	Medium
AI Developer and Teaching Kits	2 to 5 years	Instructions, examples, tools and software development kits (SDKs). They provide an abstraction layer on top of data science platforms, frameworks, analytic libraries and devices. And so they make it faster and easier for software engineers to build AI into applications.	Medium
Decision Intelligence	2 to 5 years	A practical domain framing a wide range of decision-making techniques bringing multiple traditional and advanced disciplines together to design, model, align, execute, monitor and tune decision models and processes. Those disciplines include decision management (including advanced nondeterministic techniques such as agent-based systems) and decision support as well as techniques such as descriptive, diagnostics and predictive analytics.	Medium
Data Labeling and Application Services	2 to 5 years	The process of identifying raw data (images, text files, videos, etc.) and adding one or more meaningful and informative labels to provide context so that a machine learning model can learn from it.	High
Deep Neural Networks ASICs	2 to 5 years	Hardware acceleration	Low
Intelligent Applications	2 to 5 years	Applications that use historical and real-time data from user interactions and other sources to make predictions and suggestions, delivering personalized and adaptive user experiences	High
Edge AI	2 to 5 years	A system that uses Machine Learning algorithms to process data generated by a hardware device at the local level or close to the data source.	Medium
AI Cloud Services	2 to 5 years	AI Software as a service (SaaS), AI Infrastructure as a service (IaaS) and AI Platform as a service (PaaS)	Medium

Deep Neural Network (Deep learning)	2 to 5 years	A class of machine learning algorithms that uses multiple layers to progressively extract higher-level features from the raw input.	Medium
Machine Learning	2 to 5 years	Many technologies (such as deep learning, neural networks and natural language processing), used in unsupervised and supervised learning, that operate guided by lessons from existing information.	Medium
FPGA Accelerators	2 to 5 years	Hardware acceleration	Low
Chatbots	2 to 5 years	A domain-specific conversational interface that uses an app, messaging platform, social network or chat solution for its conversations. They vary in sophistication, from simple, decision-tree-based marketing stunts, to implementations built on feature-rich platforms. They are always narrow in scope. A chatbot can be text- or voice-based, or a combination of both	High
Computer Vision	2 to 5 years	Interdisciplinary field of study that deals with how computers can be made to gain high-level understanding from digital images or videos.	Medium
Insight Engines	2 to 5 years	Relevancy methods to describe, discover, organize and analyze data. This allows existing or synthesized information to be delivered proactively or interactively, and in the context of digital workers, customers or constituents at timely business moments.	Medium

All existing AI technologies must be properly combined in order to generate coherent systems that allow progress from Industry 4.0 (focused on technologies) to Industry 5.0 (focused on humans and their interaction with the technologies). Moreover, AI REGIO ecosystem, focused on Regional DIH and AI for Manufacturing issues, is aligned with all AI previous technologies, over all those focused on data analytics, although it is needed increase digitalization level at SME level before these technologies become useful for these kinds of factories.

4 A Platform for Industry 5.0 adoption by SMEs

4.1 Industry 5.0 within AI REGIO

The project AI REGIO aims to deal with the human-centric aspects of AI-based manufacturing systems, such as the integration of systems that adapt to the human context, systems that collaborate with humans, as well as learning and training systems. Specifically, to face the challenges posed by the paradigm shift towards Industry 5.0, AI REGIO aims to provide a modelling playground for Industry 5.0 and Human-AI Collaborative Intelligence workflows within a fit for purpose platform. The latter will support the experimentation of Industry 5.0scenarios, set in contexts where AI-driven autonomous systems are efficiently and effectively interacting with Humans according to the Collaborative Intelligence paradigm.

The developed models will support the orchestration of human-centred processes in terms of process management and Human-AI interaction assessment, enabling the comparison of different technological solutions and selection áccording to users' needs.

This proposed platform will enable an AI-based digital workplace that is both immersive and pervasive, providing augmented workers and managers with on-demand capabilities tailored to their needs and preferences. A seamless suite of tools, including apps to support specific roles and jobs, dashboards that integrate business data into meaningful outputs, and chatbots using natural language processing. This will simplify interactions with information, processes, machines, and people, thereby enabling work to happen more easily. Personal digital assistants will be enabled by AI REGIO technologies to interact with an organization's digital workplace. These assistants will support workers on their decision-making, suggesting appropriate options based on previous behavior and working across channels to achieve desired outcomes.

The back-end of the proposed platform is played by specific data models that will embody the link between Humans and Autonomous Systems and between Collaborative Intelligence systems of different categories. These models will be specified to drive the flow and exchange of digital data and the specification of these data models will leverage existing relevant standards such as RAMI 4.0, OPC-UA, Automation ML, B2MML, SAREF and more. One of these models is the Human Data Models, that will support a coherent representation of Human-AI interaction, which is key for successful human-centric engineering and adaptive automation that fits the specific needs of different employees(e.g. for novice, older and disabled people). Human Data Models will include but will not be confined to: human role, goals and tasks; demographics, key anthropometrics, functional (sensorial, physical and cognitive) capabilities; knowledge and skills; needs and preferences; physical, cognitive and emotional status (e.g., based on physiological measures) & dynamic behaviours.

Finally, as part of the activities of AI REGIO to implement Industry 5.0, an orchestration and enactment service will be defined to support the design of operational and interaction Collaborative Intelligence workflows and the configuration of specific applications and services.

4.2 Motivational Scenarios for the platform

To better understand the objectives and key enabling factors for the platform, it is essential to focus on the analysis of practical scenarios that can help us understand and elicit the requirements of the Industry 5.0 platform. For this reason, in this section, we analyze some application scenarios within the context of Industry 5.0.

4.2.1 Collaborative robotics based on AI to assist workers through a physical interaction

In this scenario, robots assist humans by adapting themselves to the worker's specific needs, skills, and physical abilities, also leveraging a computer vision component. The scenario comprises **nine** different steps.

At the **first** step, the human worker starts a task while the computer vision component observes the operations performed by the worker. In the **second** step, the computer vision component starts to analyze the human intention and to understand the workflow by leveraging AI based observation to predict human intention. At the **third** step, the computer vision component communicates to the robot the intent of the worker.

In the **fourth** step, once received the communication from the computer vision component, the robot starts to move to pick up an object from the workbench to help the human worker. At the **fifth** step, the robot picks up an object of interest for the human worker.

At the **sixth** step, the robot brings the object to the worker. Finally, at the **seventh** step, the robot delivers the object to the worker when required and is accepted by the human worker. At the **eigth** step, the information about the delivered object is shown to the worker through an AR viewer. This way, AI supports the human decision-making process by providing the correct information at the right time.

Finally, at the **ninth** step, the worker retrains the AI algorithm, if needed.

4.2.2 Orchestration, monitoring, simulation of the Collaborative Intelligence interactions

Luca is one of the company's stakeholders involved in the previously described scenario (Scenario1). In this scenario, Luca needs to monitor the interactions between robots and workers to identify any problems in their collaborative phases. At the same time, Luca needs to configure and orchestrate the interactions between robots and workers by balancing between machine and human components. Afterward, Luca and other users need to simulate these interactions (also when the processes are running) to select the most efficient solution that satisfies the requirements. In this regard, Luca must be supported by a Collaborative Intelligence platform which must enable the two different contexts, where there is a physical interaction between machines and workers, and where there is no physical interaction, but instead, the interaction between machines and workers is based on voice or visual interaction.

Through this platform, Luca can:

- Access to models representing Human and AI processes;
- Design the orchestration of human-centred processes workflow in terms of process management and Human-AI interaction;
- Promote harmonization and orchestration between machines and the human factors, especially considering the cognitive and physical workload related to manufacturing operations;
- Design the workflow of human-in-the-loop solutions through their combination into business processes;
- Use of an orchestration and enactment service to support the design of operational and interaction workflows and the configuration of specific applications and services;
- Check the efficiency of each designed process through off-line and run-time simulations. For this reason, a quantitative modelling of the process is used in order to simulate and assess all the possible scenarios. Some KPI can be used such as Flexibility, Speed, Scale, Decision-Making, Personalization;

- Enable the man in the digital twin loop to simulate and monitor the orchestration of the processes
- Allow comparison of different solutions of orchestrations in order to select the most efficient solution that satisfies the requirements of a specific scenario.

4.2.3 Trusted, Ethical and Efficient Human-Robot Collaboration

The rise of trusted, ethical and collaborative AI technologies opens new horizons in human computer interaction. There are nowadays Industry 4.0 systems that adapt their operations to the characteristics of the human workers towards boosting the safety and human centricity of manufacturing operations. Furthermore, cobots are developed and deployed for various functions, including pick and pack, quality control, and repetitive processes like polishing and grinding. Nevertheless, most human robot collaboration systems are monolithic and do not optimized the benefits for both humans and robots. This requires the establishment of trust and transparency between the systems, and subsequently, the implementation of synergetic processes for knowledge exchange. In a typical quality inspection scenario, a cobot could involve an AI system that consults the human when it lacks data or information to perform the quality check. Likewise, the human should have full transparency regarding the operation of the AI system towards boosting the efficiency of the collaboration. Overall, Industry 5.0 will be characterized by the establishment of mutually beneficial interactions between humans and robots towards:

- Freeing humans for laborious and repetitive tasks and letting them focus on creative and knowledge intensive task.
- Enabling robots to learn from humans and to consult humans towards accelerating their knowledge acquisition.

Importance of AI Technologies: Novel learning paradigms that accelerate knowledge acquisition for robots can boost the above Industry 5.0 scenario, including active learning and transfer learning, as well as their combination with unsupervised learning. Moreover, explainable AI technologies (including explainable robots) will boost the transparency of robotic operations and their acceptance by humans. This will contribute to the overall trustworthiness of the human robot collaboration.

4.3 Platform Requirements and Specifications

4.3.1 Motivational Scenarios: criticality analysis and requirements elicitation

To define key aspects of the AI REGIO Industry 5.0 platform, a set of its main high level functional requirements are elicited in the following (underlined in bold), starting from the motivational scenario reported in Section 4.2.1 and 4.2.2.

The provided solution for the platform shall provide:

(FR_1) A graphical environment for orchestration of human-centred processes. It is needed the **implementation** of an **orchestrator** of human-centred processes within a graphical environment, where the orchestrator plays the role of balancing between the human component and machine within a human-centred process.

(FR_2) A functionality for the optimization and Simulations of the CI interactions. The platform should allow the simulation of different possible scenarios of the Collaborative Intelligence interactions by changing the percentage of work performed by humans and machines.This setting can be used to balance between high value-added tasks (requiring human brainpower and creativity of humans) and repetitive tasks (requiring high speed, precision, and security typical of the machines). In addition, it should also be possible to simulate the type of planned interactions between humans and machines to enable a proactive evolution of the configured collaboration.

(FR_3) An **efficiency checker of each designed human-centred process.** This functionality allows checking the efficiency of each designed process, promoting harmonization between machines and the human factors, especially considering the cognitive and physical workload related to manufacturing operations.. For this reason, quantitative modelling of the processes is used in order to simulate and assess all the possible scenarios. Some KPIs that can be used are Flexibility, Speed, Scale, Decision-Making, Personalization.

(FR_4) A functionality for the comparison of different configurations of a human-centred process. The platform should also enable the comparison of a different technological solutions of configuration and selection according to the requirements of a specific scenario.

FR_5) Support for a learning model paired with the physical machine. To support the pattern "Machines Assist Humans", the platform should endow each machine with a learning model, through which machines learn from the interactions with humans.

4.3.2 Harvard Business Review Collaborative Intelligence

An interesting idea to implement I5.0 within the AI-REGIO project comes from the concept of Collaborative Intelligence (CI) reported in the *Harvard Business Review "*Collaborative Intelligence: Humans and AI Are Joining Forces"[3] above.

In this report, Collaborative intelligence envisages two bidirectional collaborative interaction channels.

In one direction, "Humans Assist Machines", the goal is to train machines to perform specific tasks; explain the results of those tasks, and sustain the responsible use of machines. It can be interpreted from the metaphor of a Parent-Child family relationship. In that, the parents aim at transferring as much of their knowledge to children (train), to understanding their viewpoint and establishing a constant positive dialogue with them (explain) and in taking a collaborative and not punitive attitude when they make mistakes (sustain).

In the second direction, "Machines Assist Humans", the goal is to amplify humans cognitive strengths and physical capabilities, interact with customers and employees and embody human skills to extend their physical capabilities. This interaction is similar to the Caregiver-Elderly relationship, where the caregiver aims to raise the elderly cognitive capabilities when the latter is insufficient.

Since we have seen the CI is envisioned in two directions, which direction can be of interest and mut be implemented in the scope of AI-REGIO? The answer is, inboth the directions. The direction to be taken is largely depdends on the case studies.

4.3.2.1 The interactions in the Collaborative Intelligence

Human behavior in the workspace of the future should be driven by a new information infrastructure to enable the exploitation of the full potential of collaborative intelligence along the human-manufacturing system interaction. This infrastructure is not only a digital assistant looking over a worker shoulder to support a more efficient, safer, even proactive interaction in the workspace, but rather worker's digital replica/twin, looking inside-out to reflect in the interaction the worker's skills, preferences, even the mood, fear/excitement. In addition, it can enable a continuous and autonomous improvement of the collaboration, through a full understanding of (the model of) the collaborative human-machine behaviour, achieved by analyzing past behaviour, but also by simulating and reasoning about possible future interactions and required evolutions of the models.

To do this, various technologies are required, divided by their roles in supporting human-machine collaboration:

- (Machine assisting humans), enabling human work (physical, mental) through an efficient decision-making and execution support. The examples are various types of decision support systems, knowledge-based and cognitive systems. One major challenge that must be faced to implement this interaction, consists in adapting the (physical and virtual) machines to the needs of each specific person, to take into account human diversity.
- (Human assisting machines), enabling an efficient learning process (by machines), which will provide models for automateddecision-making. The example is various types of supervised learning methods, where human prepare datasets for machine learning.
- (Human assisting machines assisting humans) collaboration continuum, where the humans support the creation of models (by machines), which are used in the decision making support (for humans) and these decision can create data which is used in refining the models.

This complex interaction process is illustrated in Figure 4, where three major levels (worlds) are introduced:

- Cognitive world (Intelligence): related to modelling human (worker, manager, …) as a self-reflective being (in the psychological context) with desires/temptation, goals, and preferences. In this world, collaborative behavior can evolve based on reasoning on the data from the digital world and constraints from the (manufacturing) business world
- Digital world: responsible for modelling the collaborative behaviour of a human and the interaction with Manufacturing Digital Twin. It is defined through the human professional skills (including soft one) in the relation to the manufacturing/production context. Basically, it realizes two above mentioned aspects of the collaborative intelligence: Humans Assisting Machines and Machines Assisting Humans
- Physical world: relevant for the physical interaction, reflecting the collaborative behaviour (model) defined in the Digital World and enabling the collection of data that is used for the validation of that behaviour. On this level, the Personal Digital Twin, beside its role for the safety in the workplace, enables the definition of more personalized and adaptive interaction that can be tailored to the status and preferences of a person, continuously improving the effects/outcomes of the interaction.

In the physical world, humans and machines are working/interacting collaboratively to create (physical) products. However, this interaction is driven by the collaborative behavioral models which are built and tuned in the Digital world through an intensive exploration (analytics) of the interaction between human Personal Twin and manufacturing Digital Twins.

On the top is the interplay between the human and artificial intelligence (collaborative intelligence) required for understanding problems and opportunities in collaborative behavior models. It is done by data analytics and by analyzing the simulations of planned interactions to enable a proactive evolution of the models (behavioral, as well as personal ones).

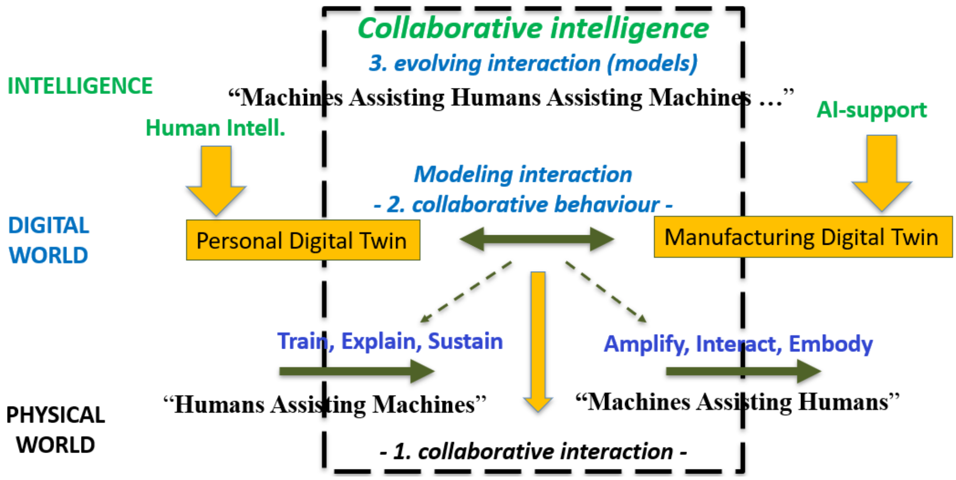

Figure 4. Collaborative intelligence exposed through the interaction between twins (personal, manufacturing)

4.3.3 Classification of AI REGIO experiments from an industry 5.0 perspective

This section reports a classification of the AI REGIO experiments from the Industry 5.0 perspective. This classification is based on the descriptions reported by each experiment leader in the AI REGIO experiment handbook (seen WP2 working documents), leverages the following criteria:

- the direction of the Collaborative Intelligence (machines assist humans or humans assist machines)
- the type of interactions (physical, visual, voice, digital). Specifically, the physical interaction can occur through a haptic technology or can be a simple interaction such a handshake. Finally, the digital interaction can occur during an operation of data entry.

Main outcomes of the work of classification are the following:

Five experiments support both the pattern interaction; they are described in the following.

Exp 1. An AI system is expected to assist humans in the process of identification and selection of the needed sheets in the warehouse. Namely, the system can support the user by identifying the specific sheet that can fulfill the request of the production line. Moreover, if the algorithm fails in the problem identification, the operator feedback on the actual cause would allow the system to extend the available information enhancing its performance over time. Under these conditions, in this experiment, the system will support humans in identifying the sheets. In contrast, humans will assist the system in the training process, providing feedback on its performances and updates.

Exp 2. In this experiment, the human-machine interaction is intended to support the diagnosis process providing a significant saving of time and cost. On the one hand, the AI system is expected to assist humans in the screening process. Namely, the system can support the user by identifying the specific needs and the dedicated operator or supplier that can fulfil those needs. On the other hand, the proposed tool can provide the equipment supplier with useful information drawn from the data acquired on-site and referred to real applicative context. In summary, the system will support humans in identifying the issues, while humans will assist the system in the training process, providing feedback on its performances and updates.

Exp 12. The application of computer vision and machine learning for adding intelligence to the digital twin representation will allow robots and humans to better collaborate in industrial operations by allowing robotic agents to alter their behaviour according to the position of nearby human operators. It will also allow human operator to easily monitor the state of entire workplaces. Additionally, the inconsistency detection mechanism will allow for human operators to be notified of possible inconsistencies in the digital twin representation, so that they act accordingly to assist any robotic agent.

Exp 13. Human-machine cooperation is relevant for the experiment. In one scenario, human-machine cooperation is needed in order to make the production line more interactive and then to avoid operators loosing time and spending energy in unnecessary movements. More, cooperative machines can be useful to guide the worker in operations and/or self-regulating parameters for interaction with the operator, in order to simplify its work. In this specific scenario, there is the need of mutual assistance: machine assists humans and humans assist machines.

In another scenario, human-machine cooperation is relevant due to the need for machines to avoid injuries and accidents. Machine should identify dangerous conditions (man falls down on the floor) and avoid risks, injuries, fatalities (the robotic arm stops if the man is raising and the risk of hitting the operator is high). In this scenario, the machines assist humans in working safely and staying healthy.

Exp 16. In this experiment, the human-machine interaction is intended to support the faulty detection process providing a significant saving of time and cost. On the one hand, the AI system is expected to assist the human throughout the entire process, in coherence with the emerging Industry 5.0 paradigm. On the other hand, the system can also take advantage of human interaction. For instance, if the algorithm fails in the problem identification, the operator feedback on the actual cause would allow the system to extend the available information enhancing its performance over time. Long short, the system will support humans in the identification of the faulty pieces, while humans will assist the system in the training process, providing feedback on its performances. Thus, the human-machine interaction will impact the assumed KPIs in terms of time-saving, drastically reducing the diagnosis time especially in the presence of an inexpert user, and refining the identification of the needs, so as to improve the remote assistance services.

Four experiment supports only the pattern "machines assists humans"; they are described in the following.

Exp 5. This experiment includes human-machine collaboration to support the real time planning and scheduling production, providing saving of time and cost, and maximizing the use of resources. Specifically, the AI system is expected to assist the production manager in the planning production process.

Exp 8. The AR operator support system will be helping operators (and development of their skills) in giving the right amount of suggestions to complete complex modules. The proposed system goes in the direction of Industry 5.0, by allowing the personalization of the machines depending on the human needs through the "dynamic customization of operator guidance based on skill level, performance, errors, instantaneous operator capacity and operator knowledge and feedback to improve effectivity of instructions;"

Exp 10. In the experiment the role of the human-machine collaboration will be to provide assistance to the operators to estimate future heat demand. This will lie in the area of "Machines Assist Humans". The benefit will be more efficient energy use for the client (more sustainable energy use).

Exp 11. The experiment includes collaboration between human designer and the provided matchmaking (MM) system that allows to configure the resources. Human will provide the search space as an input to the matchmaking system, including the Product Requirement Description, Resource Pool and/or existing System layout description. In addition, he/she will control during the matchmaking rounds the strategy of the matchmaking. Finally, when the MM system provides the results, the designer will make the analysis and final selection of the resources to the workstations. The type of the collaboration can be defined as "machine assists human". The MM system does the time consuming and cumbersome search and filtering of the feasible resources from large search spaces, while the designer makes the final system design and optimisation decisions.

In the remaining 7 experiments, either there is no human-machine interaction (**Exp 15**. **Exp 17. Exp 6. Exp 14**.) or the interaction has not been specified yet (**Exp 3 Exp 4 Exp 7)**

In the second part of the project, the leaders of these experiments will be further interviewed in order to understand if a human-machine collaboration can be taken into account in their experiments.

4.3.4 Simulation and optimization of Industry 5.0 based human-centred processes

One of the main goal of the task 5.1 consists in providing a valid solution to support orchestration, optimization, and simulation of human-centred processes oriented to Industry 5.0. To clarify the specifics of this solution, we analyzed scenarios 1 and 2 reported in Section 4.2, which have allowed us to elicit the requirements and others.

The real-time monitoring of the current human-centred process capabilities enables to update the decisions about resources management, to predict failures, and to implement optimization strategies. In order to dynamically assess the performance of a real asset and check the efficiency of each designed process, it is essential to connect to the latter and then process its produced data in real-time. In particular, as Industry 5.0 aims at merging computational intelligence (and cognitive computing capabilities) with human intelligence in collaborative operations, it is essential to refine these collaborative interactions between humans and machines, leveraging a real-time monitoring solution of the human-centered processes. This way, the platform should promote harmonization and orchestration between machines and human factors, especially considering the cognitive and physical workload related to manufacturing operations. Under these conditions, the platform should enable the comparison of these different solutions, also in accordance to scenarios needs.

Since Digital Twin (DT) is becoming a consolidated technology to simulate the physical industrial asset performance, allowing to predict failures or investigate problems, this section investigates the potential of a solution based on DT for optimizing human-centered processes. Specifically, the DT represents a virtual and faithful mirror of the physical process that allows to monitor the process parameters, to compare them with any analytic models, and to supply in real-time specific variations of parameters to keep the process always in optimal conditions.

4.3.4.1 The Digital Twin role in Industry 5.0

The ongoing digitalization of the worldwide industry is paving the way to the realization of sophisticated virtual models which represent replicas of a specific physical asset (e.g., a robot, a production machine, etc.). In particular, these models are used to simulate their behavior (e.g. kinematic, thermal, flow, performance, energy consumption and more). The integration of AI models (of physical objects) and Big Data Analytics for processing big data pushes the evolution of these simulation models in synchronized models by creating the conditions to realize the so called DT. The latter is an integrated multi-physics, multiscale, probabilistic simulation of an as-built system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding twin. It provides a representation of its physical twin (characteristics and behavior), according to a specific level of fidelity. In this regard, ISO (DIS) 23247-1[30] defines DT for Manufacturing as follows: DT is "a fit for purpose digital representation of an Observable Manufacturing Element (OME) with synchronization between the OME and its digital representation" where an OME is an entity that has an observable physical presence or operation in manufacturing. It could be personnel, equipment, material, process, facility, environment, product, or supporting document.

These models are commonly referred to as DT, but also other similar terms are often used (e.g., Asset Administration Shell, Virtual Representation, I4.0 Component, etc.). In particular, these models provide a representation of the characteristics and behavior of its physical counterpart, according to a level of fidelity, which is adequate to the specific scope they address. The general idea is that a DT approach can augment the physical assets, thus extending the latter with a kind of shadow in the digital space. It should be underlined that the Digital Twin becomes a real replica of its physical counterpart when it is fully synchronized with it through a circular process across the physical and virtual world (Fig. 1). Indeed, in this case, the DT can support the whole product/systems' life cycle from the conceptual design to operation and maintenance, by mirroring the real operating conditions. Thus, it is possible to simulate the real-time behavior, make forecasts of performance indicators, anticipate failures and plan prompt interventions to mitigate damage or degradation.

Under these conditions, the DT has a big potential in manufacturing, which has been recently analyzed in several scientific articles and publications. The relevance of this topic, also demonstrated by its inclusion in the scope of various strategic roadmaps of industrial and scientific research, is continuously growing. In addition, Gartner evaluated DT as one of the top 10 strategic technological trends for 2019. Its market is estimated to have a high growth which is confirmed by a recent financial analysis evaluated that the global market value for the DT enabled solutions is at around $3 billion in 2018 and it is expected to grow to $26 billion by 2025.

So far, various methodological approaches have been described and various solutions have been implemented by the leading technology providers such as Siemens, Beckoff, and Microsoft DT.

4.3.4.2 The traditional model of Digital Twins 4.0

Figure 5 provides a picture of the traditional DT model, which puts in evidence the continuous synchronization between the real asset and its digital counterpart, i.e., a constant mirroring of the two sides. The synchronization is realized by means of two streams of data. The first one (from left to right) represents the real-time monitored data flow and includes all physical variables sensed at the physical level by ubiquitous sensors and transmitted with a high frequency towards the digital space. Conversely, the second stream (from right to left) involves actions to be performed real-time

[30] https://www.iso.org/obp/ui/#iso:std:iso:23247:-1:dis:ed-1:v1:en

or near real-time at shop floor level, representing the feedback returned from the digital space to the real factory, e.g., corrective actions and planning decisions that can be the result of the execution of control algorithms. In addition, it is generated a low-frequency wave returning back to factory floor (arrow in blue at the top), which implements all strategic decisions taken from company management and generates long-period benefits with proper return of investments along the whole factory's lifecycle.

Under these conditions, the traditional conceptual model of DT comprises three major blocks: the Digital Model, the Digital Shadow, and the Digital Thread[31] (Figure 5). The first block is a formal representation of an asset used within the factory, i.e., an abstract characterization of the component with all its parts and logical relations existing between parts. Moreover, it also contains a description of the behavior of the asset and can also include a 3d representation. Digital Models of different components can be integrated, thus contributing to create the schema of the entire factory floor leveraging the modularity capabilities of the DT. The second block is the Digital Shadow, also called Factory Telemetry, which allows the continuous bidirectional synchronization between the physical artifact and its digital counterpart, i.e., a constant mirroring of the two sides thanks to two opposite streams of data in motion. The stream from left to right in Figure 5 represents the real-time monitored data flow. It includes all variables sensed at the physical level by ubiquitous sensors attached to physical component and transmitted (eventually also with a high-frequency) towards the digital space. Conversely, the second stream (from right to left) involves actions to be performed real-time or near real-time at shop floor level, representing the feedback returned from the digital space to the real factory, e.g., corrective actions and planning decisions that can be the result of the execution of control algorithms.

Finally, the Digital Thread or Historical Factory Telemetry, the third block, is the temporal (or historical) extension of the twin, which keeps track of the evolution of the physical twin by accumulating and storing (at rest) the data acquired at the real level. It should be noted that the Historical Factory Telemetry is historicized on a specific database and then used as an input to the model (through appropriate playback of data in motion) to perform predictions against which to compare the behavior of the relal system. Additionally, historical data can be used to make comparisons to the current telemetry. In addition, the Digital Model has as a possible further input the data that covers the entire life cycle of the system and coming from the various enterprise information systems.

[31] https://www.sciencedirect.com/science/article/pii/S2212827119302422

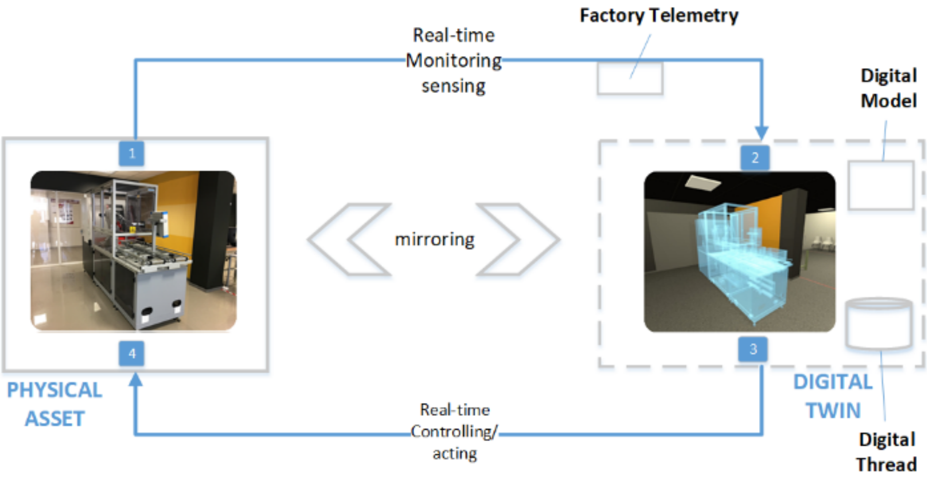

Figure 5. The 3 major blocks of the DT conceptual model

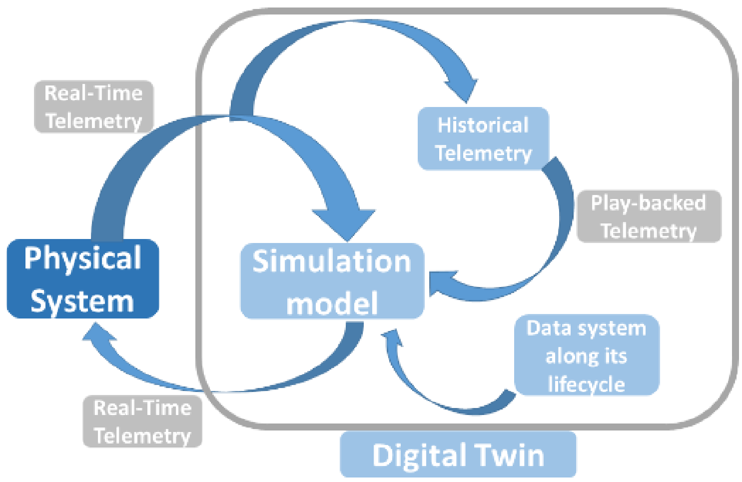

Figure 6, The data pipelines within the DT conceptual model

It should be noted that one of the initial motivation behind the creation of a DT of a physical asset was the creation of a system capable of monitoring, processing, and then taking some decisions of corrective or preventive actions to be applied to the real asset, automatically and without human intervention (Figure 7). This vision, however, does not take into account the human component which in many cases is relevant within the DT loop. Under these conditions, the traditional model of DT, which does not take into account the presence of the worker, cannot be compliant with the concept of Industry 5.0, which instead foresees the centrality of the worker.

To contribute to bridge this gap, the main goal of the following section is to propose a conceptual model that can be adopted as a reference architecture by a manufacturing company that wants to realize a valid DT compliant with industry 5.0. In addition to the framework, the task 5.1 of the project AI REGIO will implement a new DT adhering to the proposed conceptual model's specifications. The future goal of this work will also be validating this implementation within a real case study, thus demonstrating the correctness of the overall proposed approach.

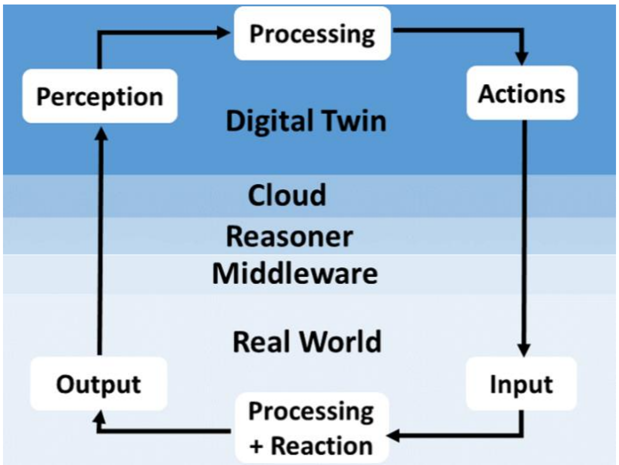

Figure 7. Closed loop of the DT

5 The DT AI REGIO model for Industry 5.0 and Collaborative Intelligence

This section studies the impact of the Collaborative Intelligence concept on the traditional model of the DT with the overall aim to make this model compliant with the Industry 5.0 paradigm. In this context, the study investigates which are the new blocks of the conceptual model and which are the interrelations that involve these blocks. Since these interrelations also imply new streams of factory telemetry data, the study will continue with the analysis of these data flows and, in particular, with the analysis of a software infrastructure that enables pipelines for the telemetry data.

The new proposed model of DT, which is reported in Figure 8, introduces the blocks corresponding to the physical workers and their corresponding Personal Twin (PT). In addition, the model introduces the different blocks interrelations deriving from the two interaction patterns of the Collaborative Intelligence. These interrelations (represented in figure as brown hatched arrows) are then also characterized on the basis of the type of interactions of the workers with the assets (physical, visual, voice, digital). Thanks to these interrelations, humans, and machines work and interact collaboratively to create (physical) products. In addition, the new proposed model of the DT analyzes the data pipelines through which information flow between two different components of the model. In Figure 8, these pipelines are represented as blue solid uni and bidirectional arrows. It should be noted that blocks represented in the model can be complex macro-blocks and they can in turn include various components. In particular, the PT can comprise two macro-components: 1) the model representing the information of the Physical Worker; 2) the behavioral \ cognitive model.

In the proposed model, the process of synchronization between the Physical asset and its DT (DTA) is represented through the bidirectional arrow A, while the bidirectional arrow B represents the process of synchronization between the Physical worker and its Digital Personal Twin. In addition, the arrows 1 and 2 represent both a physical interaction, but declined in two different directions. Indeed, the Physical Interaction of the worker, through which the worker acts on a haptic \ mechanical device, implies a connection from physical worker towards the physical system (the unidirectional arrow 1), while the unidirectional arrow 2 stands for the Physical Interaction of the machine towards the worker. This interaction interprets the pattern "Machines Assist Humans" (amplify interact embody), such in the case of exoskeleton or in the case of AR viewer. In order to allow a machine to adapt to the needs of a specific person with whom the machine is collaborating, the DT of the machine must access the information of the person included in the PT. In addition, another component essential to support this interaction is a learning model paired with the DTS, through which machines learn from the interplay with humans. This learning model represents a distinctive element of the DT's architecture compliant with Industry 5.0. Combining the information from PT and DTA which are then processed from the learning model (or eventually by some physics based or data models such an analytics), the DTA takes some decisions to apply some action at the physical level.

The unidirectional arrow 3 embodies the interaction patterns "Humans Assist Machines" (train explain sustain), which links the physical worker to the (DT of the) machine. The unidirectional arrow 4 stands for the Digital Interaction (e.g., data entry, etc.) \ Voice interaction of the worker towards the machine. Through this interaction, it is implemented the pattern "Humans Assist Machines" described by the arrow 3, which allows to train the learning model of the DTA.

Moreover, the Visual Interaction of the worker, which allows to show the information from the DTA to the worker (e.g., through an AR viewer, a monitor, or another physical device), implies a connection from physical system towards the physical worker (the unidirectional arrow C).

Finally, the bidirectional arrow D represents the interplay between DTA and PT and viceversa. This link allows to integrate the different DTs in a federation of DTs, creating the conditions to realize a DT of DTs (red hatched rectangle in Figure 8). For example, the link corresponding to arrow 6 is essential if DTA contains a model based analytics which also needs the data of the person for its processing and elaboration.

The DT of DTs also include some further components (**Cross DTs Components**), which are transversal to the various DTs.

The following observations can be derived from the AI REGIO CI model:

- The interaction pattern "Machines Assist Humans" is declined through a link between the physical system and the physical worker (**arrow 2**), while the interaction pattern "Humans Assist Machines" is declined through a link between the physical worker and the DTA (**arrow 3**).
- In the DT compliant with the Industry 5.0 paradigm, there is not a link which goes from the DTA towards the physical worker. Indeed, the information of the DTA are typically conveyed to the physical worker through a physical device (such an AR viewer), by exploiting the data pipeline represented by the **arrow C**.
- Since PT comprises two macro-components (the model representing the information of the Physical Worker; the behavioral \ cognitive model), it could be interesting to investigate how the two macro-components are linked between them and \ or how they are integrated with the DTA. Indeed, workers interact with each other and with machines, also through DTs. In order for DTs to be real alter egos of the people associated with them, rather than primitive virtual assistants, they will have to incorporate paradigms of human behavior, going to reproduce the social behavior that the person they represent would have held in the same context and with those specific people. A typical example is when the DT has to decide what kind of information to share with another DT, or whether or not to trust the information they receive.
- Which represented flows (arrows) are affected by an Orchestrator component, which plays the role of balancing between the human component and machine? The affected links are **2** and **3**, as well as **A**, **B**, and **D**.
- One of the future direction of the study is the identification of a valid software infrastructure capable to support the automatic data pipeline (the affected links are **A, B, C**, and **D**).
- As underlined in Figure 8, the data do not only flow in a circular process as in the traditional model of DT.
- Enabling technologies of Collaborative Intelligence could be even brainwaves[32]. But in this case which is the direction of the Collaborative Intelligence? The brain impulses are transmitted to PT or even directly to DTA (in this case arrow 4 will manage also brainwaves interaction).
- The arrow 3 represents the way through which worker supports DTA, and this interplay can take place in turn using a voice or digital interaction (arrow 4).
- Since it is becoming more and more common the use of Explainable AI[33], i.e. a set of tools and frameworks thar help to understand and interpret predictions made by machine learning models, which is their impact on this proposed model and in particular which are the pipelines that support explanations? Explainable AI extend the interactions "machines assist humans" and two options can be considered in the proposed model to manage the explanations sent from

[32] https://news.mit.edu/2018/how-to-control-robots-with-brainwaves-hand-gestures-mit-csail-0620
[33] https://arxiv.org/abs/1710.00794

the DTA to the worker: 1) the same pipelines used for the other data (arrows A and C) are used; 2) the explanations are sent using ad hoc pipelines which are used only for this goal.

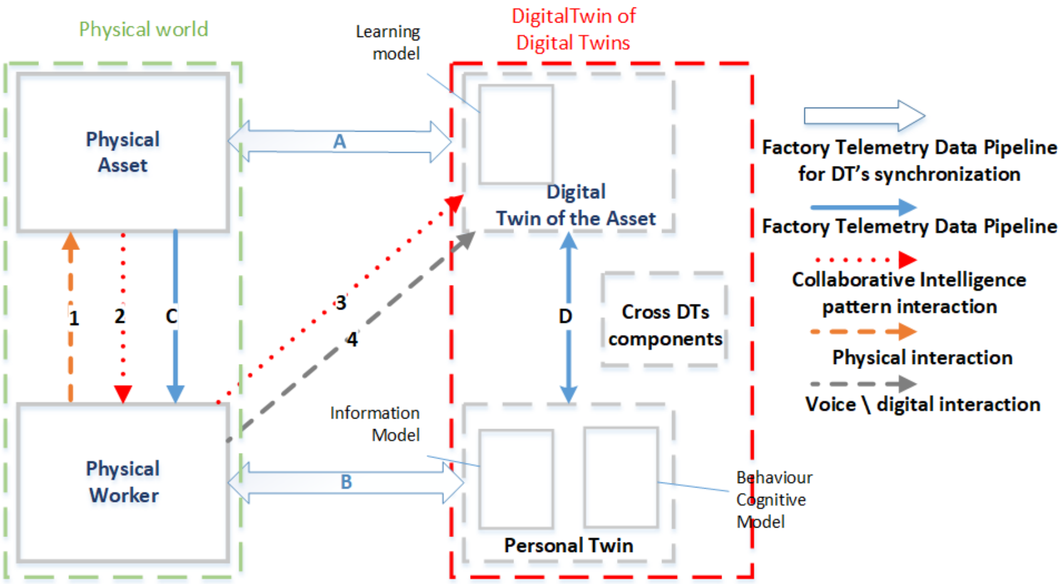

Figure 8. Evolution of the DT model to become compliant with Industry 5.0 and Collaborative Intelligence

5.1 Application of the conceptual model to the motivational scenarios

This section investigates the conceptual model's potential to support the motivational scenarios reported in Section 4.2.1. In this regard, the model represented in Figure 8 has been updated and the overall application of the model is pointed out in Figure 9.

In particular, in order to support the scenario 1, the DTA (in this case the DT of the robot) includes the computer vision component and the learning model trained by the workers. In addition, the learning model uses the information of the worker which are contained in the PT.

The scenario 2 is an extension of scenario 1 and requires two **Cross DTs components**:

a) the Orchestrator which allows to configure and orchestrate the interactions that occur between robots and workers; it includes and persists the different possible solutions of configurations of the Collaborative Intelligence interactions.
b) the Simulator which allows to simulate the interactions between machines and workers.

As provided by the conceptual model, these two components must be positioned in the DT of the DTs, since they are transversal to the different DTs.

Finally, to support the scenario 3 which provides the Explainable AI, a further Cross DTs component called **Explainable AI Tool** is added.

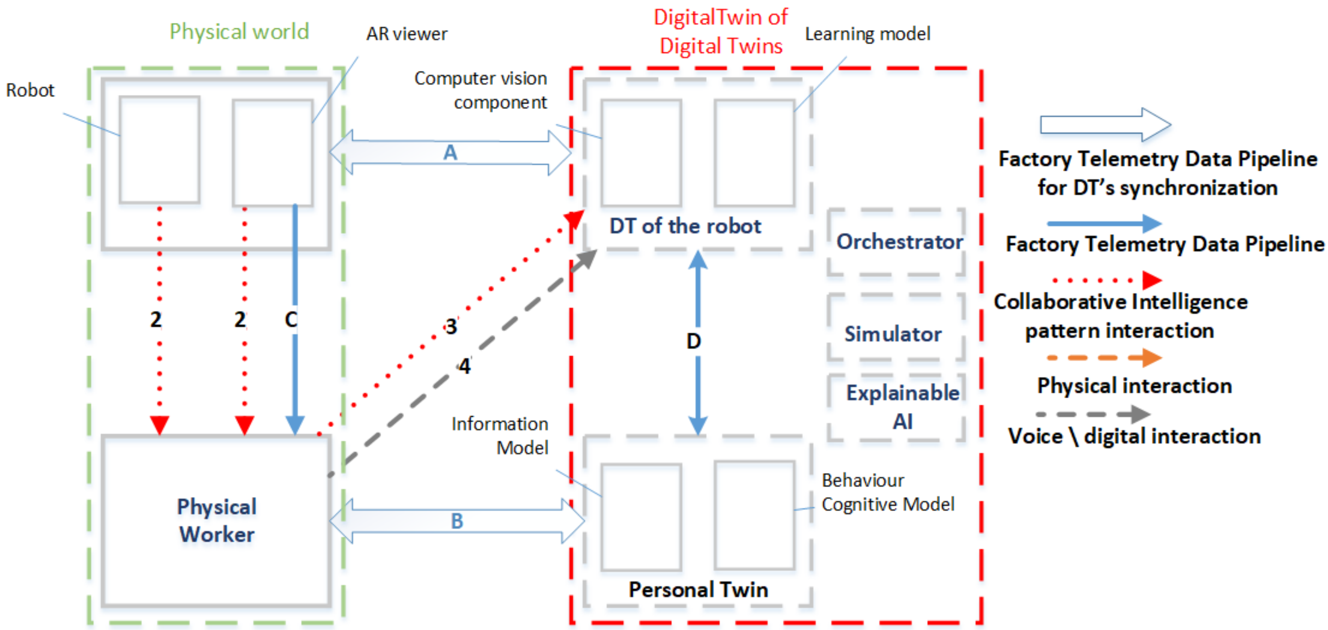

Figure 9. Application of the conceptual model to the Scenario 1 described in section 4.2.1

5.2 AI REGIO Industry 5.0 Architecture Description

This section aims to answer the following research questions: "Which software infrastructure must be adopted to implement the new proposed conceptual model compliant with Industry 5.0? Which are the differences compared to the architecture that support the traditional model of DT?".

The outcomes of this investigation will be exploited by the future second stage of our research, which aims at implementing the platform. Specifically, the section describes the conceptual architecture and its main functional building blocks, by leveraging the functional requirements elicited from the motivational scenarios and also taking into account some technical constraints and requirements which are based on the specific solution based on DT.

5.2.1 Non-functional requirements for the I5.0 platform

This section presents a list of non-functional requirements that should be taken into account during the implementation of the platform. In particular, the provided solution must:

(NFR_1) Manage the real-virtual synchronization, i.e. the bidirectional data pipeline of the Factory Telemetry (data in motion) (links A and B in Figure 8).

(NFR_2) Ensure the interoperability between various models of different types (physics based, data based, etc.) included in a DT.

(NFR_3) Guarantee the interoperability between different DTs (arrow 6 of Figure 8), thus enabling the creation of a DT of DTs.

(NFR_4) Preserve the data sovereignty within a DT's circular process internal to an organization. Under these conditions, the DT becomes a safe and trusted ecosystem.

(NFR_5) Preserve the data sovereignty when the DTs of an organization is exposed towards actors of external organizations.

(NFR_6) Enable an enactment service to support the design of operational and interaction workflows and the configuration of specific applications and services.

(**NFR_7**) Ensure data cleansing and data quality close to the various sources of data, by dealing with the not reliable, missing, and incomplete data, which should be specifically processed.

(NFR_8) Adapt to the business and operational needs, thus upscaling or downscaling according to specific variations (scalability).

5.2.1.1 Architectural components of the I5.0 platform

This section describes the different architectural components needed to support the implementation of an Industry platform having its root in the DT based conceptual model presented before. All these components are also reported in Figure 10, which emphasizes the role of pillar for the Industry 5.0 platform played by these components.

(C1) Industry 5.0 data space. The DT concept requires a homogeneous perspective of the handled CI information persisted across the different internal and external boundaries. Indeed, this information should not only be available vertically between value chains, but also distributed horizontally in an **Industry 5.0 data space** across organizational boundaries, where different assets (machines, workers, etc.) and the various architectural components of the DT (including the legacy databases) can exchange data while maintaining the sovereignty over them. In order to realize this horizontal data space, **two further architectural components** are needed:

(C1.1) Industry 5.0 Semantic data model and Ontology. This component aims at enhancing the interoperability among assets involved in the CI workflows and acting both as data producers and consumers. Specifically, the interoperability consists in the capability for different systems and applications to exchange information and exploit the exchanged information between the involved resources. In the proposed Industry 5.0 platform, a DT can include data sources (models, databases, various enterprise tools and even the factory telemetry data) characterized by heterogenous format of data, which often lack of **interoperability** between them. In addition, different Dts can lack of interoperability as they can include different types of data formats. Moreover, the lack of widely accepted standards and of architectural references to achieve interoperability contributes to worsen this scenario. As a solution to this issue for the herein conceived platform, it is proposed an Industry 5.0 Semantic model in order to harmonize the semantic differences between the different involved concepts. A preliminary design of this semantic data model is presented in the following section. In addition to the definition of the semantic model, in order to enable interoperability within and across organizations, DT can also provide a **standardized application programming interface (API)** to manage the data access and usage in a trusted ecosystem (C1.2).

(C1.2) Trusted and secure ecosystem. This ecosystem would enable the secure and standardized exchange and the easy linkage of data across different sectors. Specifically, while today this data sharing process is limited to agreements negotiated on case-by-case, it is needed a standardized and secure way of managing data ownership and access rights on DT, which allow data owner to retain control over data. In this way the data owner always determines the terms and the conditions of use for the data provided, thus maintaining the data sovereignty across the proposed platform. Consequently, the data sovereignty concept arises, which is defined in fact as the ability of the data owner to decide itself how to share and use its data. One potential solution of data sovereignty is based on Industrial Data Space (IDS)[34] which would enable a trusted and secure Industry 5.0 data space. In this case, the data sovereignty and interoperability of the DTs and models internal to an organization would be managed by an internal IDS connector (Figure 12), while the interoperability between DTs belonging to different organizations would be managed by an external IDS connector (Figure 12).

(C2) Middleware for the real-virtual synchronization. The real-time monitoring of the current system capabilities enables to update the decisions about maintenance strategy, to predict failures, and to implement optimization strategies. In order to dynamically assess the performance of a real asset, it is essential to connect to the latter and then process its produced data in real-time. The DT of a physical asset is the faithful mirror of its real counterpart and can be exploited to its full potential only if the virtual and real asset are bidirectionally synchronized. To achieve this synchronization process, the technological infrastructure supporting the DT must have a **middleware** application as a pillar, thanks to which the data (so-called **Factory Telemetry**) have to be managed within a circular process in the two directions: from the real factory to the DT for feeding the Online DT and from the DT to apply actions to the real factory (Figure 11). In particular, the **middleware** will have to transmit streaming data, i.e. the data that, acquired and collected in real time by the sensors (but not only) distributed within or near the asset, which will be then transmitted in the form of telemetry to be used as input for specific analyzes (eg simulations of certain configurations). In particular, the middleware and its infrastructure supporting the DT must be endowed with scalable capabilities that enable to harvest real-time data which can be captured, processed and transformed into significant insights in an efficient manner.

(C3) Time-series databases and other NoSQL databases. Another relevant challenge consists in the persistence and accumulation of the acquired data (historical data) for feeding the offline analysis. The processing and analysis of data transmitted in the form of telemetry (data in motion), possibly combined with historical data (data at rest), will provide the DT with both short-term decision-making skills, even in real time, and long-term analysis capabilities, off-line and scalable. An example of a decision could be a corrective action that in the form of telemetry is applied on the real asset (synchronization in the direction from the virtual to the real model). Referring to the common Big Data characterization of the three Vs, the handling of the real-time data affects mainly the data Velocity Dimension, while the accumulation of the historical affects the data Volume Dimension. Enabling technologies to cope with this challenge are the mechanisms for managing data leveraging **databases and microservices to historicize and display the acquired data, and cutting-edge processing and storage mechanisms operating on cluster system** (e.g., NoSQL databases) distributed on **cloud**. In this regard, cloud based systems have to be taken into account to ensure the horizontal scalability of storage, computation, and communication capabilities, and to decouple storage, data processing, and data management. It should be noted that Factory telemetry data is typically under the form of Time Series, i.e., couples of (timestamp, value). Such a data do not fit well with the well-defined and rigid structure of the more common databases (based on relational model). For this reason, the current efforts of researchers and technicians are addressed towards the implementation of so called **time-series databases** (e.g., InfluxDB, etc.), i.e. purpose-built databases to manage time-series data, which belong to the set of NoSQL database. Finally, it is essential to investigate data security issues with the aim to ensure confidentiality, integrity and availability of sensible data.

(C4) Multi-scale models simulating the interaction "Machines Assist Humans". It should be noted that the DT is represented by a model that must be precise and detailed in order to perform accurate simulations and evaluations. However, a detailed model synchronization process can involve significant processing cost, especially when coupled with a high sample rate. For this reason,

[34] https://internationaldataspaces.org/

it is important to identify the right compromise between the level of detail (granularity) of the DT and the efficiency of the synchronization process. One solution can be the development of **multi-scale models** for both live telemetry and historical data which **allow to simulate the two pattern interactions of the CI**. In particular, the channel that need to be simulated is the "Machines Assist Humans", while for the channel "Humans Assist Machines" the simulation is less interesting while it is needed a learning model for the DTA (C7). Specifically, for the interaction "Machines Assist Humans", it is useful to simulate and understand live (when the process is running) to what extent the machine has to assist the worker on the basis of the latter capabilities and other aspects such his level of fatigue. This simulation can be exploited to assess a physical interaction (as in robotics scenarios) or visual\digital interaction where behind a physical component there is the DT's model. The application of the simulation in the first case seems more important as it allows to evaluate the mechanical \ physical aspects, but anyway it interesting to explore the difference deriving from the application of the simulation in the two cases.

(C5) Data cleansing mechanisms. It is essential to study valid strategies to distribute the intelligence and data of the DT close to the various data sources, thus limiting the use of the transmission band. One potential solution is applying a **data cleansing mechanism** at the edge level and in particular on the data produced at the physical level, since the quality of the data generated by the sensors or machines is typically less good than the data produced by an AI module.

(C6) Orchestrator. It is needed the **implementation** of an **orchestrator** of human-centred processes, which plays the role of balancing between the human component and machine. In Figure 8, the links affected by the orchestrator are **2** and **3**, as well as **A**, **B**, and **D**. In addition, the orchestrator will be paired with a workflow enactment service which allow to interpret a chain and control the instantiation of services and sequencing of activities.

(C7) Learning model for DTA to support the interaction "Humans Assist Machines". DTA must comprise a learning model, through which machines learn from interplay with humans.

Finally, another technological challenges that have to be faced in the construction phase of the technological infrastructure is the implementation of the **connection with the physical assets**, since of the methods for connecting the Real Factory with its DT have not yet been fully standardized and they also often lack of key functionalities.

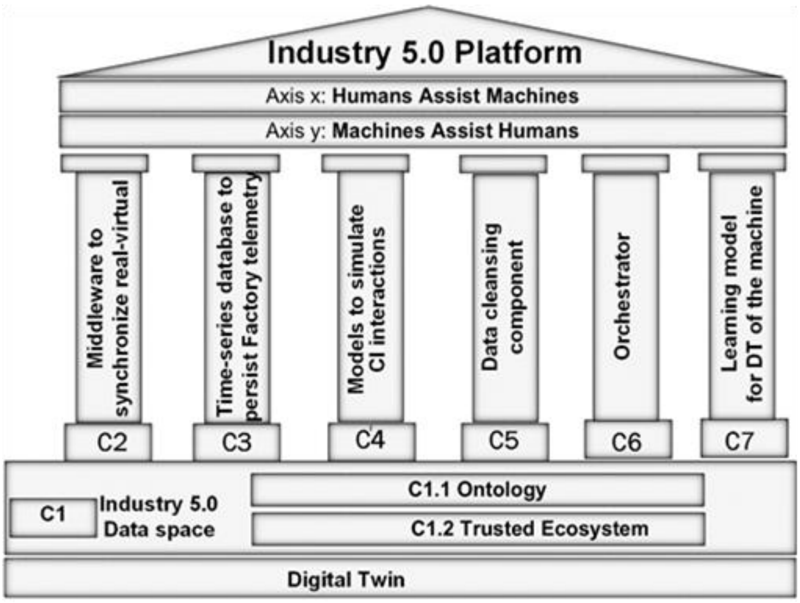

Figure 10. Architectural components for the Industry 5.0 platform

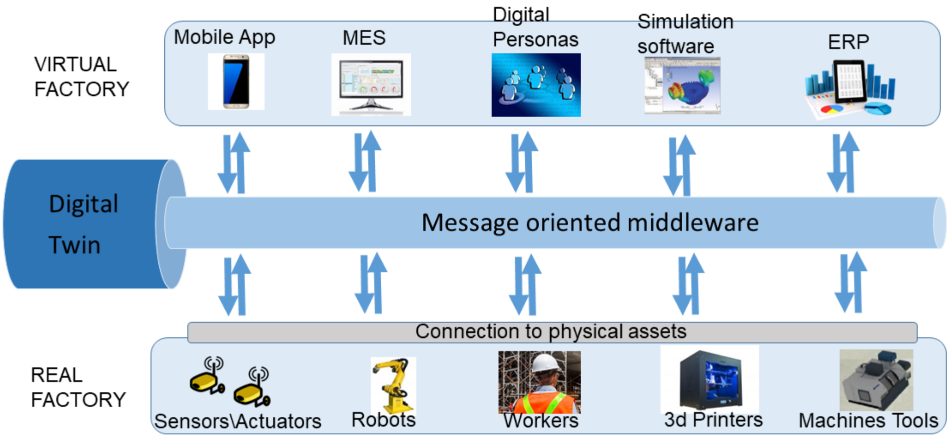

Figure 11. Middleware to synchronize real and virtual[35]

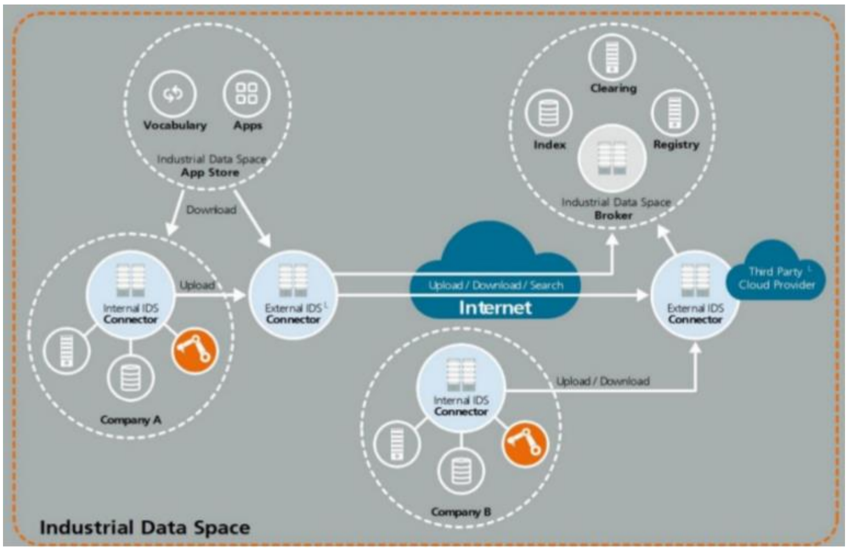

Figure 12. Internal and external connectors for IDS [Source https://internationaldataspaces.org/]

5.2.2 An Industry 5.0 data space

Since one of the preliminary activity of the task 5.1 of the AI Regio project is the definition of the concept of Industry 5.0 and collaborative Intelligence, the efforts are also addressed towards the representation of the main aspects related to these concepts within a data space. In particular, the idea is to develop a conceptual model that expresses the meaning of the main terms and concepts used by domain experts (such as collaborative intelligence, orchestration) and also represents the correct relationships between the different concepts, with the final aim of harmonizing the various aspects related to knowledge on Industry 5.0. For this reason, in collaboration with partners of task 5.4, we expect to define a new model from scratch but it will be also important to reuse existing models (such some of the ones analyzed in the context of T5.4) which covers specific topics such

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[35] https://www.tandfonline.com/doi/abs/10.1080/0951192X.2019.1571232

for example the interaction between human and machine or human and AI. A particular focus of the new model will be devoted to the DT model previously defined.

In addition, it should be noted that the defined model could be used at a second stage as the basis of the Industry 5.0 data space to support the collaboration and interaction of humans and machines, by enabling the information exchange within trusted and secure ecosystem.

5.2.2.1 The Industry 5.0 and Collaborative Intelligence Ontology

The definition of a reference model is proposed as a solution to provide a systematic manner to classify and integrate the valuable knowledge about Industry 5.0. The data model defines the reciprocal relationship between the different concepts involved in Industry 5.0 scenario, aggregating and unifying all this information. In particular, the definition of such virtual individual model stems from a conceptual model of relations linking virtual and physical machines with humans in a Collaborative Intelligence context.

This reference model is represented through a set of ontologies by adopting the Semantic Web Technologies (SWT). An ontology based approach offers the significant key advantages of allowing to represent a formal semantics which contributes to enhance the interoperability of different software applications. In addition, it allows to exploit reasoning tools that can infer from and reason about an ontology, thus providing a generic support that is not customized on the specific domain. Finally, it allows to efficiently model and manage data to be distributed over the network, under the form of Linked Open Data (LOD). The latter is a proven way to publish and interlink public set of data in the scientific community (and also other fields).

5.2.2.2 The development of the ontology

The development starts with the identification of the knowledge domains of interest, through a deep understanding of the main invoved concepts. An extract of the latter is reported in Figure 13.

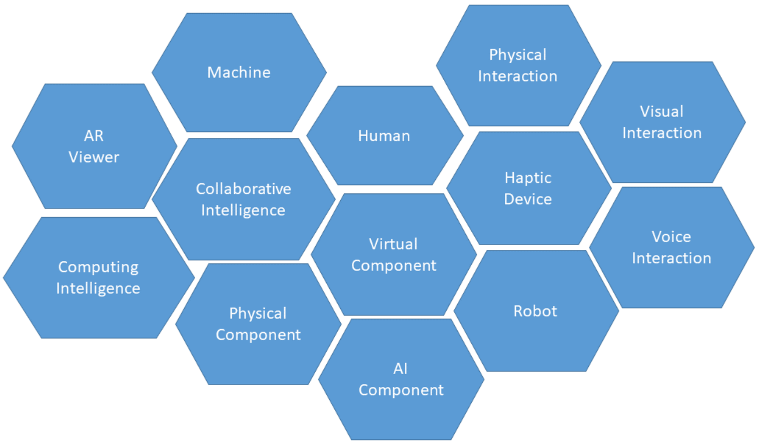

Figure 13. An extract of concepts concerning Industry 5.0

Through a concept map, main aspects related with Industry 5.0 are reported in Figure 14.

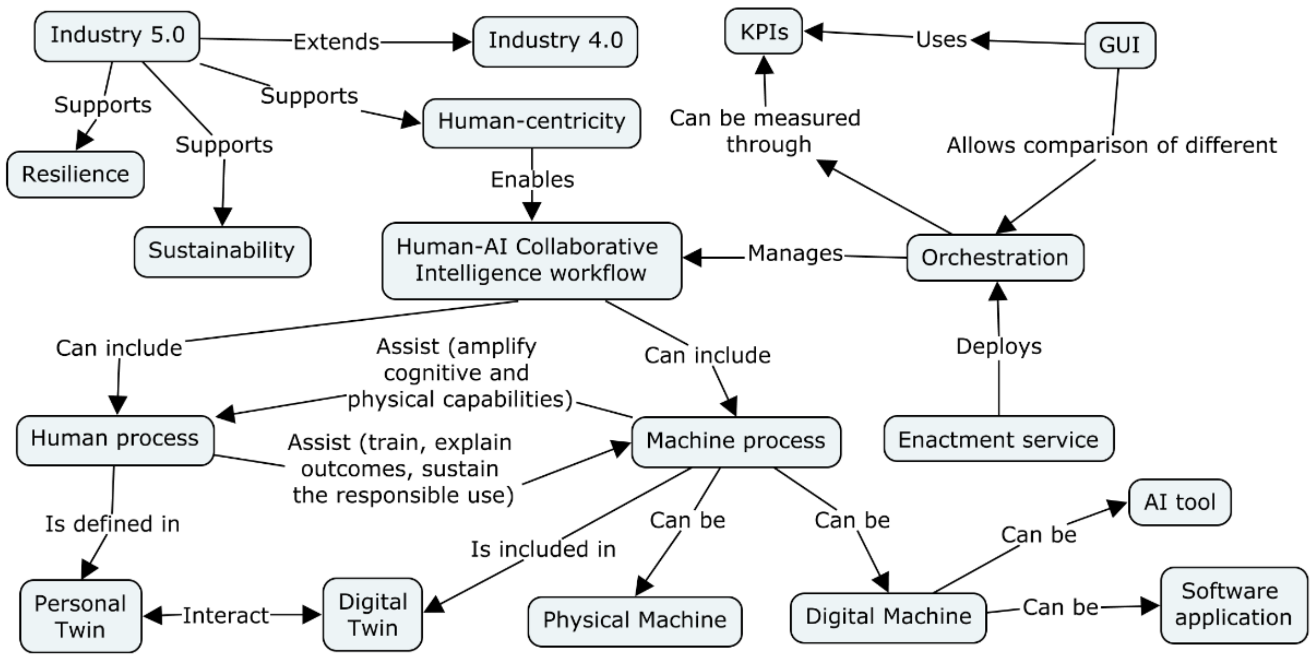

Figure 14. A concept map which illustrates main aspects related with Industry 5.0 and human.centricity.

Some of the relevant entities represented in the map are *Machine* and *Human*. *Machine* can be a *Virtual* or *Physical Machine* exploiting a subsumption relationship, represented through the axioms (Ax1) and (Ax2). The latter expresses the mentioned relations in Manchester OWL Syntax, which has been also used to represent the other axioms reported in this section.

(Ax1) *Class: Machine SubClassOf: PhysicalMachine*

(Ax2) *Class: Machine SubClassOf: VirtualMachine*

In turn, *VirtualMachine* can be *AITool* or a *SoftwareApplication*:

(Ax3) *Class: VirtualMachine SubClassOf: AITool*

(Ax4) *Class: VirtualMachine SubClassOf: SoftwareApplication*

Moreover, various concepts of the domain ontology are semantically enriched through a property, as represented through the axioms (Ax5) to explicit the property that links *CollaborativeWorkflow* with *Machine*:

(Ax5) *ObjectProperty: canInclude Domain: CollaborativeWorkflow Range: Machine*

Moreover, the properties declaring the interactions patterns of the *Collaborative Intelligence* are represented through the following axions (Ax6) and (Ax7):

(Ax6) *ObjectProperty: assist Machine: CollaborativeWorkflow Range: Human*

(Ax7) *ObjectProperty: support Human: CollaborativeWorkflow Range: Machine*.

The design of this Ontology will continue at the second stage also leveraging the reuse of existing reference models and ontologies analyzed in the context of T5.4. In addition, as the Industry 5.0 paradigm focuses on the centrality of the workers within the factory, the Industry 5.0 Ontology will exploit two ontologies :

1) A specific Ontology focused on the Person.
2) The Ontology model representing the factory's knowledge (the *Factory Assets Ontology*).

These two models are briefly described in the following subsections.

5.2.2.3 The Digital Person Ontology

This model provides a formally multi-faceted description of the operator within the factory and represents all the knowledge related with the Person and in particular it includes biographic info, disabilities or impairments, work aspirations and attitudes, training activities and courses the worker has already taken part, his/her skills and responsibilities[36]. In addition, the model represents the logical links existing between worker skills and competencies, and machines process tasks and technological solutions able to support the workers in accomplish their tasks. The latter (machines and technological solutions) are represented in the Factory Asset Ontology which is briefly described in the following section.

The top level classes of this ontology are:

- *User*, which subsumes its direct subclass Worker. This one is used to profile a worker inside the company with all biographic info belonging to him/her (gender, age, language and so on).;
- *Training Activity*, any formative activity a worker accomplishes in order to get trained for carrying out a specific production process phase (or step).
- Courses, a wider formative activity designed for workers making them able to use a particular technology. With respect to Training Activity a course includes many formative units and present interdisciplinary links to similar courses or related technologies courses.

In addition, this Ontology includes the *Skills Virtual Model* which provides a formal representation of the skills the operator need in order to perform each single phase of the production process. It includes the knowledge of product and its parts, processes, competencies and operator capabilities. This model is imported from the previous one that in turn is imported from the first one. One of the existing model that have inspired this ontological model is the technical report entitled: Skills for Key Enabling Technologies in Europe by the European Commission[37]. The top level classes of this ontology are:

- *Competence*, a class embodying the concept of ability to do something successfully or efficiently within the workplace, specifically concerning a profession, e.g., programmer, manager, seller, etc.;
- *Skill,* a class embodying the concept of ability to do something successfully or efficiently specifically concerning a practice in a production processing.

[36] http://www.thinkmind.org/articles/eknow_2018_4_10_60063.pdf
[37] https://ec.europa.eu/growth/content/final-report-skills-key-enabling-technologies-europe-0_en

5.2.2.4 The Factory Assets Ontology

This model contains concepts and logical relations representing the entire production system involved inside the factory (from the shop floor to the manager desk) including production process, final products (with all their specific parts), by-products (meant as secondary product made in the manufacture or synthesis of something else), services, components, raw materials, and so forth. It borrows some concepts and idea from the Virtual Factory Data Model[38].

The top level classes contained in this module are:

- *Component*, an high-level abstraction class used to represent a part or element of a larger whole, especially a part of a machine or vehicle or a product;
- *Manufacturing Production*, a class meaning a process of converting raw material into finished products by using various processes, machines and energy. Production is a process of converting inputs into outputs;
- *Product*, an high-level abstraction class representing an article or substance that is manufactured or refined for sale. It is also conceived as a product anything that can be offered to a market and that might satisfy a want or need;
- *Production Process* is a class representing a process of combining various material inputs and immaterial inputs (plans, know-how) in order to make something for consumption (the output). It is the act of creating output, a good or service which has value and contributes to the utility of individuals;
- *Production stage*, any phase of a production process meant as a step to be accomplished in order to obtain a final product;
- *Raw Material*, a class representing a basic material that is used to produce goods, finished products, energy, or intermediate materials which are feedstock for future finished products.

[38] https://www.sciencedirect.com/science/article/abs/pii/S0007850613000462

6 Conclusions and Next Steps

This document presents a conceptual model of a platform for Human-AI interaction in Industry 5.0, which is focused to orchestrate, monitor, and simulate the human-centred processes. The design of the platform leverages the outcomes of an analysis of the fundamentals related with the concepts of Industry 5.0 and of Collaborative Intelligence (conducted as preliminary activity of the task 5.1), and also the definition of a set of motivational scenarios oriented to the new Industry paradigm.

Based on the design of the conceived conceptual model, a roadmap for future actions within AI REGIO is developed and proposed. Indeed, the design of the conceptual model represents the main step of a roadmap which will continue, at a second stage of the project starting at M10, with the implementation of the AI REGIO Industry 5.0 platform having its root in the defined conceptual model as specified in Section 0. In this regard, the needed future developments are reported in the following section, coupled with a brief description.

These developments will be addressed at a second stage of the task 5.1 starting from M10.

i. **Identification of valid solutions for the technological components.** In collaboration with leader and partners of WP4, a valid solution for each technological components of the Industry 5.0 platform defined in Section 5.2 will be identified. In particular, it will be necessary to identify a valid solution for the middleware synchronizing physical and virtual world and a valid solution for the Time-series database in order to persist data related to machine, components, and people.

ii. **Evolution of the Data Space based on Industry 5.0 and Digital Person Ontologies**. The Ontologies initially presented in Section 5.2.2.1, 5.2.2.3 5.2.2.4 must be enriched of further concepts and relations, also leveraging the reuse of existing reference models and ontologies analyzed in the context of T5.4. Some of the significant extensions to be applied on the preliminary model are the following:

    - representing the human capabilities (human brainpower, creativity, teamwork, and social skills) and machine capabilities (high speed, precision, scalability, and security);
    - adding the type of interaction between human and machine: physical, visual, voice based, brainwave. For each type of interaction, specify the corresponding properties (e.g., for physicality, the ergonomics and security);
    - adding the complexity perceived by the user on the digital component (see XMANAI project[39]);
    - adding the key features to evaluate when an industrial company is compliant with Industry 5.0.

    This activity will be conducted in collaboration with leader and partners of task 5.4.

iii. **Development of the graphical orchestrator and workflow enactment service**. A specific activity will be focused on the design of a graphical environment which allows the orchestration of human-centred processes workflow in terms of process management and Human-AI interaction. In particular, the orchestration plays the role of balancing between the human component and machine, especially considering the cognitive and physical workload related to manufacturing operations. This activity will be conducted in collaboration with partners of task 5.1.

[39] https://ai4manufacturing.eu/project/

iv. **Study of the interactions between internal PT's macro-components**. The PT can include two macro-components: 1) the Digital Person Ontology representing the information of the Physical Worker, which is dealt in the previous point; 2) the behavioral \ cognitive model \ computational intelligence, which should be conceived and designed. In addition, it will be interesting to investigate and understand how these two macro-components are linked and how are integrated with the DTA, and also how they are linked with human intelligence. This activity will be conducted in collaboration with partners of task 5.1 and with leader and partners of task 5.4.

v. **Development of models to simulate the "Machines Assist Humans" and a learning model included in the DTA to support "Humans Assist Machines**". The efforts of task 5.1 partners must be devoted towards the development of **multi-scale models** for both live telemetry and historical data which **allow to simulate (off-line and on-line) the** "Machines Assist Humans" interaction and a learning model to support "Humans Assist Machines" interaction. For further details and specifics, see Section 5.2.1.1. This activity will be conducted in collaboration with leader and partners of task 5.1.

vi. **Representation of the PT using Open Standard approaches**. In addition to an ontology, it should be investigated how the Industry 5.0 based DTs and Digital Person can be represented using Open Standard approaches (e.g. adopting RAMI Asset Administration Shell). It will be also interesting to evaluate the Impact of Industry 5.0 concept on reference models such RAMI AAS. Moreover, it should be noted that, in order to define the conceptual model, it could be be also interesting to use a language as DTDL models and ontologies for assets[40] (Microsoft Azure Digital Twin) with a view to being based on an open model for integration with devices. This activity will be conducted in collaboration with leader and partners of task 5.4.

vii. **Data sovereignty mechanisms that should be adopted to support the new proposed model of DT**. This work aims to find valid solution to meet the requirements NFR_4 and NFR_5. A potential solution that meets the two requirements is based on IDS, the framework studied within the task 5.2. Such a solution can support:

- Scenarios of secure data exchange between DTs (or models) internal to an organization (e.g., by implementing an internal IDS connector as in Figure 12).
- Scenarios where an organization expose a DT towards external stakeholders within a virtual and trusted data space (e.g., by implementing an external IDS connector as in Figure 12).

In order to reach these goals, data providers have to express their restrictions on their data in a formal way through IDS Contract and IDS Rule. In addition, an IDS based solution will give each worker the opportunity to specify how his data can be managed and from whom, thus keeping the usage control on his own data. In order to proceed with this activity, the collaboration of leader and partners of task 5.2 will be asked.

viii. **Data cleansing and data quality mechanisms that should be adopted to support the proposed model of DT**. Another challenge that must be faced to implement a valid Industry 5.0 platform based on DT consists in the study of valid strategies for data cleansing and data quality close to the various sources of data. These mechanisms should ensure that the data will be available for the DT in the right quality and quantity and at right time (by also applying to different levels of data granularity), and they should also deal with the not reliable, missing,

[40] https://github.com/Azure/opendigitaltwins-building

and incomplete data, which should be specifically processed. This activity will be conducted in collaboration with leader and partners of task 5.3.

ix. Assessment of the Industry 5.0 platform within the experiments more oriented to Industry 5.0 \ Open Call projects. In order to verify the potential of a list of AI REGIO experiments more oriented to Industry 5.0 which have been already selected through a preliminary classification reported in Section 4.3.3, these experiments will be analysed more in depth at a second stage of the project, by surveying the stakeholders involved in these experiments. Afterwards, these selected experiments will be exploited, paired with some of the Open Call projects, to assess the realized AI REGIO Industry 5.0 platform. In addition, the leaders of the experiments where the human-machine interaction has not been specified as reported in Section 4.3.3 will be surveyed in order to understand if a human-machine collaboration can be taken into account in their experiments.

    This activity will be conducted in collaboration with leader and partners of task 6.2 and 5.5.

x. Evolution of a Digital Factory belonging to the AI REGIO network towards Industry 5.0. One or more Digital Factories belonging to the AI REGIO Digital Factories network will be selected on the basis of the willingness to support Industry 5.0, in order to adapt the principles of this paradigm. In this context, in addition, the AI REGIO Industry 5.0 platform will be tested and evaluated. This activity will be conducted in collaboration with leader and partners of task 7.2.