POLITECNICO
MILANO 1863

SCUOLA DI INGEGNERIA INDUSTRIALE
E DELL'INFORMAZIONE

Industry 5.0

A first step to find new balance in the market through MADE©

MASTER THESIS IN
MANAGEMENT ENGINEERING

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Academic Year: 2021-2022

Abstract

Despite digital technology has rapidly evolving, the adoption rate of digitalization in the European industry appears to be more gradual, in particular, small and medium-sized enterprises are still far from widespread adoption of Industry 4.0 technologies. However, research and technology leaders are already looking to the Fifth Industrial Revolution or Industry 5.0 given that, over the course of its existence, Industry 4.0 has shifted its attention away from the initial concepts of social fairness and sustainability to digitalization and AI-driven technologies for enhancing production efficiency and flexibility. So, Industry 5.0 can alternatively be regarded as reintroducing the 'human/value-centered Industry 4.0' dimension that was lost and provide a regenerative purpose and a new direction to the technological development in the industrial production aiming the people-planet-prosperity rather than profit only.

A survey of the literature was conducted to explore the first attempts to define Industry 5.0. This methodology enabled us to achieve the overall understanding of the concept and current developments described in multiples reports. The first step of the literature review process was the scoping of search, in which the keyword 'Industry 5.0' was searched in combination with 'sustainab*', 'digital factory', human-centric*' in the scientific database Scopus®, recognized by high quality research hosting.

A strengthening of public-private partnerships, such as MADE© – Competence Center for Industry 4.0, aimed at speeding up economic transformation and collaboration along sustainable lines can encourage European companies and universities to improve. Along with its partners, MADE© could be the starting point to introduce and spread the paradigm of Industry 5.0 towards a more human-centric, sustainable and resilience industry, as it has been considered by some authors not a replacement, but a logical continuation of the existing Industry 4.0.

Keywords: Industry 5.0, human-centricity, sustainability.

Abstract in lingua italiana

Nonostante la tecnologia digitale sia in rapida evoluzione, il tasso di adozione della digitalizzazione nell'industria europea sembra essere più graduale, in particolare le piccole e medie imprese sono ancora lontane dall'adozione diffusa delle tecnologie dell' Industria 4.0. Tuttavia, le aziende leader nei settori scientifici e tecnologici stanno già guardando alla Quinta Rivoluzione Industriale o Industria 5.0 dato che, nel corso della sua esistenza, l' Industria 4.0 ha spostato la sua attenzione dai concetti iniziali di equità sociale e sostenibilità alla digitalizzazione e alle tecnologie basate sull' IA per aumentare l'efficienza e la flessibilità della produzione. Quindi, l'Industria 5.0 puo', in alternativa, essere considerata come la reintroduzione della dimensione dell' "Industria 4.0 incentrata sull'uomo/valore" che era andata perduta, e fornire uno scopo rigenerativo e una nuova direzione allo sviluppo tecnologico nella produzione industriale, mirando alla prosperità delle persone-pianeta piuttosto che al solo profitto.

È stata condotta un'indagine della letteratura per esplorare i primi tentativi di definire l'Industria 5.0. Questa metodologia ci ha permesso di raggiungere la comprensione generale del concetto e degli sviluppi attuali descritti in molteplici reports. Il primo passo del processo di revisione della letteratura è stato l'ambito della ricerca, in cui la parola chiave 'Industria 5.0' è stata ricercata in combinazione con 'sustainab*', 'fabbrica digitale', human-centric*' nel database scientifico Scopus®, riconosciuto da hosting di ricerca di alta qualità.

Un rafforzamento dei partenariati pubblico-privato, come MADE© – Competence Center for Industry 4.0, finalizzato ad accelerare la trasformazione economica e la collaborazione su linee sostenibili può incoraggiare le imprese e le università europee a migliorarsi. Insieme ai suoi partner, MADE© potrebbe essere il punto di partenza per introdurre e diffondere il paradigma dell'Industria 5.0 verso un'industria più umano-centrica, sostenibile e resiliente, in quanto è stata considerata da molti autori non un sostituto, ma una logica continuazione dell'attuale Industria 4.0.

Parole chiave: Industria 5.0, centralità umana, sostenibilità.

″We cannot solve our problems with the same thinking we used when we created them.″

Albert Einstein

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Executive Summary

Introduction

It is well acknowledged that Industry 4.0 concept has been adopted by companies and it is still now being developed, especially by small and medium-sized enterprises that want to remain competitive in the market. However, the current problem of unemployment that is spreading more and more and the Covid-19 pandemic have forced Europe to go beyond the vision defined by Industry 4.0 and try to reach a more inclusive one that is able not only to grow internally through technologies, asl well as to focus on company and environment as a whole. This idea brought the European Union to search for a new concept that is able to deal with the uncertainty of the future and with emerging needs of the society, defining the first guidelines for a new revolution: Industry 5.0 or Fifth Industrial Revolution.

Literature argues that Industry 5.0 will be able not to eliminate but to 'upgrade' the concept of Industry 4.0, since it envisions a workplace where technologies and machines do not replace humans in the daily working activities, but are leveraged for working with them, supporting them for creating a more inclusive and sustainable environment.

Starting from analyzing this new concept and the benefits that Industry 5.0 can bring together with its key enabling technologies, this thesis tries to give an overview of the development of the concept over time, the main pillars of the concept and possible applications it can provide to firms in general and suggests how MADE©[1] could be one of the cradles in delivering this concept to small and medium enterprises.

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[1] MADE©'s Digital and Sustainable Factory supports the enterprises in their digital transformation path towards Industry 4.0. It is part of the Industry 4.0 Italian ecosystem created by the Competence Centers and the Digital Innovation Hubs.

Literature Review

Analyzing current academic and professional writings allowed to divide the literature review part into three main chapters, each one devoted for better comprehending what Industry 5.0 is and the related benefits and challenges. Despite this subdivision, these chapters are seen as an evolutionary narrative to understand how we came to feel the need to face a new revolution, revisiting the society we have created.

Better said, a brief timeline of the industry was needed for understanding the evolution of the societies over time and the related discoveries and technologies. Firstly, the term 'Industrial Revolution' has been defined. In particular, starting from the first Industrial Revolution and arriving up to the last one, so the Industry 5.0, an analysis of how the five Industries occurred in the related periods of time and the corresponding changes the societies have faced have been pointed out.

Considering the well-established Industry 4.0, it is important to understand the main differences that characterize and distinguish the last two Industrial Revolutions that are in place. Foremost, Demir K. A. (2019) and the European Commission's Independent Expert Report (2021) allowed to better understand those differences – and also the similarities -, not only in terms of concept, but also related technologies from Maddikunta P. (2021) and Sanghavi D. (2019) papers. Specifically, were identified the main problems that it raises, such as the increasing unemployment or the achievability and sustainability of this revolution mainly referring to SMEs, as also cited by the European Commission.

Many authors seem to agree that Industry 5.0 should be considered as a logical continuation of Industry 4.0 towards a more efficient in order to fulfill the economic, social and ecological objectives of the green production.

There has been an extensive analysis of existing literature pertaining to Industry 5.0 and its related characteristics, especially three main reports that were published by the European Commission: 'Enabling Technologies for Industry 5.0 – Results of a workshop with Europe's technology leaders' (2020), 'Industry 5.0 – Towards a sustainable, human-centric and resilient European industry' (2021) and 'Industry 5.0 – A Transformative Vision for Europe' (2021). Essentially, it has been analyzed the 'history' of how Industry 5.0 has been conceived by different authors, such as Michael Radar, named as 'father' of the term Industry 5.0; Østergaard E. H., founder of the company Universal Robots; and Demir K. A., since he has contributed to more than one paper on the topic and has covered not only the definition, but the legal and regulatory issues and social, psychological and ethical implications. Subsequently, it has been detailed the core pillars on which I5.0 is based: human-centricity, resilience and environment. I was important as well to understand the relationship with Society 5.0 concept, which has been discussed in Rojas, C. N. et al paper entitled 'Society 5.0: A Japanese Concept for a Super intelligent Society' (2021). Then, essential enabling technologies were introduced to illustrate their significance within Industry 5.0, followed by real-world examples of potential tools and areas of application where I5.0 may be developed to improve existing circumstances.

Case study: Industry 5.0 within MADE

The aim of the study was to identify a possible application of the Fifth Industrial Revolution concept within MADE©, a place where companies can learn about Industry 4.0 and its technologies, as well as how to begin and/or continue their digital transformation for boosting productivity and efficiency, streamline operations, and boost revenues. Since the technologies of interest were mainly present in the Digital Factory area, the study started focusing from there but then enlarged also to the other areas of MADE©.

Objectives

The purpose of this document was to provide a systemic literature review regarding Industry 5.0, as an attempt to provide a more clear understanding on the concept, from its inception to current times, as well as its relation to Society 5.0 and the European Commission priorities. That has revealed that Industry 5.0 concept has to been seen as a must have inside the organization in order to reach efficiency and competitiveness in the market without jeopardizing the future generations. In particular, the inherent features of Industry 5.0 might imply that it needs to be put into practice in order to deal with the new market environment outlined in the research. Given that the technologies presented at MADE© overlaps some technologies from Industry 5.0, a study on a possible application of the concept within MADE© was also performed, as it could be the starting point for SMEs towards a more sustainable industry.

Research Methodology

In order to have a full knowledge and a fully understanding of the addressed concepts, deep research of the literature was performed in order to aggregate common perspectives, opinions, and thoughts, a semantic analysis was conducted. To this end, the literature review search was made in the scientific database Scopus®. Specifically, the scope of search stage of the literature review method involved using the keywords 'Industry 5.0' together with 'sustainab*', 'digital factory', and 'human-centric*', where 22 out of 42 published papers found contains the word 'Industry 5.0' in the title, and 3 of them were officially published by the European Commission. The other papers served as a support to understand better the concept of Industry 4.0, so to perform a comparison between concepts, technologies, and techniques that might not be entitled as 5.0, however the basis is directly linked to it. However, it is crucial to emphasize that due to the novelty of the subject, more papers and articles are still being published in relation to the Industry 5.0 concept and that many materials on this topic have been discovered in web pages (URL).

For what concerns MADE©, Emanuele Barina, project manager representing Siemens in MADE©, was the main reference that helped understanding what the center is and how it works. In particular, through visits in presence, he showed how daily visits are operate, during which each technologies' characteristics are presented to companies.

Findings

From the literature, many authors agreed that Industry 5.0 should now be considered as a replacement of the Industry 4.0 concept, but a chronological continuation, where the industry should not consider only profits, but also people and the planet. In addition, some authors already point the future challenges, such as the gap on skills towards technologies, the creation of new jobs, ethical issues related to the man-machine interactions, and so on.

By analyzing Industry 5.0, comprehensive information was gained that made it possible to reason on a theoretical application of the concept in MADE©.

After analyzing all the collected information, it was concluded that Industry 5.0 can benefit enterprises in a variety of ways:

- Improved and more personalized human-machine interaction
- Minimize inefficiency
- Reduce waste and boost sustainability
- Enhance human potential
- Promote creativity and innovation while minimizing operational risk
- Enhance problem-solving abilities of human/robot partners

These ideas could also be reflected in MADE© and, with the help of gamification elements, it would be possible to improve companies' engagement in the Digital Transformation process, while introducing the concept of Industry 5.0, which according to some authors, should be taken into consideration since the beginning of any transformation process. The reasoning is that, if MADE© includes techniques related to the Industry 5.0 core pillars, such as product life cycle management, product data management, or concurrent engineering, in addition to focusing solely on Industry 4.0 technologies, this could prompt businesses to look further for a solution that would enable them to be in line with these novel concepts and the European Commission priorities.

Conclusions

The purpose of this thesis was to analyze how MADE© may fully benefit from the most imminent Industrial Revolution: Industry 5.0. In particular, the goal is to understand the main differences from Industry 4.0, how the Industry 5.0 concepts could be applied in real-world industrial contexts to achieve efficiency, competitiveness and increase customers' satisfaction. By combining Industry 4.0 technology advancements with Industry 5.0 value-driven initiatives, it will be feasible to create a more human-centric, sustainable and resilient environment. MADE© might serve as the beginning point for SMEs to become more value- and technology-driven simultaneously, as well as more involved in the transformation process, through gamification and a shift in mindset regarding technologies application and methodologies towards the main pillars of Industry 5.0. We believe that Industry 5.0 could be a solution able to help organizations in addressing some of the issues brought on by Industry 4.0, such as the need for general up- and re-skilling and a skills gap, and to correctly implement innovative technologies and their related applications. However, it may also bring other social and ethical issues, which open the field for deeper research.

Introduction

People have always been reliant on technology throughout history, and it has always changed along with the societies. The movement from one industrial method to another, which is typically motivated by technological improvement, has been referred to as the Industrial Revolution. Since the 1870s, this has led to other revolutions until the one we are living in nowadays, the Fourth Industrial Revolution – or simply Industry 4.0 -, an industry based on digitalization and AI-driven technologies. However, in recent years, this concept is being revaluated since it does not fit for purpose in the context of a climate crisis, as Covid-19 pandemic, and planetary emergency due to an excessive exploitation of the resources. In addition, the increasing adoption of AI technologies is bringing companies in reducing the number of operators, pointing out the problem of unemployment and addressing deep social tensions. All this resulted in introducing the Fifth Industrial Revolution – Industry 5.0 -, a new frontier of opportunities for better addressing these new societal and technological issues. Industry 5.0, which was first proposed in 2016 by Michael Rada, who is regarded as its founder, takes into account social, environmental, and societal aspects. By creating a "new normal" with a more sustainable and ecologically conscientious industry, this leads to achieving competitiveness. I5.0 is considered as a logical continuation of I4.0 because the majority of the I5.0's main enabling technologies are also present in I4.0 [4,23]. This does not imply that businesses that have not yet adopted I4.0 technologies would experience a disruption or suffer significant losses. Instead of focusing on technologies, we need a paradigm shift where people are at the center, there is collaboration between people and machines, and there are social and environmental advantages [23].

It is not just the industries that need to change; also, the society as a whole. The idea of a 'super-smart society' or Society 5.0, has been introduced in response to the urgent need to build a society that can adapt to a quickly changing society. In 2016, the most influential industrial association in Japan, Keidanren, introduced the concept of Society 5.0 for the first time. Subsequently, the Japanese government used and promoted this concept in the 'Fifth Science and Technology Basic Plan'. This is a program that aims to connect physical space and cyberspace while utilizing all the potential of new technologies in order to achieve an ideal future society [29]. As a result, it has been made clear that innovation in technology is essential for achieving the shift to Society 5.0 that will be developed, putting an emphasis on each person's wants and abilities.

Industry 5.0 lays its foundation on three main core pillars: human-centricity, sustainability, and resilience. Thus, numerous applications in various fields only now beginning to emerge as a result of the support of several key enabling technologies, going from healthcare and education up to more industrial sectors, as Cloud manufacturing or Circular Manufacturing processes. These outcomes can undoubtedly be improved by aligning with the priorities of the European Commission. It identifies three major Commission priorities to which the Industry 5.0 approach contributes: a people-centered economy, the European Green Deal, and a Europe fit for the digital age.

However, the majority of I5.0 applications as well as the general knowledge are in their early stages. This document put together the first and most recent works related to Industry 5.0 in order to give an overview of the development of the concept over time and its current stage. In the first chapter, a brief history about the industrial revolutions is provided in order to support the understanding of the evolution of technologies and its impact on society. Chapter 2 provides a comparison between the Industry 4.0 and Industry 5.0, as the former is still under development and not completely widespread in the market, especially among SMEs; and the latter has already been introduced by the European Commission and might be mistakenly interpreted. Moving on to the third chapter, the main focus of this document is presented, which is the collection of different perspectives and definitions from researchers and companies' publications regarding the concept of Industry 5.0, from its beginning in 2015 until the launch by the European Commission in 2020. In addition, it is presented the core pillars, its enabling technologies, examples of applications, its relation to the European Commission priorities, and the relation with the concept of Society 5.0. In the fourth chapter, a brief presentation of MADE, a public-private partnership created in 2019 to support companies' on their Digital Transformation, given its potential to become the cradle of SMEs in the understanding and implementation of the Industry 5.0 concept, which leads to the fifth chapter, where it is discussed the possible application of game elements to make MADE's visitors more engaged in the learning and transformation process, as well as the techniques that are in line with this new paradigm.

1. Industrial Revolutions

An Industrial Revolution is the transition from a manufacturing process to another, usually driven by technological progress [7]. Traced back to 1780s in Great Britain, the First Industrial Revolution – also known as Industry 1.0 - was marked by the transition from hand production methods to mechanized systems powered by steam or water [24,42], and the increase on the development of machine tools. As a result, factories were no longer tied up to natural energy sources, such as wind, and goods could be produced regardless of location or season [46]. Before this period, a basic manufacturing process was applied to any product created by an individual or group since humans were able to produce items for their own use or for sale through simple tools, materials, and equipment [90]. For instance, merchants were providing these simple tools, as spinning wheels, needed for producing mainly textiles and threads that were produced at home. This was challenging to control since managing the production and manufacturing large quantities of items were constrained by workers' own schedules [90,92].

Industry 1.0 revolution impacted on different industries like the glass, coal mining, steam navigation, agriculture, and textile industries, thanks to the development of the mechanical loom or the spinning machine. As more entrepreneurs needed loans for investments, banks also gained importance [90,94]. In addition, in the transport sector, steam locomotives made possible to transport goods in shorter and lower costs [46]. According to Maddikunta P. et al (2022, p. 1) this led to "a massive gain in the economy as production capacity has increased".

The main significant drawback was the pressure on the lower working class because there was more demand than supply. In addition, since there was no prior law regulating how factories were to be operated, this resulted in using hazardous equipment and machines which frequently resulted in terrible injuries for workers. Moreover, people had to work extremely long hours, frequently into the night, which increased these risks. The employment of child labor was one of the ugliest aspects of this new industrial age. These circumstances led to the 1833 Factory Act, which restricted the number of hours that children may labor and imposed rules to protect workers [90,97].

In the 1870s, the Second Industrial Revolution (i.e., Industry 2.0) began with electricity, transforming factories into modern production lines primarily focused on mass production, resulting in high productivity and significant economic growth [42]. Moreover, Industry 2.0 led to the development to the introduction of the assembly line. Introduced for the first time by Ransom E. Olds in 1901, the creator of Oldsmobile cars, the company was able to produce 20 units per day, increasing the output by 500 percent more than the previous output and just in one year. As a result, more vehicles were produced at a reduced price. Henry Ford, recognized as the real innovator behind the assembly line and mass production of automobiles, ultimately utilized this approach as the basis for his own car assembly system. In his company, the manufacture of individual parts was substantially faster because each person only needed to do one single manual task in step-by-step procedure and through the support of a conveyor belt, leading to the production of a larger quantity of quality products in a faster and cheaper way [90,94,46]. Furthermore, in order to increase output quality and assure better production management, more strategies and methods were implemented, including better labor division, resource allocation. Tele-communication in offices has improved too since calls and telegrams were used and consequently speeding up many business operations and transfer of information [92,94]. The growth of the modern industry brought huge numbers of migrants from rural communities leading to massive urbanization and an increase in environmental pollution [24].

The Third Industrial Revolution evolved in 1969 with the use of robots, electronic devices, and communication technologies in the production process, leading to the concept of automated production [24,35,42]. "In this expanded digital economy, private enterprises connected to the Internet of Things can use big data and analytics to develop predictive algorithms that can speed efficiency, increase productivity, and dramatically lower the marginal cost of producing and distributing products, making businesses more competitive in the global marketplace" [89]. It focused on partial automation through electrical engineering and information technology, using

Programmable Logic Controllers, also defined memory-programmable controls, and computers [90].

The mass manufacture and the widespread usage of digital logic, MOS[2] transistors, integrated circuit chips, and technologies resulting from them, such as computers, microprocessors, digital cellular phones, and the Internet, are the focal point of this period. Traditional production and commercial practices have changed as a result of these technological advancements. In essence, we can state that the digital revolution transformed analogue technology into a digital format [90].

Back in the 1820's, Charles Babbage and Ada Lovelace laid the groundwork for the independently programmable computer with their Analytical Engine. However, the first operational devices were produced in 1941 after further development. Still during this period, Konrad Ernst Otto Zuse, a German pioneer in computer science, developed the prototype 'Z3', a completely autonomous, freely programmable, and program-controlled computer, and that was developed into the 'Z4' by the ETH Zurich[3] as the 'first commercial use of a computer' [94]. Then, the development became faster and in the early 80s, as mentioned before, calculating machines needed for solving complex equations turned into fully automated personal computer (PC), where the Commodore was dominating the office and household market, replacing the typewriters used in Industry 2.0. Later, new companies as Apple and Microsoft were also established [94].

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[2] Metal Oxide Semiconductor transistor is the building block of digital memories, processors, and logic chips, and it works as a switch, an amplifier, or a resistor.

[3] Swiss Federal Institute of Technology in Zurich (in English) is a public research university founded by the Swiss Federal Government in 1854.

(a) Z4 Computer, 1944

(b) Commodore Computer, 1982

Figure 1: Comparison of computer development.

Electronics and information technology (IT) were integrated into numerous production processes, increasing automation in the manufacturing processes that was further advanced thanks to the expansion of connection and internet access [92]. The software systems enabled the development of a variety of management procedures and since this period, information technology and electronics have been continuously used to develop and automate the systems. The software tools, for instance, made it possible to perform tasks like inventory management, product tracking, enterprise resource planning, product flow scheduling, and logistics for shipping [92]. All these changes in the automation software field replaced many of the manual operations that had previously been done by humans, spreading the problem of mass human unemployment [105], issue that will still be important in the Industry 4.0 age. In the following table it is possible to see summarized the main differences between each of the Industrial Revolution:

	Industry 1.0	*Industry 2.0*	*Industry 3.0*
Period	1760 - 1840	1871 - 1945	1945 - today
Major inventions	Water and Steam engine	Electricity in production processes	Computer and Automation
Firm	Textile and mining	Each king of sector: chemical, mechanical, food, …	Multinational globalization
Source of power	Water and steam	Electricity and oil	Internet technology
Production system	Traditional artisan method	Mechanical machines and Assembly line	Automated systems and Lean manufacturing
Labor	Increase of labor force	Decrease of labor force	Decrease of labor force
Society	Industrial society	Mass society	Industrial society
Symbol	Steam engine and train	Car	Computers and telecommunications

Table 1: Comparison among the I1.0, I2.0 and I3.0.

In 2011 at the Hannover Fair, a project in the high-tech strategy of the German Government introduced the term Industry 4.0 to refer to the Fourth Industrial Revolution, marked by the utilization of the Internet of Things (IoT) and Cloud Computing to enable Cyber-Physical Production Systems (CPPS) to make intelligent decisions through real-time communication [42,5]. According to Sanghavi D. et al (2019, p. 3) "the term 'Industry 4.0' is associated with many other words such as 'smart factory', 'smart manufacturing', 'cyber-physical system' and 'smart machine'. […] This revolution refers to the accumulation of technology incorporate into successive generations of advanced tools and techniques. Industry 4.0 enables the use of all these technologies in a synchronized and efficient manner".

Despite assertions that digital technology has rapidly evolving and becoming increasingly disruptive, the adoption rate of digitalization in the European industry appears to be more gradual, in particular, small, and medium-sized enterprises are still far from widespread adoption of Industry 4.0 technologies [23,4]. However, research and technology leaders are already looking to the Fifth Industrial Revolution or Industry 5.0, as the European industry's competitiveness may be harmed sooner rather than later by insufficient investments in innovation [4].

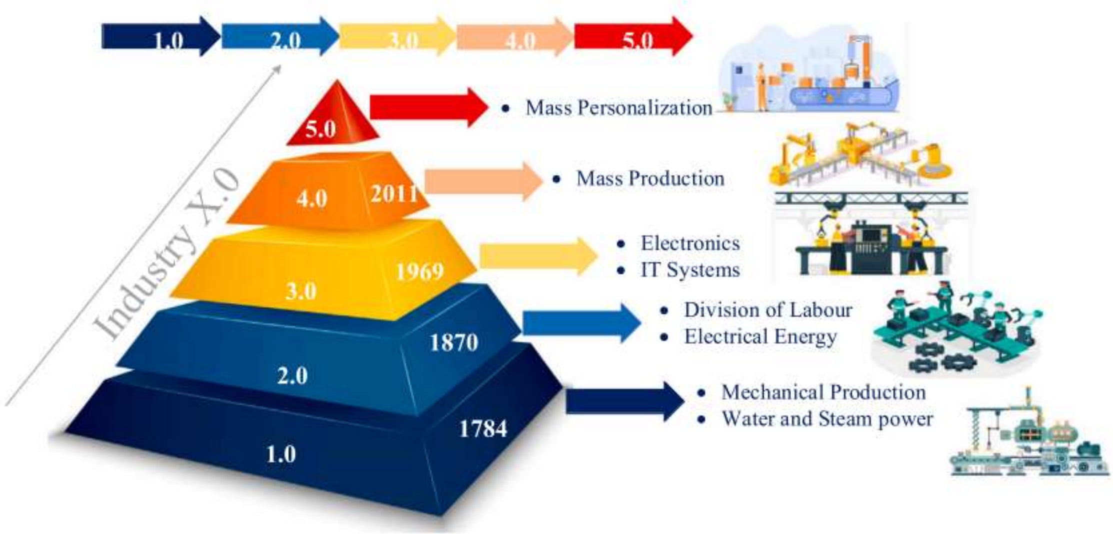

Figure 2: Illustration of industrial revolution [21].

As can be seen in Figure 1, there were 100 years between the first three revolutions and only 40 years between the third and the fourth [6]. Furthermore, it took less than 10 years to start talking about the Fifth Industrial Revolution and it is possible that it is not so far in the future to be widespread.

Michael Rada, dubbed the "Father of Industry 5.0", was one of the first to raise the topic in December 2015. According to Rada, since all machines can operate and communicate with each other autonomously in Industry 4.0, workers appear to be the industry's bottleneck, which may be eliminated. However, humans and the environment are not fed with digits "1" and "0", which are at the heart of all virtual worlds; as well as tools are not fed by humans with brain to work for them, but work with them. Rada named it as 'Industrial Upcycling', in which the concept is a new industry that does not harm the environment and utilize the best in every human being to contribute to development [58].

In 2016, Japan's most powerful Industrial Association, Keidanren, introduced for the first time the concept of Society 5.0 - which was subsequently used and promoted by the Japanese government in the "Fifth Science and Technology Basic Plan" [29] -, as an answer to the Industry 4.0 originated in Germany and given the emerging and urgent need to create a society that can answer to rapidly changes [58].

In September 2020, the European Commission published the results of two workshops done with Europe's research and technology leaders, where the goal was to get feedback on the general concept of Industry 5.0, and to discuss the enabling technologies and possible challenges [23]. The participants agreed that Industry 5.0 has its roots in the concept of Industry 4.0, hence it should not be considered as a replacement, but a logical continuation of the existing Industry 4.0.

Despite the fact that Industry 5.0 is a relatively new concept, there is some early academic material detailing its primary elements. Based on these materials, it is possible to say that Industry 5.0 recognizes the capacity of industry's ability to achieve societal goals beyond jobs and growth to become a resilient provider of prosperity by ensuring that production respects our planet's boundaries and prioritizes the well-being of industry workers. Furthermore, researchers have pointed that only when there is a spark of human creativity that automation can be used to its fullest potential.

In addition, even though the concept of Industry 5.0 was developed prior to Covid-19, it can be viewed as an exemplary challenge that highlights the need to consider concepts such as working methods, local generation of added-value, optimization and the rapid changes in society and the industry [23].

The accelerating pace in the development and adoption of new technologies poses new challenges to business and decision-makers, given that these represent significant opportunity to achieve not only competitive advantage, but also the 2030 Agenda, also known as Sustainable Development Goals (SDGs), which were adopted by the United Nations in 2015 to achieve a better and more sustainable future for all [47]. As a result, it is critical to fully comprehend the concepts and enabling technologies of Industry 4.0 and 5.0 so that there are no gaps and decision-makers can make the best use of these new concepts and technologies to promote new jobs, meet customer needs, and meet environmental and societal requirements. Furthermore, the definitions of Industry 4.0 and 5.0 are still being developed, as rapid technology advancements may confuse the true meanings of those two revolutions.

2. Industry 4.0 vs Industry 5.0

As previously mentioned, an Industrial Revolution is usually marked by technological advancement. The term Industry 4.0 came to light in 2011 by the German Government to represent the Fourth Industrial Revolution, which has the simple and similar goal to previous revolutions: to optimize the production process and achieve mass production by using all innovative technologies, such as Artificial Intelligence (AI), the Internet of Things (IoT), Cloud Computing, Cyber-Physical Systems (CPPS) and Cognitive Computing [6,34,21]. According to Martin (2018, p.3), "the concept outlines a vision of the intelligent factory, characterized above all by real-time control with ICT (Information and Communication Technologies), by the growing use of robots and cyber technology, by the massive application of the IoT to industrial production". Some researchers consider the concept of Industry 4.0 rather marketing-driven than technological-driven, not totally recognizing it as a revolution, because it does not involve any inventions which are based on any great breakthrough scientific discoveries; it is just the upgradation of the machines from Industry 3.0 and integration with cloud computing and big data analysis [23,34].

According to the Boston Consulting Group, Industry 4.0 was possible to be realized thanks to nine key enabling technologies that allow to increase efficiency and flexibility in the production process [21].

Figure 3: BCG Industry 4.0 technologies [21].

These technologies can be combined to one another by implementing centralized systems such as Computer Aided Drafting (CAD), Enterprise Resource Planning (ERP), Manufacturing Executive Systems (MES), Computer Aided Manufacturing (CAM) and Product Lifecycle Management (PLM) [35], which are system models for the collection, planning, storage, and management of company's data in order to support on short and long-term decision making.

In addition to new technology implementation, businesses must establish well-designed processes that consider how technology will optimize departments to allow employees to perform what they do best in order to achieve a successful technological integration. As a result, experts have identified 4 design principles that organizations must adhere to in order to fully profit from Industry 4.0 technology [55].

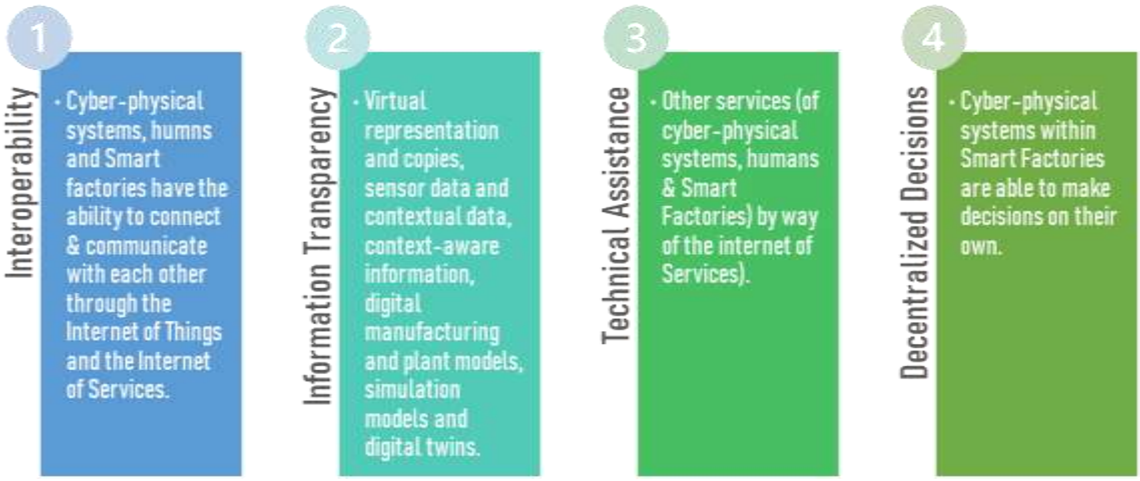

Figure 4: Industry 4.0 Design Principles [6].

Moreover, end-to-end engineering across the entire value chain and new social infrastructures in the workplace are other core aspects which are in the base of Industry 4.0 [21].

The Fourth Industrial Revolution can also be defined as new level of control over the value chain – from research and development to customer care - since it aims at satisfying the increasing individualized customer requirements. According to Sanghavi D. (2019, p. 6), "the goal of the Industry 4.0 paradigm is to setup a network among machinery to allow them to communicate and allow them to make minor decisions without any human interaction". Indeed, "the motto set by Germany Trade and Invest (GTAI) for Industry 4.0 is 'Smart Manufacturing for the Future'" [3]. For example, the concept of a smart factory encompasses modularization, where the system is divided to form a series of subsystems – or modules – which have low levels of interdependencies. With the use of flexibly regulated combinations of standardized modules, new product development lead time and time-to-market can be considerably reduced [7].

Figure 5: The benefits of Industry 4.0 through different sectors [57].

As observed in Figure 4, the benefits of the Industry 4.0 related to productivity increase can be verified throughout different sectors. Moreover, there are other numerous advantages brought from Industry 4.0 [35] which can be listed hereafter:

- Scalability: scalable processes have the ability to adapt to changes in volumes or sixes. IT systems can adapt to new requirements and smaller businesses with fewer resources and budgets for customized hardware or software will benefit from cloud computing.

- Security: cloud computing can handle IoT cognitive and cyber-physical management, eliminating technological concerns.
- Visibility and Control: better collaboration amongst businesses all around the world.

- Satisfied customers: the client is kept informed at all times, from the time the order is placed until it is delivered, including research and development, product recycling, and factory commissioning. It focuses on the needs of the person.

- Customization: commercial 3D printers can now swiftly make changes, create superior components, and fix imprecise design.

Despite of all the benefits above mentioned, the full development of the potential of Industry 4.0 requires its combination with other tools, such as Lean Techniques. The use of sensors and real time data through RFID[4] technology with Cloud Storage enable the access to data without wasting time and to detect disturbances in the manufacturing process line. This enables organizations to detect disruptions in the manufacturing process line, resulting in improved OEE[5] (Overall Equipment Efficiency) and decision-making [34].

According to Saad S. (2021, p. 342), "although there are similarities, it is interesting to note that lean manufacturing is associated with the empowerment of employees and is considered a low-tech approach, contrary to the implementation of higher automation levels in Industry 4.0, which leads to a reduction of manpower". Hence, the increasing level of automation which brings standardization within a production process, leading the reduction of human involvement and consequently a reduction of jobs [35] could be considered as a relevant inadequacy that have now become object of discussion of many authors.

A transformed industry will also have a transformative effect on society. This is especially true for industry workers, whose jobs may be altered or even threatened. New skills will be required as roles change and reliance on complex technologies grows. More substantial changes in the way the workforce is organized will emerge, affecting the traditional education lifecycle of training, job, and retirement for industry workers. Automation may jeopardize industry's societal function as an employment and source of prosperity [4]. Moreover, the rapid pace of change

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[4] Radio-Frequency Identification uses electromagnetic fields to automatically identify, and track tags attached to objects.
[5] Overall Equipment Efficiency is a performance indicator to identify the percentage of manufacturing time that is truly productive, that is, producing good parts with no stop.

requires the implementation of new systems and redesign of production and business processes able to manage huge amount of collected data [35].

Hirsch-Kreinsen et al. and Sachsenmeier (2016), expressed a critique to the Industry 4.0 revolution since they doubt about the achievability and sustainability of it. Indeed, the cost required to implement these new technologies is high, especially to Small and Medium Enterprises (SMEs) [3].

According to the European Commission (2021, p. 10), "advanced globalization has raised global prosperity, but has also increased local inequality, which led to more fragile strategic value chains for critical supplies and infrastructure and has worsened our overuse of natural resources and pollution of the environment" [4].

In addition, the European Commission (2022, p. 5) stated that "the Industry 4.0 paradigm, as currently conceived, is not fit for purpose in a context of climate crisis and planetary emergency, nor does it address deep social tensions. On the contrary, it is structurally aligned with the optimization of business models and economic thinking that are the root causes of the threats we now face" [51].

Furthermore, industry's rising usage of information technology will place a high reliance on the IT sector, making IT firms wealthier, larger, and more powerful, which brings concerns among some people. However, regardless of the state of the economy, IT firms keep growing in strength, since people utilize computers for a variety of functions, particularly in their daily lives. The effects of various industries and IT on one another will be unpredictable. There are also concerns related to the increased autonomy of robotic systems, such as autonomous vehicles, specially related to safety and data privacy [3].

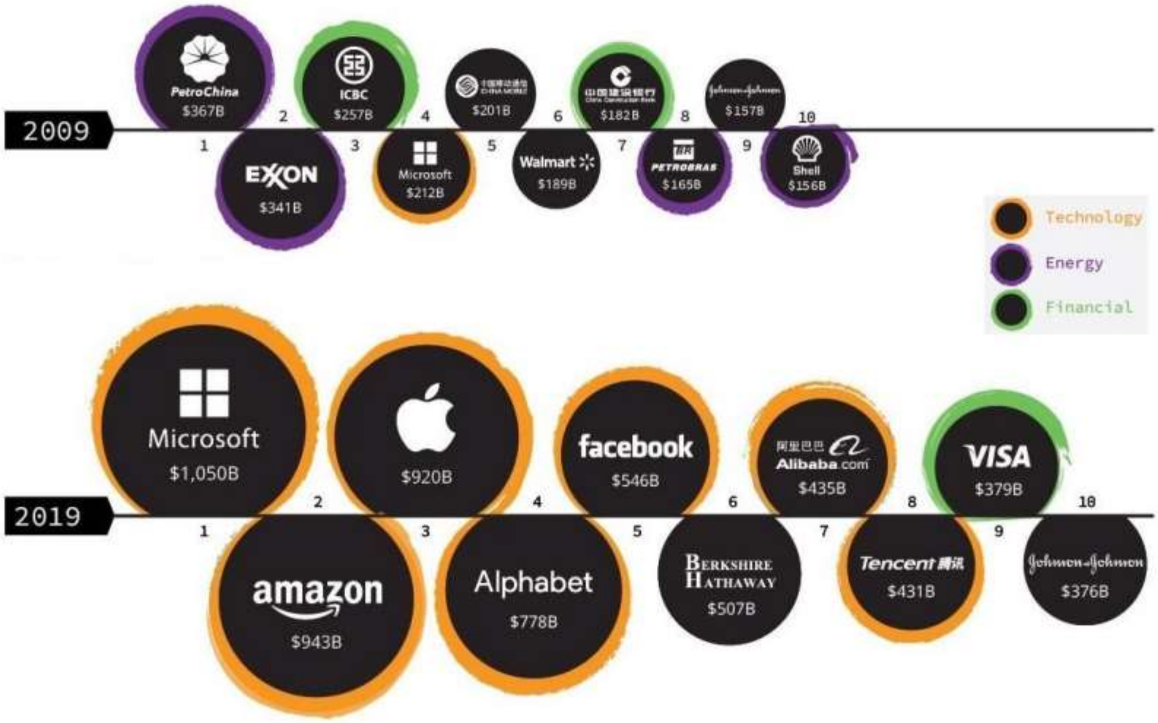

Figure 6: Largest companies by market cap, July 21st, 2019 [4].

To show how quickly and dramatically digital technology has grown in prominence, Figure 5 shows that in 2009, only one tech company was among the top ten publicly traded corporations; in 2019, the entire top-5 was made up of just tech companies. According to the European Commission (2021, p. 10), “for all the good technological innovations have brought, society is now facing the downsides and risks they pose, including threats to our environment, to European values, including democracy itself, and to fundamental rights”.

According to Xu et al (2021, p. 532), “since 2017, scattered academic efforts have been pushing the introduction of the Fifth Industrial Revolution. In 2021, the European Commission formally called for the Fifth Industrial Revolution - Industry 5.0 -, after discussions among participants from research and technology organizations as well as funding agencies across Europe in two virtual workshops organized by Directorate “Prosperity” of Directorate-General for Research an Innovation, on 2nd and 9th July 2020, by the formal release of the document titled “Industry 5.0: towards a sustainable, human-centric, and resilient European Industry”. The participants agreed that Industry 5.0 has its roots in the concept of Industry 4.0, hence it should not be considered as a replacement, but a logical continuation of the existing

Industry 4.0, which was originally linked to how the industry could be more effective in the future in order to stabilize the number of production workers and meet the economic and ecological requirements of the green production [1,4,24]. However, over the course of its existence, Industry 4.0 has shifted its attention away from the initial concepts of social fairness and sustainability to digitalization and AI-driven technologies for enhancing production efficiency and flexibility. So, Industry 5.0 can alternatively be regarded as reintroducing the 'human/value-centered Industry 4.0' dimension that was lost [1,4].

	Industry 4.0	Industry 5.0 (Vision 1)	Industry 5.0 (Vision 2)
Motto	Smart Manufacturing	Human-Robot Co-working	Bioeconomy
Motivation	Mass Production	Smart Society	Sustainability
Power Source	Electrical power Fossil-based fuels Renewable power sources	Electrical power Renewable power sources	Electrical power Renewable power sources
Involved Technologies	Internet of Things (IoT) Cloud Computing Big Data Robotics and Artificial Intelligence (AI)	Human-Robot Collaboration Renewable Resources	Sustainable Agricultural Production Bionics Renewable Resources
Involved Research Areas	Organizational Research Process Improvement and Innovation Business Administration	Smart Environments Organizational Research Process Improvement and Innovation Business Administration	Agriculture Biology Waste Prevention Process Improvement and Innovation Business Administration Economy

Table 2: A Comparison of Industry 4.0 and Industry 5.0 Visions [6].

According to Demir et al (2019, p. 690), two perspectives for Industry 5.0 has emerged, as seen in Table 2. The first is "human-robot co-working", where robots and humans will work together. Humans will focus on tasks requiring creativity and robots will do the rest. The second is "bioeconomy", where smart use of biological resources for industrial purposes will aid to achieve a balance between ecology, industry, and economy [6].

Industry 5.0 provides a regenerative purpose and a new direction to the technological development in the industrial production aiming the people-planet-prosperity rather than profit only [51].

According to the European Commission (2021, p. 11), "in terms of technology, Industry 5.0 wants to come to grips with the promises of advanced digitalization, big data, and artificial intelligence, while emphasizing the role these technologies can play to address new, emergent requirements in the industrial, societal, and environmental landscape. This means using data and AI to increase production flexibility in times of disruption and rendering value chains more robust; it means deploying technology that adapts to the worker, rather than the other way around; and it means using technology for circularity and sustainability".

The vision for Industry 5.0 proposed by the European Commission in December 2021 focusses on human progress and well-being, new form of sustainable, circular and regenerative economy, and equitable prosperity. The shift from Industry 4.0 requires new economic orientations, new design for business models, value chains and supply chains, new approaches to policymaking and new capabilities and approaches to research and innovation [7].

Industry 4.0	Industry 5.0
• Centered around enhanced efficiency through digital connectivity and artificial intelligence. • Technology – centered around the emergence of cyber-physical objectives. • Aligned with optimization of business models within existing capital market dynamics and economic models – i.e., ultimately directed at minimization of costs and maximization of profit for shareholder. • No focus on design and performance dimensions essential for systemic transformation and decoupling of resources and material use from negative environmental, climate and social impacts.	• Ensures a framework for industry that combines competitiveness and sustainability, allowing industry to realize its potential as one of the pillars of transformation. • Emphasizes impact of alternative modes of (tech) governance for sustainability and resilience. • Empowers workers through the use of digital devices, endorsing a human-centric approach to technology. • Builds transition pathways towards environmentally sustainable uses of technology. • Expands the remit of corporation's responsibility to their whole value chains. • Introduces indicators that show, for each industrial ecosystem, the progress achieved on the path to well-being, resilience, and overall sustainability.

Table 3: Differences between industry 4.0 and industry 5.0 [7].

In Table 3, the European Commission [7] compares and contrasts Industry 4.0 and Industry 5.0. This brief comparison reveals that Industry 5.0 will have a much broader and deeper impact on society. It is worth noticing that neither of these industrial revolutions has yet to occur and this comparison is based on the most recent debates.

It is also worth mentioning that Industry 4.0 was about mass customization, while Industry 5.0 will be about mass personalization [79]. While both terms aim to achieve the same goal – meet customer's requirements -, the paths to reach this goal are different. Customization is the action made by the user of modifying something to suit a particular individual purpose; while personalization is the company's action to tailor an experience based on a customer's previous behaviors. Hence, the difference lies with who is making the changes [53].

Personalization	**Customization**
Controlled by company	Controlled by user
Relies on data	Relies on user choice
Requires no conscious input	Requires conscious input
Involves no effort from user	Involves effort from user

Table 4: Difference between Personalization and Customization [52].

Even though the concept of Industry 5.0 was developed prior to Covid-19, it is a paradigm-shifting model that reflects the post-Covid thinking, as it incorporates lessons learned from the pandemic as well as the need to develop an industrial system that is more resilient to future shocks and strains [1,4,7]. In addition, the pandemic has brought attention the need to reconsider current working methods and approaches.

Research based on a survey of senior manufacturing professionals made by 'The Manufacturer' commissioned by IBM highlighted the impact of the COVID-19 pandemic in company's Digital Transformation priorities. "Pre-2020, the majority of manufacturers were focused on a handful of core strategic imperatives: improving operational efficiency and resilience, identifying cost savings, customer growth and strengthening supply chain integrity/visibility", as seen in Figure 5 [11].

Figure 7: Manufacturing decision makers significant business imperatives [11].

Due to the nature of industrial environments, health and safety are essentials components of any production activity. COVID-19 has elevated this significance to new heights. Workers had to quickly adapt to remote working, new processes to remain onsite, or both, on top of their concerns for themselves, their families, and their livelihood. "Many of those surveyed acknowledged the significantly greater emphasis their organization now places on employee wellbeing and the work environment compared to 12 months previously" [11].

Figure 8: Pandemic priorities [11].

In essence, Industry 5.0 takes into consideration learnings from the pandemic and the need for a more resilient industry as well as the integration of the European Green Deal – explained in more details in chapter 3.6.2. -, social and environmental principles.

Despite Industry 4.0 is only getting started, researchers have pointed out the weaknesses of it and have been proposing Industry 5.0 as a solution to these flaws. One reasonable conclusion could be that Industry 4.0 have been implemented without adequate vision and pushed upon the industry [5]. In one hand, Industry 4.0 appears to be currently aiming for smart mass production. On the other hand, the fundamental subject in Industry 5.0 is sustainability [5,42]. Combining these two goals may thus be a superior strategy since sustainability and mass manufacturing are not mutually exclusive concepts [5].

3. Industry 5.0

As previously mentioned, the current version of the Industry 4.0 paradigm is unsuitable for purpose in the face of a climate crisis and planetary emergency, and it fails to address profound social tensions. On the contrary, the core causes of the current dangers are structurally aligned with the optimization of businesses models and economic thinking [51].

A narrow focus on profit in a globalized world fails to account for environmental and societal costs and benefits effectively. Industry's actual aim must encompass social, environmental, and societal factors if it is to become a true provider of true prosperity for all parties (i.e., investors, workers, customers, society, and the environment) [4,23].

In addition, the industry must establish circular processes that re-purpose, recycle and reuse natural resources, as well as reduce waste and environmental impact in order to avoid natural resources depletion and degradation, and meet the demands of current generations without jeopardizing the needs of future generations [4].

Michael Rada, the founder of Industry 5.0, came up with the term for the first time in December 2015 in a LinkedIn publication entitled 'Industry 5.0 - From Virtual to Physical'. In this publication, Rada criticizes the fact that Industry 4.0 puts at the margin the human by considering it as the 'bottleneck'. He introduced the need of creating a system in which there is human-machine collaboration, where hands, hammers, and cutters, as well as computers, 3D scanners and printers are used as tools, not to work for us, but work with us. He referred to this system as 'Industrial Upcycling' and stated that the tools and environment of the industry are not virtual but physical [58]. As a result, numerous researchers, technology enterprises, and governmental entities began to debate Industry 5.0 in an attempt to come up with a definition of the concept, as well as understand its similarities and differences from Industry 4.0 concept and enabling technologies.

In May 2016, Østergaard E. H., founder of the company Universal Robots, published an article in the company's blog entitled 'Industry 5.0 – Return of the human touch', stating that while robots excel in standardized procedures, adding that 'special something’ to each and every product is a task for which robots require assistance. As a result, he “recognizes the need to bring back the human touch to production processes” [15,27,66].

In June the same year, Prime Creative Magazine published an article entitled ‘Bringing back the human touch: Industry 5.0 creating factories of the future’, sharing the same point of view stating that “in production processes, automation can be used to its fullest potential only when there is a spark of human creativity influencing the process”. Moreover, while Cobots[6] (Collaborative Robots) are beneficial in taking over monotonous, repetitive, or dangerous jobs, human workers move into higher value when it comes to customization. Hence, it is crucial to keep the human touch in production processes [30].

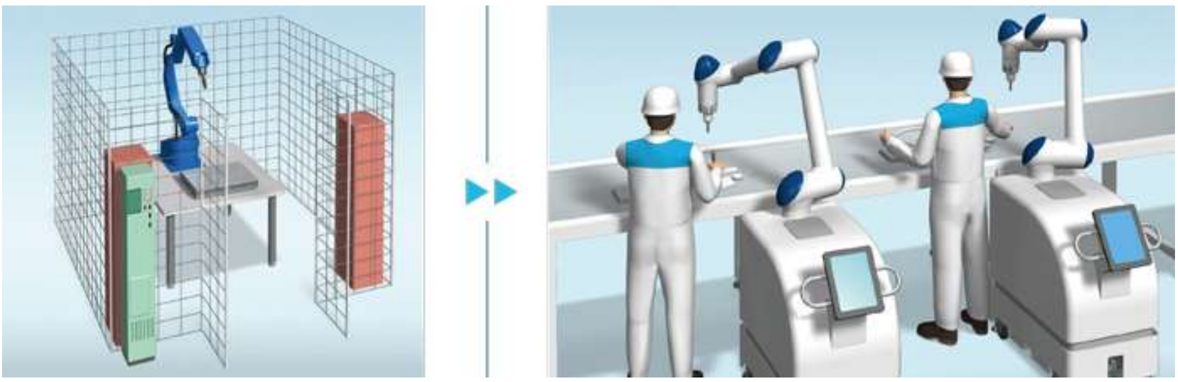

Figure 9: Industrial Robot vs Collaborative Robot [65].

At the same time, in Japan, the concept of Society 5.0 has been introduced for the first time by Keidanren, Japan's most powerful Industrial Association, in 2016, and subsequently used and promoted by the Japanese government in the Fifth Science and Technology Basic Plan [29], which is a program whose aim is to connect physical space and cyberspace, taking advantage of all the potential of new technologies in order to achieve an ideal future society [1].

[6] A Cobot is a robot intended for direct human robot interaction within a shared space, or where humans and robots are in close proximity. Cobot applications contrast with traditional industrial robot applications in which robots are isolated from human contact.

In particular, Japan, which defines its strategy to guide technological innovation processes in the proposed future Society 5.0, "has decided to put technological innovation in the spotlight based on the fact that it can be fully considered as a tool for social innovation and not just a factor leading to changes in firms and business processes" [1]. As a result, it has been explicitly stated that technology innovation is critical to realizing the transition to Society 5.0. This topic will be discussed in more detail in chapter 3.2.

In February 2017, Michael Rada published another article called 'Industry 5.0 definition', where he stated that "Industry 5.0 is future, but already penetrating trend, of change processes directing towards closer cooperation between man and machine, and systematic prevention of waste. Industry 5.0 priority is to utilize efficiently workforce of machines and people, in synergy environment". According to Rada, Industry 4.0 focuses on high volume and mass production, while Industry 5.0 focuses on life standard, creativity and high quality [64]. In the same post, Rada also presented the 6R methodology (i.e., Recognize, Reconsider, Realize, Reduce, Reuse, Recycle) and L.E.D. principles (Logistics Efficiency Design) as tools of the design principles for Industry 5.0 [64].

Figure 10: 6R Principles [64].

In one side, the 6R methodology is considered a sequence of actions to follow taken from the 3R principles (i.e., Reduce, Reuse, Recycle) applied mainly in the waste management industry, and they define a business improvement model, that can be a business process improvement or a business process innovation [5]. On the other side, the L.E.D. principles are designed for Global Supply Chain efficiency improvements. The principles are transparency, profit sharing and efficiency and their goal is to eliminate the waste created by the modern standard buyer-seller business relations. Together, they can be applied both inside and outside Industry 5.0, almost in all life and business cycles [64].

Based on those early discussions regarding Industry 5.0, Demir K. A. and Cicibas H., on behalf of the Istanbul University in Turkey, published a paper in 2017 in the 4th International Management Information Systems Conference 'Industry 4.0' entitled 'Industry 5.0 and a critique of industry 4.0', where they first pointed out that a study indicated that Small and Medium Enterprises (SMEs) find Industry 4.0 irrelevant. In addition, SMEs are in disadvantage compared to big corporations when it comes to costs to deploy technologies such as IoT, robotics and big data [5]. Then, the authors reinforce that Industry 5.0 emphasizes a superior quality of life and creativity through high-quality personalized items, seeking not only of people involved in industrial processes but of society as a whole, and that sustainability is the central subject of Industry 5.0. The latter is also at the heart of the bioeconomy vision of the European Commission [24,26,30]. According to the European Commission (2012), "bioeconomy is the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products, and bioenergy. It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries. Its sectors have a strong innovation potential due to their use of a wide range of sciences (life sciences, agronomy, ecology, food science and social sciences), enabling and industrial technologies (biotechnology, nanotechnology, information, and communication technologies (ICT), and engineering), and local and tacit knowledge" [5]. Demir K. A. and Cicibas H. also mentioned the 6R methodology and the L.E.D principles, adding the four types of waste identified in 'Industrial Upcycling' (Figure 10).

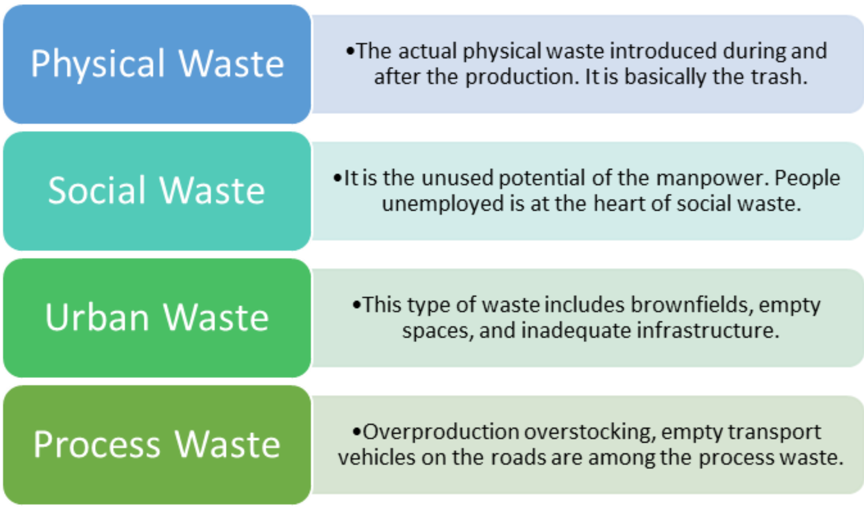

Figure 11: Industry Upcycling Four Wastes [5].

Atwell C. also published an article in the Endeavor Business Media Trade Journal in 2017 entitled 'Yes, industry 5.0 is already on the horizon', where he mentioned Østergaard's point of view and adds that manufactures have been expanding the human component, not only for personalization, but also for better production efficiency, where an example is "Toronto's Paradigm Electronics, which manufactures high-end loudspeakers [27]. The company uses Universal Robots' UR10 robotic arm to polish the speaker cabs to a high-luster sheen, but it takes considerable time to do so. By adding a human counterpart, however, it increased its production efficiency by 50%" [2].

In 2019, Østergaard E. H. sustained the importance of the human touch in the production process in another article entitled 'Welcome to Industry 5.0', published by Quality Magazine, and where he added that "customers choose from a growing list of options. This set of choices is configured and packed in just the right order. […] This is Industry 4.0, where workers are expected to work like 'programmed' machines by management to perform a number of tasks, […] and it would not surprise me if a lean analysis of this type of factory were to find that it wastes human problem-solving skills, value-adding human creativity, and the critical and exclusively human ability to deeply understand customers", reinforcing that mass personalization can only be achieved when human touch returns to manufacturing [27].

Other researchers, such as Nahavandi S., on behalf of the Institute for Intelligent Systems Research and Innovation of Deakin University in Australia, published a concept paper in 2019 entitled 'Industry 5.0 – a human-centric solution', where they also highlighted the importance of the human brainpower and creativity to increase process efficiency when combined with intelligent system [15,24] and added that, besides Cobots interacting with humans, "when accounting for uncertainty in the process, Digital Twins[7] present an immense opportunity by allowing reduced wastage in the process flow and system design. Coupled with state-of-the-art visualization and modelling techniques, technologies such as Digital Twins are set to increase the productivity of all sectors in any industry". Hence, the visualization and modelling of the production line is an extremely important tool for developing regulations as well as managing and personalizing future products and product lines. Furthermore, Nahavandi S. declared as well that "Industry 5.0 will create a new manufacturing role: Chief Robotics Officer (CRO). A CRO is an individual with expertise in understanding robots and their interactions with humans. […] I will also create many jobs in the field of Human Machine Interface and Computational Human Factors Analysis".

Figure 12: Digital Twin application in a production line [69].

[7] A Digital Twin is virtual model of a process, product or service.

Collaborative Robots, Digital Twin and other Industry 5.0 enabling technologies are presented more in deep in chapter 3.3.

Demir K. A., on behalf of the Gebze Technical University in Turkey, also published a paper in 2019 entitled 'Industry 5.0 and Human-Robot Co-working', in the 3rd World Conference on Technology, Innovation and Entrepreneurship (WOCTINE) where he stated that "one emerging theme for Industry 5.0 is human-robot co-working. At this point, we cannot be sure what the theme of Industry 5.0 will be. But we can be sure that human-robot co-working will be a significant innovation for society, and it will significantly affect the way we conduct business" [6]. In addition, he provided a comparison between Industry 4.0 and Industry 5.0 – as previously seen in chapter 2 -, and pointed some issues related to the integration of robots into organizations, such as significant changes in organizations in terms of structure, behavior, workflow, ethics, privacy and trust in a human-robot co-working environment, redesign of the workplaces, education, and training, and so on [6]. Moreover, Demir pointed out the fact that, different dictionaries provide different definitions of what a robot is, which indicates that we don't have yet a satisfactory definition of it. As a consequence, the lack of the necessary regulations having into consideration a proper definition of what is a robot might create problems. "While there are scientific definitions for the robot, only a legal definition of a robot is binding for businesses and organizations" [6].

Aside the legal and regulatory, Demir also presented other issues, such as social, psychological, and ethical implications, changing role of human resources and information technology, learning and competition with robots [6], which are not covered in this paper, nevertheless they could be considered for further studies.

In the first months of 2020, the Covid-19 pandemic has emphasized the necessity to reconsider current working methods and procedures, especially global supply chain vulnerabilities, in order to create businesses more resilient, sustainable, and human-centric [42]. This event led Europe to consider the concept of Industry 5.0 in the way of production and the key role of human beings in the production process, as well as Society 5.0, seeing the necessity to reshape the society [79]. "We have vaulted five years forward in business digital adoption in a matter of around eight weeks" (McKinsey, 2021, as cited in Keever, J., 2021). Hence, in September the same year, the European Commission published the results of two workshops done with Europe's research and technology leaders, where the goal was to get feedback on the general concept of Industry 5.0, and to discuss the enabling technologies and possible challenges [23]. The document entitled 'Enabling Technologies for Industry 5.0' highlights that Europe recognizes Industry 5.0 as in co-existence with Industry 4.0, able to complement and extend it to make it more adaptable to the industries and emerging societal trends and needs [42].

According to the two workshops' talk, the following aspects of Industry 5.0 were highlighted, in particular [23]:

- Human and technological skills and strengths are combined for the mutual advantage of industry and workers, with technology complementing rather than replacing humans. This enables humans to solve problems creatively, take on new jobs, and improve their abilities in safer, more pleasant, and ergonomic work situations.

- The primary concept underlying Industry 5.0 is to select technologies based on how they support human values and needs, rather than what they can do from a purely technical or economic perspective.

- To create products and services, technologies such as human-machine interfaces, integrating human brain capacities with AI, and collaboration with robots and machines are used. Closed loops, energy self-sufficiency, emission-neutrality, and the Circular Economy can all be achieved with these products and services.

Furthermore, the participants of the workshops, which included Research and Technology organizations from across Europe, held a discussion on the concept of Industry 5.0 based on the preliminary definition [23]:

"Industry 5.0 recognizes the power of industry to achieve societal goals beyond jobs and growth to become a provider of prosperity, by making production respect the boundaries of our planet and placing the wellbeing of the industry worker at the center of the production process".

European Commission, 2020.

Unlike Industry 4.0, Industry 5.0 emphasizes a systemic approach rather than individual technologies and it positions the industry worker's well-being at the core of the production process, allowing it to meet societal goals beyond jobs and growth [1]. "For example, the primary focus of technologies used should not be to replace the worker on the shop floor, but to support the workers' abilities and lead to safer and more satisfying working environments" [23]. Thanks to this, "there will be a creative human touch on the production instead of a standard robotic production and new jobs will be created". That is the reason why people are referring to it also as 'mass personalization' [5,15].

Previously to the publication of the European Commission, Longo F. et al published in June 2020 in the MDPI journal of Applied Sciences, an article entitled 'Value-oriented and ethical technology engineering in Industry 5.0: a human-centric perspective for the design of the factory of the future', where they stated that "the Age of Augmentation (Industry 5.0) will be focused on the cooperation between human intelligence and cognitive computing and on treating automation as a further enhancement of the human's physical, sensorial, and cognitive capabilities" which is needed to process, understand and analyze the increasing amount of data collected [18].

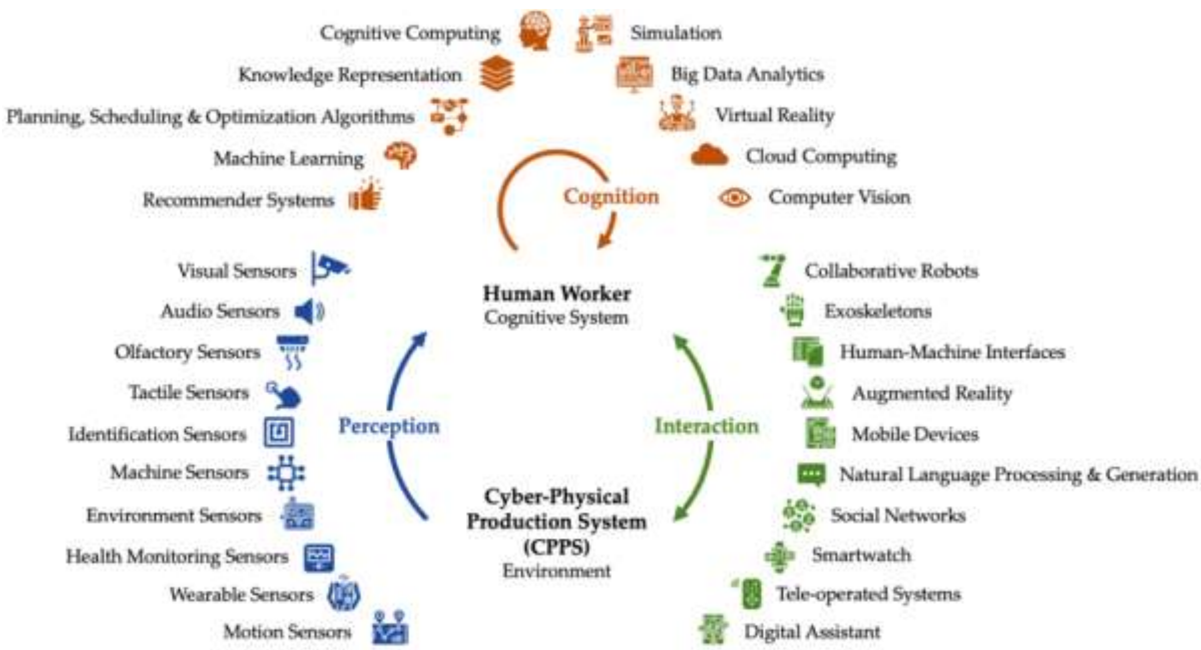

Figure 13: Human-machine symbiosis: technology-augmented human capabilities as part of a cognitive process [18].

The authors also presented what is known as 'Value Sensitive Design (VSD)', which is an approach that aims to consider the values not only of the users, but of all others impacted by a technology – regardless of whether those individuals will ever actually use the technology [18,29]. They stated that the VSD could be used "as the theoretical and methodological framework to guide the design of the Factory of the Future in the perspective of Industry 5.0". In addition, "VSD methodology aims to be fundamentally proactive and anticipatory, engaging with stakeholders to guide technological development in Industry 5.0". VSD research has also produced a list of human values that may be relevant to technology design, as shown in Table 3.

Human Value	Technology Shall Be Designed to…
Self-actualization	…enable the workers to accomplish their own goals and obtain personal success, to demonstrate their own capabilities and competence in order to advance their career.
Accountability	…ensure full transparency of how the symbiotic CPPS operates and makes decision. I includes that the actions of a worker or group of workers is shared transparently to ensure that any problem can be traced back to the cause.
Trustworthiness	…be honest, trustworthy, reliable, and avoid systematic bias, thus performing its required function under given conditions for a stated time interval, as well as to improve interpersonal trust in a human-machine hybrid system.
Privacy	…ensure informational privacy, respect for the worker's private sphere and the right to determine what information can be communicated to others through informed consent.
Welfare	… ensure worker's health (physical well-being and peaceful psycholgical state) also thanks to a proper work-life balance, a balanced workload and a confortable and pleasant work environment.
Autonomy	...allow workers to be independent, free and flexible while at work in order to express themselves, engage in autonomous thinking, make independent activities, utilize their creativity and fully use their own intelligence.
Altruism	…enhance teamwork and mutual care among the workers and to favour the wellbeing of all those one comes into contact with during one's professional activities, thus demonstrating oneself as sincere, open to helping and responsible.
Common Good	…ensure environmental welfare and sustainability as well as to contribute to the beauty of the world and make good things.
Security	…provide a secure return (economic or abstract) to the workers and preserve order, stability and harmony within the physical environment, work-related relationships and professional activities.
Stimulation	…keep stimulating workers with challenging, various and novel tasks, that require continuous learning and professional growth and may sometimes require even a certain level of risk.
Sociability	…stimulate good social relationships and interactions with fellow workers, thus working in a social environment rather than in isolation.

Identity	…to ensure people's equality, universality, respect and inclusion and avoid discrimination of any kind. It also required proper actions to guarantee to everyone the same possibilities of others as well as certain amount of human control over the events.
Authority	…allow workers to attain and/or exercise a prestigious or authoritative position and/or social status that increases one's influence or ability to control other members of the organization and resources.
Conformity	…support the workers to respect rules and expectations, thus demonstrating social discipline and loyalty. At the same time, it shall restrict one's actions and/or conditioning one's choice, inclinations, impulses and desires.

Table 5: Values to uphold during techno-social change towards human-machine symbiosis in Industry 5.0 [18].

The evolution of Industry 5.0 concept has also been influenced by European political agendas. In January 2021, the European Commission published another paper entitled ‘Industry 5.0 - Towards a sustainable, human-centric and resilient European industry’. To be competitive, the European industry must continue to innovate. It needs to invest in the future to overcome the economic challenges given by the coronavirus crisis and develop a “new normal” with a more sustainable and environmentally conscious industry [4,23]. The notion of Industry 5.0 is centered on values such as human-centricity, environmental, and social benefits, rather than technologies. This paradigm shift is founded on the premise that technologies can be tailored to support values, rather than the other way around, and that technological revolution can be created to meet societal requirements rather than vice-versa [23]. This increases the level of complexity and the need for policy setting at a governance level, aiming to better frame and steer the ongoing revolutions, maximize their benefits for European society and mitigate the emerging risks they pose [4]. This is reflected in the current European Commission’s top priorities: the ‘Green Deal’, an all-encompassing strategy to make Europe climate-neutral by 2050, and the ‘Europe Fit for the Digital Age’, which aims to boost technological innovation while introducing new and updated rules for technology and the digital economy [4]. Those and other governmental priorities are further discussed in chapter 3.6. Furthermore, customers must be encouraged to make informed decisions about the technologies and products they use in order to improve their trust in new technologies, as individual trust in technologies grows in tandem with one’s ability to maneuver them, necessitating extensive training and upskilling across supply chains [23].

In an interview given to the Oil & Gas News Magazine in June 2021, Brent Kedzierski, Head of Learning Strategy and Innovation at Shell, stated that a completely autonomous industry is complex and nonlinear, in which conditions will constantly be uncertain and "This is where humans come into play. Hyper complex and interconnected production environments cannot be achieved or sustained without human intervention to see patterns and drive operational planning" [15]. He also pointed the power of humans and collaborative robots working together to create value across industry and added that automation leverages humans' knowledge and thinking process.

As a result, Industry 5.0 enhances and expands on the key elements of Industry 4.0. "It emphasizes aspects that will be deciding factors in placing industry in future European society; these factors are not just economic or technological in nature, but also have important environmental and social dimensions" [4].

In July 2021, Nardo M. and Yu, H. published an editorial entitled 'Special issue – Industry 5.0: the prelude to the sixth Industrial Revolution' in the MDPI Journal of Applied Science and Innovation, where besides the discussion regarding different authors perspectives on Industry 5.0, they also stated that "With the introduction of the concept of Industry 5.0 in Europe, although the focus of Industry 5.0 is still industrial, it is difficult to avoid being compared with Society 5.0. Thus, the comparison between Society 5.0 and Industry 5.0 is bound to cause an uproar" [26].

Maddikunta P. K. R. et al [21] also published an article in the Journal of Industrial Information Integration entitled 'Industry 5.0: a survey on enabling technologies and potential applications', where they put together different definitions of Industry 5.0 from various practitioners and researchers – including some above mentioned in this chapter:

"Industry 5.0 is a first industrial evolution led by the human based on the 6R (Recognize, Reconsider, Realize, Reduce, Reuse and Recycle) principles of industrial upcycling, a systematic waste prevention technique and logistics efficiency design to valuate life standard, innovative creations and produce high-quality custom products".

Michael Rada, 2017.

"Industry 5.0 is the age of Social Smart factory where Cobots communicate with the humans. Social Smart Factory uses enterprise social networks for enabling seamless communication between human and CPPS[8] components".

Koch, P. J. et al, 2017.

"Industry 5.0 brings back the human workforce to the factory, where human and machine are paired to increase the process efficiency by utilizing the human brainpower and creativity through the integration of workflows with intelligent systems".

Nahavandi, S., 2019.

"Industry 5.0 compels the various industry practitioners, information technologists and philosophers to focus on the consideration of human factors with the technologies in the industrial systems".

Friedman, B and Hendry, D., 2019.

"European Economic and Social committee states that the new revolutionary wave, Industry 5.0, integrates the swerving strengths of cyber–physical production systems (CPPS) and human intelligence to create synergetic factories. Furthermore, to address the manpower weakening by Industry 4.0, the policymakers are looking for innovative, ethical and human-centered design".

Longo, F. et al, 2020.

"Industry 5.0, a symmetrical innovation and the next generation global governance, is an incremental advancement of Industry 4.0 (asymmetrical innovation). It aims to design orthogonal safe exits by segregating the hyperconnected automation systems for manufacturing and production".

Leong, Y. K et al, 2020.

Some companies have also started to discuss Industry 5.0. Sigga Technologies, an American consulting company in digital transformation, stated in the company's

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[8] Cyber-physical Production Systems are related to interlink the entities of the production system (e.g. machines) as well as to decentralized production control.

blog that the main idea of Industry 5.0 is to use Industry 4.0 technology to bring benefits to human beings [79]. Siemens also published in the blog section of the company's website an interview with Dr. Bert Pluymers, Senior Industrial Research Manager at the Department of Mechanical Engineering at KU Leuven, regarding the future of engineering, rising the topic of Industry 5.0, which according to the interviewee, encompass trends like digitalization, sustainability, innovation, and AI [49]. This interview in particular is explored in more details in chapter 5.1.

In December 2021, the European Commission published an independent expert report entitled "Industry 5.0: a transformative vision for Europe – governing systemic transformations towards a sustainable industry" where it was discussed how to ensure that European industrial development can be resilient while enabling and speeding up the transition to an age of sustainable wellbeing for all. This is an important step for the future of the European industrial strategy [7]. According to the report, Industry 5.0 entails a radical shift from neo-capitalism's focus on profit towards a more balanced perspective of value and understanding of capital, including human, natural and financial. The European Commission stated that "without a profound industrial transformation, it will be impossible for Europe to realize its ambition to become a more resilient, sustainable, circular, and regenerative economy[9] while preserving and nurturing its competitiveness at the international level" [7,51]. Applying these principles is not a zero-sum game between profit and the environment, but rather a model that allows both to coexist.

Still in the December 2021 report, the European Commission once more emphasized that global warming and the devastation of the natural environment, resources, and systems that humans and millions of other species rely on are the results of current paradigms of value-extracting economic, social, and industrial activities [7]. Hence, Europe has been facing a triple imperative: protect, prepare, and transform. The latter is of great importance to build a path to prosperity in the medium and long-term, and to achieve the objectives of the climate law. Transformation, in a systemic point of view, entails transformation of business models and mindset, economic

[9] According to the World Economic Forum, it refers to business practices that restore and build rather than exploit and destroy, aiming on net-zero carbon emissions and net-positive impacts on the planet.

approaches in policy, finance investment and corporate governance [4,7]. "This shift can be achieved by adopting a process-oriented whole system approach that restores, renews, and revitalizes energy, materials, and natural ecosystems. The process-oriented whole system approach requires building on economic models that enhance sharing, re-use, repair, re-manufacturing, re-sale, and recycling for products based on technical/non-biological materials" [7].

The European Commission also highlighted key design and performance dimensions that are missing in Industry 4.0 paradigm, such as:

- The circular economy and positive restorative feedback loops should be a key pillar of the design of entire value chains and not an afterthought.

- A social dimension, in which technology complement human capabilities instead of substituting it and aiming the workers wellbeing.

- An environmental dimension, aiming to eliminate the use of fossil fuels, promote energy efficiency, restores biodiversity and so on.

The European Commission has called the current digital transformation with sustainability and climate action as "Twin Transition". In addition, through the Economic and Societal Impact Report (ESIR), the European Commission proposed an Industry 5.0 action plan [7], in which the industry – alongside with other stakeholders -, is responsible for:

- Deep transformation of business models where sustainability is a natural component and driver of competitiveness.

- Changes in the mind-set and economic approaches to policy, finance investments and corporate governance.

- Fundamental redesign of value chains to embrace new technological possibilities and sustainability, as well as circular economic and societal well-being.
- Adoption of metrics and indicators that allow for the measurement of progress towards the vision.

- Transitioning from a narrow "energy efficiency first" principle to a wider "resource efficiency first" principle.

- Design reshoring of economic activities in such a way that it will reduce the overall carbon and material footprint of the supply chain.

- Harness digital technologies to deliver on climate commitments, bringing digital and green properly together.

- Greater emphasis in policy and measurement of economic activity on the material/real economy over financial metrics to optimize 'return on material assets', 'return on invested energy', 'return on natural assets' and 'value of human capital'.

- A system of due diligence for all value chains that bring their products into the EU Single Market.

It is possible to already see some action from some companies, such as PepsiCo., which in 2021 has announced the goal to spread the adoption of regenerative farming practices across 7 million acres until 2030 as part of their Sustainable Farming Program [88]. According to PepsiCo., many of its brands are driving investments in creative and sustainable agriculture solutions, "for example, PepsiCo's Walkers brand in the UK worked with CCm Technologies to introduce new 'circular potatoes[10]' technology that uses potato peelings to manufacture low-carbon, nutrient-rich fertilizer" [88].

As can be seen, despite the fact that Industry 4.0 is still under progress, it has been deemed unsuitable for today's economic, social, and environmental issues. As a result, the European Union has formally launched 'Industry 5.0', which can be considered as the reintroduction of the 'human-centered' dimension that was lost in Industry 4.0. Based on above definitions, we can conclude that Industry 5.0 is

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[10] https://www.pepsico.co.uk/news/stories/cutting-carbon-emissions

human-led industrial systemic transformation based on the so-called social smart factory, in which combines human brainpower and creativity with digital systems to improve process efficiency, produce high-quality personalized products, and reduce waste and environmental impacts. In order for this to happen, the industry must transform its business models and mindset in an innovative approach, considering factors such as human progress and well-being, sustainability, circular and regenerative economic value generation, and fair prosperity from the start.

3.1. Core Pillars

As briefly introduced in the previous chapter, the focus of Europe is to put the well-being of the worker at the center of the production processes and to use new technologies to provide prosperity beyond jobs and growth, while respecting the planet's production limits. As such, "industries must adapt, evolve and embrace the green and digital transition to remain competitive and remain engines of prosperity" [56].

Industries must adapt, evolve, and embrace the green and digital transition to remain competitive and remain engines of prosperity. Based on this definition, Europe defines three main core pillars on industry 5.0: Human-centricity, Sustainability and Resilience.

3.1.1. Human Centricity

Human-centricity means focusing on something called self-sovereignty, self-determination or autonomy in terms of the people involved in a process. In other words, it means "that people have the right to determine without any kind of coercion or compulsion, what happens to them" [17].

The Human-centric approach puts core human needs and interests at the heart of the production process. Technology is seen as a mean needed to serve, support, and adapt the production to the diverse needs of the worker, shifting from being a technology-driven process to a human-centric approach [4].

"A safe and inclusive work environment is to be created to prioritize physical health, mental health and wellbeing, and ultimately safeguard worker's fundamental rights, i.e., autonomy, human dignity and privacy" [1]. As such, industry must respect societal limits in order to avoid leaving anybody behind. This has a lot of ramifications in terms of a "safe and beneficial working environment", human rights, and worker skill needs [4].

According to the European Commission (2021, p. 66), "we do not distinguish between "blue collar" and "white collar" workers; in Industry 5.0, the lines between different types of industry workers are blurred. European values and fundamental rights should be binding principles, including respect for privacy, autonomy, human dignity, and general worker's rights".

As Europe states in the "Towards a sustainable, human- centric and resilient European industry" document, it is possible to define three main benefits that arise for the worker by applying a human-centric approach [4]:

- **New role for the industry worker:** Since the aim is to create an environment in which humans and machines collaborate, the worker is considered as an investment for the firm. It is the technology being adapted to specific worker's needs where the worker is more empowered, and inclusiveness is promoted. To achieve this, workers are to be closely involved in the design and deployment of new industrial technologies, including robotics and AI. Humans are placed at the center ad not anymore substituted by robots, and technology maximizes the benefits for both the company and the worker.

- **Safe and inclusive work environment:** in order to create a safer working environment, robots could substitute the human worker when repetitive, dangerous and strenuous tasks are needed to be performed, by simply automating machines and consequently reducing workplace accidents. In this way, emerging technologies like as AI, virtual and augmented reality tools can be used to guide the worker to perform more specialized jobs that would normally necessitate unique expertise and training, developing an inclusive atmosphere in which people with limited mental ability or women can perform tasks because the necessary physical strength is no longer required.
  Furthermore, as demonstrated by the Covid-19 epidemic, digitalizing industrial processes enables remote work, allowing people living in remote places to enter the labor market while also boosting the robustness of production itself.

The safety and well-being of workers refers to both physical health in the workplace and mental health. In particular, digital technologies could be utilized to help workers better control and manage the hazards and impact of the changing working environment on their mental health and well-being. For instance, wearable devices could alert workers about a critical situation that could impact on their health, both physical and mental. In this way, the culture of well-being will spread, and companies will get economic benefits because of increased production and the prevention of long-term illness and absences. To best apply these new concepts and create new working conditions, companies can follow the basic principles defined in the European Charter of Fundamental Rights.

- **Skills, up-skilling and re-skilling:** nowadays there is a skill mismatch both in general and expert skills which are missing. Technology might be made more "intuitive" and "user-friendly" so that workers do not need to be specialized to operate them, nor do they need to be re-skilled when a new one arrives.
  The World Manufacturing Forum[11] has determined the top ten talents required in future manufacturing: "Digital literacy, AI and data analytics," "working with new technologies," "cybersecurity," and "data-mindfulness" are four of them while the remaining ones are more cross-disciplinary skills in nature, relating to creative, entrepreneurial, flexible, and open-minded thinking. Companies understand which abilities are lacking and since they have knowledge, information, and direct access to best technology, understand what will be needed in the future and consequently educate and train workers in a proper manner. At the same time, workers should be encouraged to engage in the design of trainings to ensure that trainings are relevant and tailored to their audience.

[11] The World Manufacturing Forum is a prestigious event during which global policymakers, industry leaders, and eminent academic and research innovators address and discuss the challenges and trends of global manufacturing.

The World Manufacturing Forum has recognized 10 main skills that will be required in the coming future where four of them are considered 'digital skills', while the remaining ones are referring more to 'creative, entrepreneurial, flexible, and open-minded thinking' [4]:

Figure 14: Ten future manufacturing skills [4]

The human-centric paradigm is about allowing for choice for individual people and groups as they prioritize humans and their well-being, focusing on the users, their needs, and requirements in a process. This approach improves worker satisfaction, accessibility, and sustainability.

3.1.2. Sustainability

The second core value of Industry 5.0 defined by Europe is that the industry must be sustainable to respect the planet boundaries. Companies are required to develop "circular processes able to re-use, re-purpose and recycle natural resources, reduce waste and environmental impact" [4].

Sustainability is referred to a series of actions needed to adopt a circular economy perspective with the aim of reducing energy consumption and CO_2 emissions, waste management of secondary raw resources and without risking future generations' needs adopting new technologies, like AI and additive manufacturing, to better manage resource efficiency and effectiveness [4].

EU has already developed policies regarding sustainability. Indeed, The EU has fully committed to deliver on the 2030 Agenda for the 17 Sustainable Development Goals (SDGs), adopted by the UN General Assembly in 2015, as outlined in the reflection paper: 'Towards a Sustainable Europe by 2030'.

The Green Deal announced in December 2019 clearly sets out what Europe must do to transition to a sustainable economy.

Several powerful instruments helping the EU reach its carbon-neutral ambitions have been identified.

Innovations in green technology, combined with EU initiatives aimed at Digitizing European Industry (including better use of big data and artificial intelligence) are a reality and are increasingly embraced by industry. In the face of mounting public environmental and societal concerns, companies are incorporating sustainability into their business models.

Many European firms already recognize that industrial ecology and more particularly industrial symbiosis (sharing and repurposing secondary resources and by-products) is good, not only for the environment, but in helping industries compete in global markets and retaining their long-term competitiveness.

3.1.3. Resilience

The term 'Resilience' refers to the necessity to improve industrial production's robustness, equipping it better against disruptions and ensuring that it can offer and support key infrastructure in times of crisis [4].

The vulnerability of our current method to globalized production is highlighted by (geo-)political movements and natural calamities, like as the Covid-19 outbreak. It should be balanced by the development of sufficiently resilient strategic value chains, adaptable production capacity, and flexible business procedures, particularly where value chains service essential human needs like healthcare or security [4]. In addition, Resilience is needed to ensure a continuous production able to quickly recover from unexpected crisis and moving to the 'new normal' of Industry 5.0.

3.2. Society 5.0

As seen so far, Industry 4.0 brought, and it is still now bringing changes in ventures through innovative technological solutions that perform most of the work. However, the emerging and urgent need to create a society that can answer to a rapidly changing society, has introduced the concept of Society 5.0 or 'super-smart society'. For understanding better this concept, we must first analyze the impact that previous revolutions had on their societies and their consequent transformations.

Starting from Society 1.0, it can be considered the "Hunting and Gathering society" with a "non-productive economy". In particular, women were in charge of gathering food like pieces of fruit, vegetables, and roots, while men had the role of hunting. These nomads were travelling over well-known territory in groups and adapting to their new surroundings [31].

Moving to Society 2.0, the "Farming Society", as a result of the discovery and development of agriculture, people began to form tribes and live in permanent areas along rivers where they could get water for plants and fish to consume. The economy shifted to bartering, a means of exchanging things such as valuable stones for necklaces, as the civilization grew self-sufficient.

With the "Industrial Society", or also known as Society 3.0, there has been a huge change in terms of economy. Due to the introduction of currencies, people started gaining salaries and establishing social class divisions. Moreover, due to technological innovations, industries began to create mass customization, resulting in lower manufacturing costs and time, as well as higher worker compensation and income. Transportation was one of the most obvious benefits since the construction of railways and steamships allowed people to travel to new territories more swiftly.

The Society 4.0 has transformed as a result of Industry 4.0, which is built on information and interconnecting people, as well as technology breakthroughs that allow information to move quickly and precisely throughout the world. In this "Information Society", things and people are connected to any location in the world thanks to ICTs (Information and Communication technologies).

Finally, the concept of Society 5.0 has been introduced for the first time by Keidanren, Japan's most powerful Industrial Association, in 2016, and subsequently used and promoted by the Japanese government in the "Fifth Science and

Technology Basic Plan, which is a program whose aim is to connect physical space (the real world) and cyberspace, taking advantage of all the potential of new technologies in order to achieve an ideal future society" [1].

In particular, Japan, which defines its strategy to guide technological innovation processes in the proposed future Society 5.0, "has decided to put technological innovation in the spotlight based on the fact that it can be fully considered as a tool for social innovation and not just a factor leading to changes in firms and business processes" [1]. As a result, it has been explicitly stated that technology innovation is critical to realizing the transition to Society 5.0.

It will be created the Super Smart Society, focusing on individual needs and capabilities.

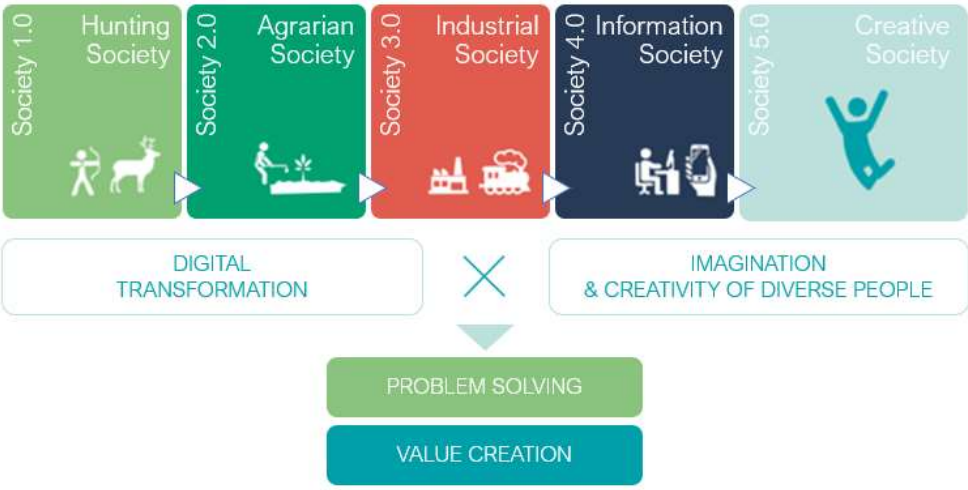

Figure 15: From Society 1.0 to Society 5.0 [25]

IoT, AI, robotics, and other supporting technologies, all of which are part of Industry 4.0, will significantly alter social structures and industrial aspects, according to the Japanese government.

Hence, Society 5.0 "is a process that must be carried out together with citizens who are required to actively participate and, therefore, not just top-down; recognizes and underlines the importance of creating less formal relationships between people, businesses, universities and the Public Administration; highlights the need to develop a more intense collaboration with foreign people and firms, which bring in technological knowledge of the frontier" [1,33].

According to Keidanren, Japan can deal with natural calamities such as the eruption, pollution, and the problem of an aging society by tearing down five walls:

1. **The wall of the Ministries and Agencies:** As defined by Keidanren, there is the need of a "formulation of national strategies and construction of promotion system by unified effort of government departments", so national strategies must be established by ministries and agencies in an integrated way with the cooperation of business and academics and through the construction of an IoT platform intended as a government support structure.
   The technologies belonging to Society 5.0 create a link between citizens and key decision makers, increasing the engagement of other players and, ultimately, having an impact on sustainability decisions [31]. In addition, ministries and agencies should institute a thinktank[12] function with the participation of private sectors, for being able to exploit proper actions aligned with "the image of future economy and society" [31].

2. **The wall of the legal system:** There is the need of promoting "regulations and system reform" and "administrative digitization" in order to exploit Industry 5.0 technologies for implementing advanced techniques by considering citizens' voices for the development of further reforms as next-generation automobiles, unmanned planes and robotics. Furthermore, "rules for promoting uses and applications of data" must be developed for not both the ease of individual people's lives and for creating competitive advantage in businesses and governments [12,31,87].

3. **The wall of technologies**: Cybersecurity, Artificial Intelligence, robotics, nanotechnology, biotechnology, and systems technology must all be leveraged and promoted. Through a strong commitment to and investment in R&D

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[12] A think tank is a group of people whose sole profession is to read, write, research, and discuss topics that are of importance to the social good. It is a form of collective intelligence.

projects, as well as a reform of national innovation systems, an environmental and long-term improvement will be reached "as a result of scientific and technological innovation but also through implementing strong social policies, decent work, inclusion and equality" [12,31].

4. **The wall of human resources:** Specializing human resources in advanced digital skills by providing educational opportunities to encourage creativity but also training them in IT knowledge, citizens will be able to "think independently and create new values by combining various items while working with others" [12] and to leverage new key technological innovations [31].

5. **The wall of "social acceptance":** This wall implies the importance of receiving social consensus and also an investigation on social effects and ethical and philosophical issues like man-machine interaction or the definition of individual happiness and humanity meaning [31,87].

Figure 16: Society 5.0's five walls [60]

Obviously, in practice, Industry 4.0 and organizations overall will be major components in Society 5.0, yet it is not the industry alone: it is about all stakeholders, including citizens, governments, academia and so forth.

Society 5.0 and Industry 5.0 are similar since they both refer to a fundamental transformation in our society and economy toward a new paradigm [4]. Respect for privacy, autonomy, human dignity, and universal worker rights should all be enshrined in European values and fundamental rights, and where "highlights the importance of research and innovation to support industry in its long-term service to humanity within planetary boundaries" [4].

As already mentioned, Industry 4.0 is considered to be technology-driven, while Industry 5.0 is value-driven.

Industry 5.0 'complements' and 'extends' the hallmark features of Industry 4.0 since they are mutually complementary, meaning that Industry 5.0 does not replace the technologies already implemented but it is in co-existence with them [23,24].

Over the course of its ten-year existence, Industry 4.0 has focused its attention on digitalization and AI-driven technologies for enhancing production efficiency and flexibility. On the contrary, as already mentioned previously, Industry 5.0 stresses "the importance of research and innovation to support industry in its long-term service to humanity within planetary boundaries" [4].

3.3. Enabling Technologies

Industry 5.0 enabling technologies are a collection of complex systems that combine technologies such as smart materials with embedded, bio-inspired sensors. As a result, each of the following categories can only reach its full potential when coupled with others as part of larger systems and technological frameworks.

The following table represents all the possible technologies identified by the 'Enabling Technologies for Industry 5.0, Results of a workshop with Europe's technology leaders, Julian Müller September 2020' [23], that could be adopted and applied Industry 5.0:

Human-centric solutions & human-machine-interaction technologies	**Bio-inspired technologies & smart materials**	**Real time-based digital twins & simulation**	**Cyber safe data transmission, storage & analysis**	**Artificial Intelligence**	**Technologies for energy efficiency & trustworthy autonomy**
Multi-lingual speech and gesture recognition and human intention prediction	Self-healing or self-repairing	Digital twins of products and processes	Networked sensors	Causality-based and not only correlation-based artificial intelligence	Integration of renewable energy sources
Tracking technologies for mental and physical strain and stress of employees	Lightweight	Virtual simulation and testing of products and processes (e.g., for human- centricity, working and operational safety)	Data and system interoperability	Show relations and network effects outside of correlations	Support of Hydrogen and Power-to-X technologies
Robotics: Collaborative robots ('Cobots'), which work together with humans and assist humans	Recyclable	Multi-scale dynamic modelling and simulation	Scalable, multi-level cyber security	Ability to respond to new or unexpected conditions without human support	Smart dust and energy-autonomous sensors
Augmented, virtual or mixed reality technologies, especially for training and inclusiveness	Raw material generation from waste	Simulation and measurement of environmental and social impact	Cyber security/safe cloud IT-infrastructure	Swarm intelligence	Low energy data transmission and data analysis
Enhancing physical human capabilities: Exoskeletons, bio-inspired working gear and safety equipment	Integration of living materials	Cyber-physical systems and digital twins of entire systems	Big data management	Brain-machine interfaces	
Enhancing cognitive human capabilities: Technologies for matching the strengths of Artificial Intelligence and the human brain (e.g., combining creativity with analytical skills), decision support systems.	Embedded sensor technologies and biosensors	Planned maintenance	Traceability (e.g., data origin and fulfilment of specifications)	Ability to handle and find correlations among complex, interrelated data of different origin and scales in dynamic systems within a system of systems	

	Adaptive/responsive ergonomics and surface properties		Data processing for learning processes	Informed deep learning (expert knowledge combined with Artificial Intelligence)	
	Materials with intrinsic traceability		Edge computing	Skill matching of humans and tasks	
				Secure and energy-efficient Artificial Intelligence	
				Individual, person-centric Artificial Intelligence	

Table 6: Enabling Technologies for Industry 5.0 [23]

Among all the listed ones, it has been possible to recognize six key enabling technologies that can be employed most effectively in Industry 5.0:

- Edge computing (EC)

According to [61], "Edge computing is a form of computing that is done on site or near a particular data source, minimizing the need for data to be processed in a remote data center".

Processing data close to its source provides significant benefits in terms of processing delay, lower data traffic, and increased resilience in the case of a data link breakdown. This computational paradigm is used in the so-called Internet of Things because it provides for the processing of enormous amounts of locally created data and the possible transmission of considerably more compact processing to remote devices.

IoT frequently encounter latency, bandwidth, and dependability issues that are not addressed by the traditional cloud architecture. In this case, the edge computing architecture can limit the quantity of data transferred to the cloud. It uses a smart gadget to handle vital, latency-sensitive data at the point of origin. Alternatively, it transfers this data to a nearby intermediate server [62].

Furthermore, EC may process data without sending it to the public cloud, reducing security concerns for major events in Industry 5.0 and ensuring data security, low latency, reliability and privacy. By reducing the amount of data transferred to a centralized server, EC enables Industry 5.0 to filter data. In Industry 5.0, EC offers preventative analytics, which enables the early identification of machine failure and mitigates it by empowering workers to make sound decisions [21].

Edge computing may also be exploited in topologies such as 5G to deliver local services with real-time answers to connected devices, which is challenging to do with cloud systems, and many other potential applications, including security and medical monitoring, self-driving cars, video conferencing, and improved consumer experiences [61].

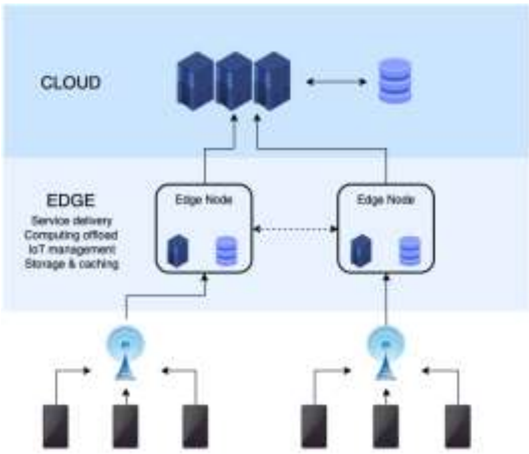


Figure 17: Edge Computing representation [63]

Edge application services reduce the amount of data that needs to be moved, the traffic it causes, and the distance it must travel. This lowers latency and lowers the cost of transmission. Advanced analytical tools and AI can operate on the system's edge since the analytical resources are close to the end users. The system benefits from this positioning near the edge, which also contributes to improved operational efficiency.

- Digital twin (DT)

A Digital Twin is a virtual replica of physical, potential and actual resources (physical twin) equivalent to objects, processes, people, places, infrastructures, systems and devices. They are used for various purposes, especially in production and for predictive maintenance, but also wind farms, industries, jet engines, buildings, and even bigger systems such as smart cities may be represented digitally using DT [26].

In general, the digital twin collects data and information, linking the physical component's parts and the equivalent virtual (cybernetic) portion via sensors and actuators. Thanks to IoT, the cost of DT has been reduced, making it more accessible to a wider range of sectors. Data from physical things is transmitted into their digital counterpart for simulation via IoT devices, consequently reducing maintenance costs and improving the performance of system.

"In Industry 5.0, DT can offer significant value for the development of customized products on the market, enhanced business functions, reduced defects and rapidly growing innovative business models to achieve profits" [21]. It provides for the rapid identification and resolution of technical difficulties, the removal of uncertainty during the design and configuration phase, the prediction of future faults, and thus the avoidance of financial losses. It creates simulation models and allows enterprises to use real-time computational data to remotely edit and update actual items [39], and through condition monitoring and sophisticated services, it enables applications while also assuring availability and dependability [67].

"Moreover, DT is utilized for customization to improve the user's experience of their product needs, as well as a purchase procedure that allows customers to construct virtual environments to witness the outcomes" [21].

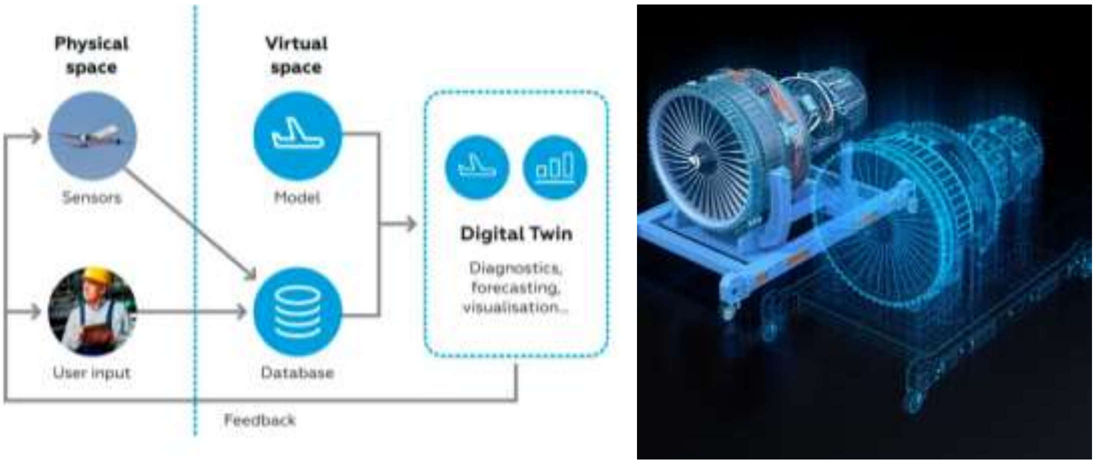


Figure 18: Edge Computing representation [63]

While both Digital Twins and simulation use digital models to reproduce s system's many operations, a Digital Twin is truly a virtual world, making it far richer for research. The main distinction between DT and simulation is scale, since the DT can run as many meaningful simulations as necessary to explore multiple processes, whereas a simulation normally only studies one specific process.

- Internet of everything (IoE)

IoE is "bringing together people, process, data, and things to make networked connections more relevant and valuable than ever before-turning information into actions that create new capabilities, richer experiences, and unprecedented economic opportunity for businesses, individuals, and countries.", (Cisco, 2013). It envisions a world in which billions of objects are fitted with sensors to detect, measure, and analyze their condition, and are connected via public or private networks using standard and proprietary protocols [70].

The difference between Internet of Things (IoT) and Internet of Everything is that IoT refers to a network of physical things that can be accessed over the Internet and which have incorporated technology that allows them to interact with internal and external states [70]. While the Internet of Things refers to "things" (physical equipment and things are connected to the Internet and each other), the Internet of Everything refers to three more components: people (connecting individuals in more meaningful and beneficial ways), processes (Getting the appropriate data to the right person or machine at the right moment), and data (Making smarter judgments by converting data into intelligence). It is therefore a system capable of merging these four dimensions of production - and not - to generate new skills and experiences and, most importantly, to boost the economic potential of businesses and individuals [71].

"In addition, IoE further advances the power of the Internet to improve business and industry outcomes, and ultimately make people's lives better by adding to the progress of IoT" (Dave Evans, Chief Futurist Cisco Consulting Services). According to Gartner, organizations will make considerable use of IoE technology, and a diverse variety of goods will be offered into multiple markets. Advanced medical devices, factory automation sensors and applications in industrial robotics, sensor motes for increased agricultural yield, and automotive sensors and infrastructure integrity monitoring systems for diverse areas such as road and railway transportation, water distribution, and electrical transmission are just a few of the products and services that will be available [70].

In Industry 5.0, the usage of IoE can generate new functions, a better user experience, and anticipated advantages for companies and governments. Indeed, it decreases latency and eliminates bottlenecks on communication routes, resulting in lower operational expenses, reducing supply chain waste and improving manufacturing operations and consequently, increasing consumer loyalty by customizing experiences based on supplied data [21].

- Big data analytics

"Big data refers to the large, diverse sets of information that grow at ever-increasing rates. It encompasses the volume of information, the velocity or speed at which it is created and collected, and the variety or scope of the data points being covered" [72].

Big data allows businesses to quickly analyze large amounts of data coming from a variety of data sources, formats, and types, and after cleaning them, it reveals information such as hidden patterns, correlations, market trends, or consumer preferences that can help them make better-informed decisions. This will result in new business process efficiencies and optimizations, as well as cost reductions and further savings. Furthermore, there is a greater awareness of client wants, which may lead to improved customer service as well as give information for product creation, being more market responsive, lowering risks, and boosting competitive advantage over competitors [72].

Data with at least one of the following qualities is classified as big data:

- **Volume:** refers to this huge mass of real-time data generation, that is constantly growing, which after running machine learning algorithms, they make decisions in order to provide the best customer experience [73].

- **Velocity:** data is being created and acquired at an increasing rate. Consider the proliferation of devices equipped with sensors capable of gathering real-time data as machines, networks, social media … The problem that businesses must face is the requirement to not only gather but also evaluate data in real time in order to make business choices as rapidly as feasible [74]

- **Variety:** variety represents many forms of heterogeneous data accessible today, increasing the difficulty in handling them and classifying them in an ordered manner

- **Value:** data must be translated into useful information for the analysis and lead to the identification of beneficial solutions and establish a competitive advantage [73]

- **Veracity:** despite the difficulties in organizing dynamic and variable data, being able to reach quality and integrity of information remain critical pillars for producing relevant and reliable analyses.

Figure 19: Edge Computing representation [63]

In Industry 5.0, Big Data are used by companies for realizing the so-called "mass customization". Indeed, the high data volumes gathered allow to analyze and predict in real time customer behavior, optimizing product prices and boosting sales, improving manufacturing efficiency and lowering overhead costs [21].

- Collaborative robots (Cobots)

According to [21], "collaborative robots are robots designed to work collaboratively with humans, and this collaboration helps to make human capabilities more efficient, extremely easy to automate for individuals and small businesses than ever before".

The simplest way to understand how Cobots and industrial robots differ is that Cobots are designed to work alongside human employees (Coboters), while industrial robots do work in place of those employees. A Cobot can assist employees with work that may be too dangerous, strenuous, or tedious for them to accomplish on their own, creating a safer, more efficient workplace without eliminating factory jobs involved in the actual fabrication of a product. By contrast, industrial robots are used to automate the manufacturing process almost entirely without human help on the manufacturing floor. This, in turn, frees up employees for more meaningful tasks that are less mundane and are less prone to repetitive motion injuries.

Cobots are also more easily programmable than industrial robots because they are capable of "learning" on the job. A factory worker can re-program a Cobot simply by moving the arm along the desired track. From there, the Cobot will "remember" the new movement and be able to repeat it on its own. Industrial robots cannot be so easily reprogrammed and require an engineer to write new code for any changes in the process to be implemented.

However, due to their size and need for working in close proximity to humans, Cobots are not designed for heavy manufacturing. Industrial robots can handle heavier, larger materials like those used in auto manufacturing, and also require safety cages to keep humans out of the workspace, while Cobots are safe enough to function around people and do not require the same kinds of safety infrastructure industrial robots do.

Packaging and palletizing, Machine Tending, Industrial Assembly, Pick and Place, Quality Inspection, Injection Molding, CNC Tending, Assembly, Polishing, Screw driving, Gluing, Dispensing, and Welding but also in other fields like for medical treatments as surgery where a doctor can be assisted to perform surgery, are just some of the applications for Cobots. In this way, in Industry 5.0 Cobots will aid in the creation of mass customized and personalized items for clients with high speed and accuracy, while also improving safety and performance and providing more fascinating duties for human workers [14,21].

Figure 20: Examples of Cobots' applications [80]

Cobots are typically equipped with sensors and are very responsive to the detection of unexpected impact, allowing them to come to a complete stop when human employees spot any misplaced things in their route. When compared to ordinary industrial robots, this makes them particularly dependable when it comes to workplace safety [21].

- Blockchain

According to the Oxford dictionary [X], blockchain is “a system in which a record of transactions made in bitcoin, or another cryptocurrency are maintained across several computers that are linked in a peer-to-peer network”. It is a database that enables the storing of encrypted blocks of data which then are chained together in a chronological order, enhancing immutability and integrity of data and accountability for significant events. Thanks to this, it offers an almost infinite number of applications in practically every sector. The ledger technology may be used to track financial crime, securely transmit patient medical information amongst healthcare experts, and even track intellectual property in the corporate world and music rights for musicians [76]. Decentralization is one of the key aspects of blockchain since it cannot be owned by a single computer or entity. Instead, the nodes connecting to the chain form a distributed ledger. Any electrical device that preserves copies of the blockchain and keeps the network running is referred to as a node [76].

In Industry 5.0, Blockchain can be used to promote operational transparency, trust and responsibility for key occurrences. For effective subscriber management in Industry 5.0, blockchain may be utilized to generate digital identities for various persons and institutions. It is required for access management and authentication of stakeholders in any industrial activity that takes place over a public network. Furthermore, these digital identities may be used to manage property, belongings, items, and services. Blockchain technology may also be used to catalog and save original work, as well as to register IP rights. By automating the agreement procedures between diverse parties, blockchains can also assist to automate the contracting process. Furthermore, blockchain-powered cloud manufacturing enables machine-level connectivity and data exchange through the use of blockchain technology [21].

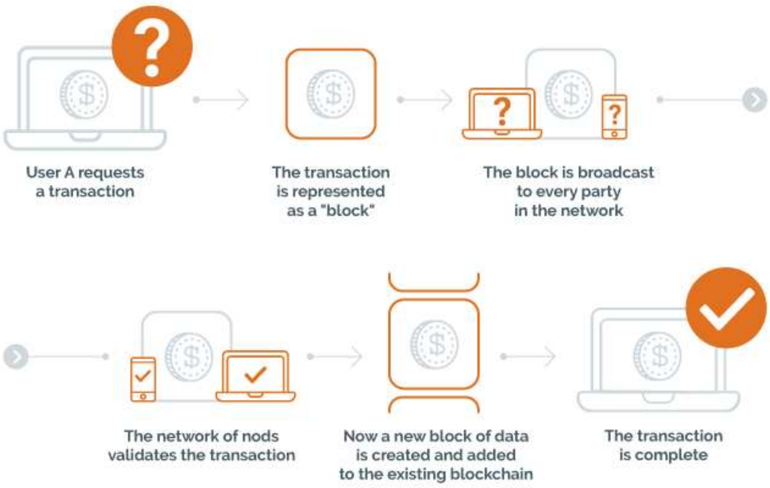


Figure 21: Key steps of the blockchain [77]

Some companies have already incorporated blockchain, such as Walmart, Siemens, Pfizer, among others. An interesting case is IBM, which has created a Food Trust blockchain to trace the journey that food products take to get to their locations [107]. This could be an example of application in supply chain, as suppliers could use blockchain to record the origins of materials that they have purchased. In addition, this could allow companies to verify the authenticity of their products, as well as common labels such as 'organic'.

- 6G and beyond

6G (sixth-generation wireless) is the next-generation advanced mobile communication system which "will serve as a distributed neural network that provides communication links to fuse the physical, cyber, and biological worlds, truly ushering in an era in which everything will be sensed, connected, and intelligent. This in turn will lay a solid foundation for Intelligence of Everything in the future" [78]. Thanks to the ability to use greater frequencies, resulting in significantly more capacity and a lower latency of one microsecond, governments and corporate approaches to public safety and critical asset security will benefit from 6G that will have an impact on, for instance, threat detection, health monitoring, feature and facial recognition, decision-making in areas like law enforcement and social credit systems, air quality measurements, gas and toxicity sensing and sensory interfaces that feel like real life. Smartphone and mobile network technology, but also developing technologies such as smart cities, self-driving cars, virtual reality, and augmented reality will have several key applications like: "intelligent connected management and control functions, programmability, integrated sensing and communication, reduction of energy footprint, trustworthy infrastructure, scalability, and affordability" [3].

As introduced by Huawei, one of the current companies developing 6G and whose goal is to make the "planet intelligently connected, sustainably developed, better protected, and full of vitality in all walks of life" [78], it is possible to identify 6 main pillars related to this key enabling technology:

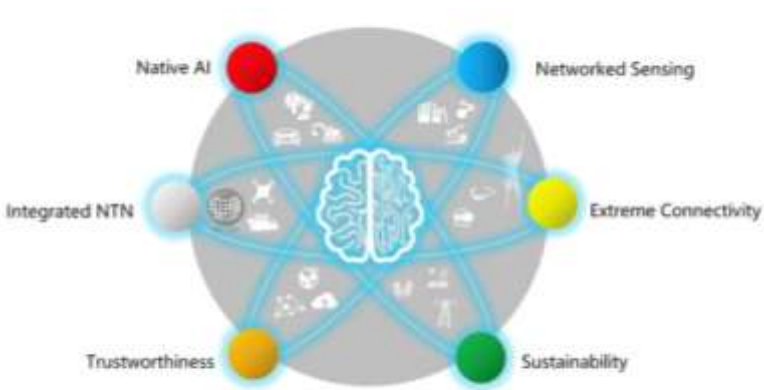


Figure 22: 6 pillars of 6G [78]

1. **Native AI:** 6G elements will integrate native communication, computation, and sensing capabilities, allowing for a smooth transition "facilitating the evolution from centralized intelligence in the cloud to ubiquitous intelligence on deep edges" and that will be able to satisfy future society's large-scale intelligence requirements and manufacturing [78].

2. **Networked Sensing:** It refers to wireless sensing technologies that employ radio wave transmission, echo, reflection, and scattering to analyze the physical environment, as a result of the continual increase in frequency bands, bandwidths, and antennas. Furthermore, these network sensing capabilities will provide high-resolution sensing, localization, imaging, and environment

reconstruction capabilities to improve communication performance and enable a broader range of network service circumstances, laying the framework for a smarter digital society [78].

3. **Extreme Connectivity:** 6G will give ubiquitous high-performance wireless connections and the ultimate experience, with speeds comparable to optical fibers. Human-centric immersive services, as well as full-scale digital transformation and vertical industry productivity upgrades, will be expedited and facilitated by linking devices such as centimeter-level localization and millimeter-level imaging, among others [78].

4. **Integrated NTN (Non-Terrestrial Networks):** in the NTN, which include satellite communication networks, high altitude platform systems (HAPS) and air-to-ground networks, it will create an "airborne wireless network", a mega satellite constellation made by a huge number of low- or very low-earth orbit (LEO/VLEO) satellites needed for providing continuous high-quality services to users anywhere on Earth [78].

5. **Trustworthiness:** To allow the widespread adoption of AI applications, the novel network architecture should support innate trustworthiness and be adaptable to activities such as collaborative sensing and distributed learning. Native trustworthiness will be increased through technologies such as advanced privacy protection, quantum assault defense technologies, and data governance frameworks that promote data compliance and monetization [78].

6. **Sustainability:** By introducing the green and sustainable design concept and native AI capability, 6G aims to improve overall energy efficiency by 100 times across the network, preventing overall energy consumption of ICT infrastructure and terminals from exceeding that of 5G while also ensuring optimal service performance and experience. As the foundation of the digital economy, 6G will make significant contributions to humanity's long-term progress [78].

In industry 5.0, 6G will connect a large number of smart devices and will optimize energy management via the employment of sophisticated energy consumption strategies and energy harvesting technologies. 6G networks are projected to match the demands of an intelligent information society by delivering ultra-high data speeds, ultra-low latency, ultra-high dependability, high energy efficiency, traffic capacity, and so on for I5.0 applications [21].

- Artificial intelligence (AI)

Artificial intelligence is a collection of technologies working together to give machines the ability to see, comprehend, act, and learn at levels of intellect comparable to that of humans. Artificial intelligence encompasses a wide range of technologies, including machine learning and natural language processing. Each is developing along its own trajectory, and when combined with data, analytics, and automation, they can assist organizations in achieving their objectives, whether those be to enhance customer service or streamline their supply chain [103].

AI attempts to examine a vast volume of labeled training data for identifying correlations and hidden patterns needed to forecast future states. In particular, learning, reasoning, and self-correction are the main 'cognitive skills' of AI programming. The learning process is concerned with gathering data and formulating algorithms that will enable the data to be transformed into useful knowledge; the reasoning process consists in selecting the proper algorithm based on the result the company would like to reach; self-correlation is the last skill, and it focuses on continuously improving algorithms for delivering the most precise results [104]

Different advantages resulting from the use of AI in businesses include [104, 43, 103]:

- AI technologies work fast and with very few mistakes with respect to humans, especially when it comes to repetitive, detail-oriented activities and vast volumes of data

- Better prediction of future outcomes, facilitating the decision-making process and consequently improving quality, effectiveness, and the creativity of human decision-making

- AI is always active, never stops, and by foreseeing repair requirements, it can help automate complicated procedures and save downtime
- AI may be used across different industries and has a large market potential
- AI delivers consistent results
- AI reduces conflicts and enhances resource and analytics use throughout the entire enterprise

The main key aspect that can be pointed out is that AI in Industry 5.0 defines human-machine collaboration as an essential element, even though computers can sometimes accomplish tasks better than humans, such as data processing tasks. In the modern world, AI is still an addition to human abilities, not a replacement. In particular, while employees spend time on more rewarding, value-added jobs, AI can handle repetitive tasks. AI is anticipated to boost human productivity by fundamentally altering the way work is done and enhancing people's contribution to promoting progress [103].

AI can be applied in different industries as in healthcare for diagnosing problems more quickly and accurately than humans and also to predict and understand the evolution of pandemics like COVID-19; education for evaluating the students and meeting their needs at their own pace; manufacturing processes supported by the use of Cobots that work alongside humans and assume more responsibility for the job in the workflow; finance for gathering personal information and offer financial guidance; or in transportation to control traffic or to forecast airline delays and in the development of self-driving cars [104]. To sum up, hereafter all the main key enabling technologies belonging to Industry 5.0 are summarized with the main respectively core pillars:

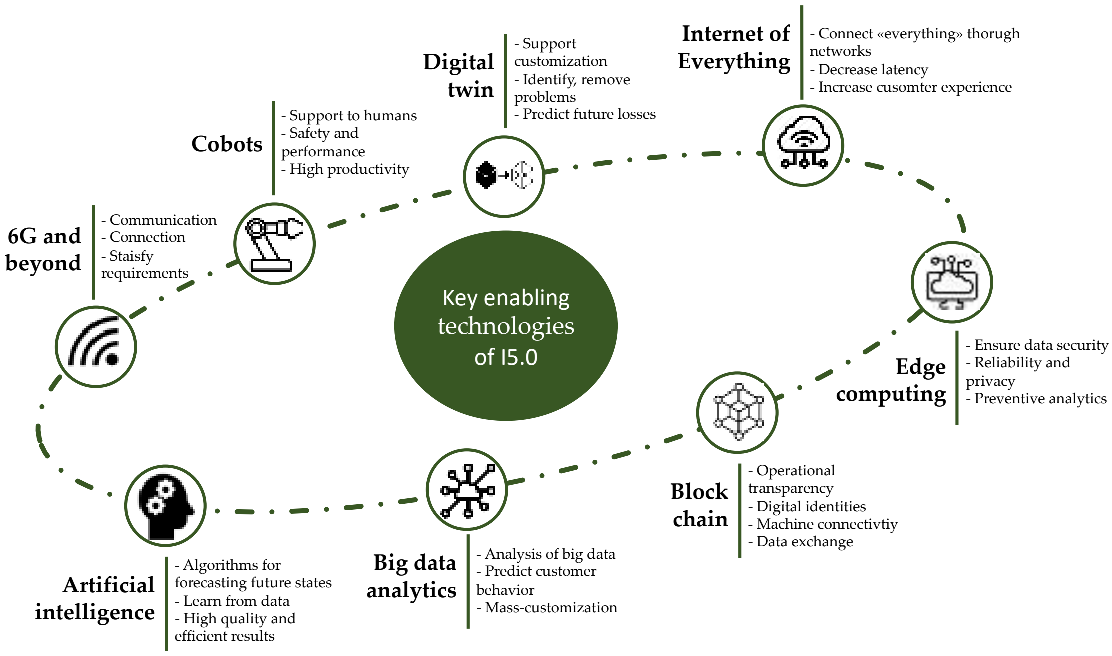


Figure 23: I5.0 key enabling technologies

In addition to the obstacles posed by complexity or technology considerations, such a notion must incorporate society and the majority of the industrial landscape. To guarantee a widespread implementation and value generation toward prosperity, customers, and entire supply chain up to SMEs must be better integrated.

3.4. Applications

Industry 5.0, as seen in the preceding chapters, takes a different approach to contemporary technologies. Some authors have already highlighted Industry 5.0's potential applications, such as Maddikunta P. [21] in the paper "Industry 5.0 A survey on enabling technologies and potential applications", where he presented six main potential areas in which Industry 5.0 could be applied:

1. **Intelligent healthcare:** the creation of technologies able to plan and create personalized treatments to the patients with the help of the doctors. These technologies, as smart watches or intelligent sensors can continuously capture the patient's health-care data in real-time and used to develop personalized requirements as measuring sugar level, blood pressure or other body parameters, with the help of Cobots that can perform ordinary tasks like routine checkups, freeing doctors who will be able to focus on higher-level jobs [21]. For example, Artificial Intelligence learns how our bodies react to

changes, or doctors can use collaborative robots to perform unique surgery on the operating table thus increasing quality and safety by receiving constant inputs [10].

2. **Cloud manufacturing:** creative technique that incorporates cutting-edge technologies as EC, IoT, virtualization and service-oriented technologies exploited to transform traditional manufacturing into an innovative manufacturing process. It provides reliability, excellent quality, cost-effectiveness, and on-demand capabilities. The cloud controls the equipment and procedures related to the production life cycle, such as service composition and scheduling. IoT sensors collect data on manufacturing process operating conditions, which can then be analyzed in the cloud [21].

3. **Supply chain management (SCM):** Some of the I5.0 technologies as co-bots or IoT, combined with human intelligence and innovation, can assist sectors in fulfilling demand and offering personalized and customized products at a faster rate [21]. In this way, SCM will be able to integrate mass customization in the production systems. The SCM industries can lower their total cost of ownership by using co-bots that can undertake regular/dangerous tasks, such as packaging, routine quality checks, lifting heavy items, and so on, whilst humans' knowledge can be used in more complicated roles in the SCM life cycle [21].

4. **Manufacturing/Production:** Implementing Industry 5.0 in manufacturing industries will increment corporate value and consumer satisfaction by combining Cobots with humans who will increase creativity and innovation in the workplace since they are not required to perform strenuous, repetitive activities anymore [21,24]. In this way, I5.0 will boost productivity and operational efficiency and shortening manufacturing cycle times, while also reducing workplace injuries and generating new job positions including AI and robotics programming, training and scheduling [24].

5. **Smart education:** By better training and educating operators about I5.0 concepts and skills, it will be possible to build a synergy between people and

autonomous machines. In this way, the Lead Robotics officer role will be created, an expert who is specialized in machine–operator relation and has worked in topics such as robotics and artificial intelligence [21].

6. **Disaster management:** Catastrophe prevention and management tactics from sudden, catastrophic events, like Covid-19 pandemic, are those that help limit the disaster's repercussions. Combining people with intelligent machines as AI and IoT can aid in the resolution of disaster-related challenges [21].

Other more practical applications have been pointed out by Nahavandi, S. in the paper "Industry 5.0 – a human-centric solution". Nahavandi, S. (2019, p. 4) also provided some examples of the application of Industry 5.0. The first example shows a human worker on the assembly of an electro-mechanical machine. "The human worker starts a task, and a robot observes the process using a camera on a gimbal. This camera works as the eye of the robot. The robot is also connected with a processing computer that takes the image, performs image processing, and learns the patterns using machine learning. It also observes the human, monitors the environment, and infers what the operator will do next using human intention analysis powered by deep learning".

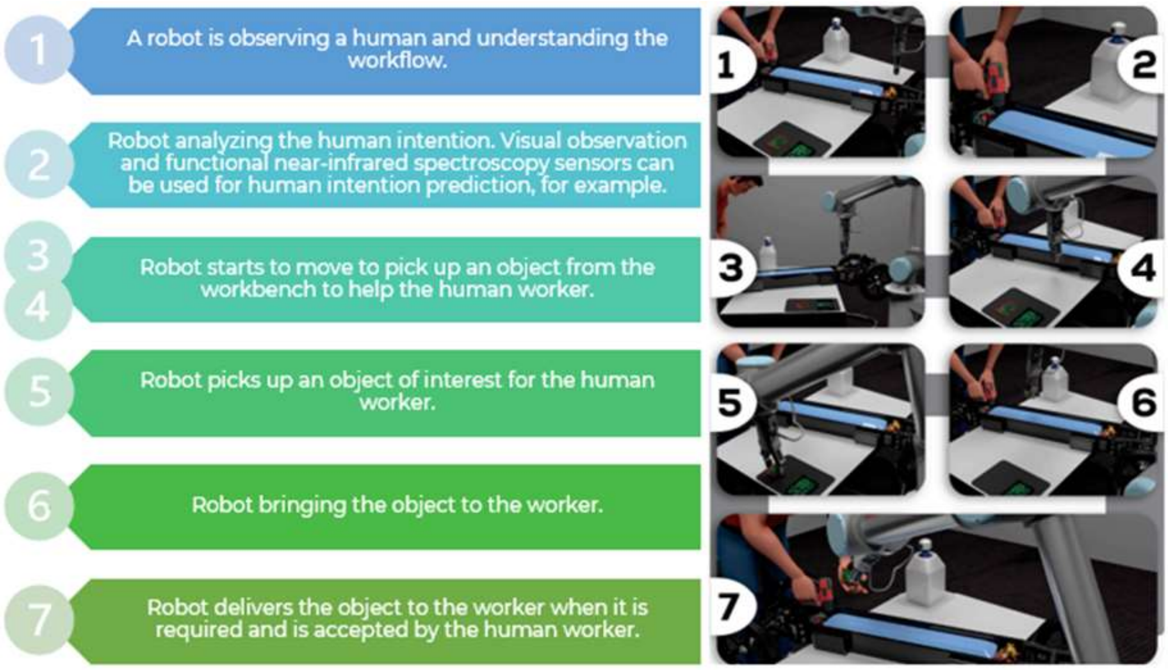


Figure 24: Industry 5.0 concept applied to assembly process [24].

Other examples can be seen from the EU Funding program 'Horizon 2020', which ended in 2020. "Several Horizon 2020 funded projects have developed evidence and further guidance on the transformative elements pertinent to Industry 5.0., even if they do not explicitly refer to the term as such" [4]. The project entitled 'Beyond 4.0' aim to examine the impact of the technological transformation on the future jobs, business models, skill needs, education, and training, and so on. "One of the key tasks for Beyond 4.0 is providing integrated and intellectual framework, which helps us to do that research, the same framework then helps us to synthesize and analyze the findings, and then we can start developing recommendations for the European Commission and other bodies that are interesting in trying to shape the future of working welfare" [98].

Another project from Horizon 2020 in line with the Industry 5.0 concept is the 'FACT4WORKERS' – shorter for 'Factories for Workers' -, where the main goal is to integrate already available IT enablers with smart factory infrastructure based on worker-centric and data-driven technology building blocks, so to increase job satisfaction and innovation skills to make the workplace attractive. "As FACTS4WORKERS is underpinned by a clear human-centric approach, usability, user experience and technology acceptance are of the utmost project interest" [98]. One of the use cases presented by the project was the 'worker-centric knowledge sharing' at EMO Orodjarna, a company located in Slovenia that produces transfers tools and progressive tools for transforming sheet metal. This use case aimed 120 workers in the manufacturing department of components for the tools, the assembly department into the tools, the testing of the tool, quality control and maintenance of machines. The aim of the use case was to provide easier and faster access to context-specific information for workers, improve maintenance process by providing relevant procedures and guidelines, provide faster decision making and response times, increase participation and provide individual and collaborative problem solving.

"Through a database connector, workers can have access to the status of part production and package assembly and also have the viewing of corresponding CAD file in an attractive way. The list of parts can be scanned via keyword-based search. On the part details screen, workers can retrieve information about meta data, history details as well as doing the quality control

check. Within the system, failures can be reported by making photos and textual descriptions. The history view of the parts provides an effective documentation of the production process, so the worker is able to keep track of which failure has to be solved or rather which parts have to be reworked. In order to make the manufacturing process more efficient, the worker is able to start a workflow for submitting ideas for improvement. The chat and video functionality support the worker in his daily tasks. Getting in contact with experts the worker receives appropriate remote supported in any situation. Several learning material and step-by-step guidelines can be consulted by the worker in different stages of education (classroom situation, in-situ learning at the machine with a mentor, gain long-term experience). There is the possibility both to record as well as playback video footage to perform and improve his actions on a daily basis".

The FACTS4WORKERS solution, 2016.

Another interesting project from Horizon 2020 is KYKLOS 4.0, which proposed an advanced circular and agile manufacturing ecosystem. "KYKLOS 4.0 will demonstrate, in a realistic, measurable, and replicable way the transformative effects that CPS, PLM, LCA, AR and AI technologies and methodologies will have to the Circular Manufacturing (CM)Framework" [81]. One of the uses cases presented by the project is 'Reduction of Energy Consumption and Waste Management' at PINDOS, which operates in the Food Industry. This is an on-going project that started in January 202 and has and end date in December 2023.

"PINDOS intends to use the services provided by the KYKLOS 4.0 platform to monitor the resources needed during production process, such as normal water, hot water, steam, or air compressors. The goal is to control the variables that ensure the quality of the production and therefore the quality of the final product offered to the consumer. Additionally, PINDOS intends to improve their circular economy approach of their integrated ecosystem by monitoring the circularity of the waste management on multiple places of the whole process".

KYKLOS 4.0, 2020

As it can be observed, even though those projects make use of the term ‘4.0’, their goals focus on a human-centric, sustainability or circular economy concepts, which are in line with the Industry 5.0 concept.

Another case that could be analyzed for understanding other possible applications of I5.0 is the case of Thermolympic S.L. This company, specialized in the design and production of the molds used in thermoplastic injection molding, has been able to improve real time data collection and analysis and create a more collaborative environment thanks to the adoption of F4W tablets. In this way, employee can help each other by sharing expertise, greater responsibilities, and knowledge about the machines they are working with, increasing operators’ opportunities to grow and to acquire most relevant positions in the company.

For instance, in order to solve the issue of not being able to address the cause of a faulty parts produced by the machine that can cause high down times impacting on production loss, the adoption of a table able to display the error could be essential in this situation. Indeed, the tablet is connected to a quality cloud and the errors are analyzed in real time, and then it will be able to provide a possible solution to the detected error and how to perform restoration of the machine accordingly. In this way, the operator will avoid interrupting the machine and fix the problem immediately and by him/her-self.

Another solution that F4W could bring in this firm is to provide an application of the F4W tablet used for learning about the machine and the manufacturing process at multiple degrees of detail, through textual descriptions, photos, or interactive movies. Moreover, the tablet sends an alarm if a problem in the machine is detected, so that the worker can have full control on it.

In addition, the manager will be ready to hear the operator's comments at the end of the shift because the tablet has a feature that enables the operator to notify the management that certain improvement activities may be performed to optimize the process. In this way the employee will gather more responsible power [83].

Some Horizon 2020 Projects aim at changing the business models that companies adopt, by fostering circular manufacturing, such as PaperChain, that was coordinated by Acciona[13] and counted with twenty partners from five European countries and included large-scale tests in various operating environments. The aim of the project was to develop a circular economy model that recovers waste generated by the paper industry and uses it as raw materials in sectors such as construction, chemical and mining [100].

The first test was carried out in Zaragoza and Valencia, in Spain, along with the research group Construction Materials and Roads (MATCAR), which "has worked on improving and stabilizing the level ground that supports a road surface and on the treated layers of the surface itself. In these layers, the binder that is normally used to strengthen resistance to traffic is cement or lime. In this case, ashes from the paper industry are used instead. The use of these ashes considerably reduces the carbon footprint in the construction of roads, as cement and lime produce high CO2 emissions" [100]. The second test was built in Villamayor de Gallego, where it was refurbished a kilometer of road surface by adding a layer of stabilized soil. The impact of adding ash to these soils is the near elimination of water content, hence increasing the capacity of ground support loads.

The results of these studies showed that utilizing ashes instead of lime or cement in stabilizations or soil treatment for level ground and surface layers of road is both technically and economically feasible, providing another step towards the goal of zero waste.

3.5. European Commission's Priorities

The obstacles and facilitators addressed in general are part of a complex system that includes technological and organizational features, political and public issues, and the Triple Bottom Line of sustainability [23].

[13] Acciona is a global group that develops and manages sustainable infrastructure solutions, especially renewable energy.

Figure 25: Triple Bottom Line [59].

The British management consultant, John Elkington, launched the term 'Triple Bottom Line' in 1994, as the idea that companies should commit to focusing as much on social and environmental concerns as they do on profits [99]. The theory says that companies should be working simultaneously on:

- **Prosperity:** the traditional measure of corporate profit.
- **People:** this measure how socially responsible an organization has been throughout its history.
- **Planet:** this measure how environmentally responsible a firm has been.

Taking this concept into consideration, the European Union (EU) has launched a series of policies in response to climate emergency and the advancement of technology in the industry and society, aiming to transform the EU into a climate-neutral and resource-efficient economy by 2050.

According to the European Commission, the Industry 5.0 approach contributes to 3 out of 6 Commission's priorities: an economy that works for people, the European Green Deal and the Europe fit for the digital age [50].

Some elements belonging to the Industry 5.0 concept are already part of some major Commission policy initiatives, such as the adoption of a human-centric approach for digital technologies which is part of the Proposal for AI regulation; the up-skilling and re-skilling of European workers which is part of the Skills Agenda and Digital

Education Action plan; resource-efficient and sustainable industries which is part of the Green Deal; and the speeding up investment in research and innovation included in the Industrial Strategy [50].

3.5.1. An Economy that works for people

In December 2021, the European Commission published the report on 'Building and economy that works for people: an action plan for the social economy'. The social economy aims to increase employment rate and reduce the number of people at risk of poverty and social exclusion. Traditionally, the term 'social economy' refers to private companies that are independent of public authorities and with specific legal forms which provide goods and services to society at large, such as cooperatives, associations, and foundations. In the context of the EU priorities, "the social economy covers entities sharing the following main common principles and features: the primacy of people as well as social and/or environmental purpose over profit, the reinvestment of most of the profits and surpluses to carry out activities in the interest of members/users ("collective interest") or society at large ("general interest") and democratic and/or participatory governance" [91].

Among the actions under this priority, the Commission will encourage mutual learning and provide guidance and support to Member States by:

- Organizing webinars and workshops as of 2022 for public officials based on mapping exercises, collection and exchange of good practices in relation to various policy fields such as State aid, taxation, social investment, business transfers to employees, labels and certification systems, social impact measurement.

- Publishing guidance on relevant taxation framework for social economy entities based on available analysis and input provided by Member States' authorities and social economy stakeholders.

- Publishing guidance clarifying the existing rules on the tax treatment of cross-border public benefit donations affecting foundations and associations and the implementation of the principle of non-discrimination with Member States.

- Launching a study on national social economy labels/certification schemes mapping those existing in Member States, identifying good practices and common features and criteria. It will also aim to provide a common approach and guidance to Member States and explore the possibility of voluntary mutual recognition.

Furthermore, while implementing these actions, it will be proposed a Council Recommendation on developing social economy framework conditions in 2023 where this will [91]:

- Invite policymakers to better adapt policy and legal framework to the needs of social economy entities.

- Provide recommendations in relation to specific policies such as employment policy, state aid, public procurement, taxation, research, education, skills and training, care and social services, providing financial and non-financial support tailored to all stages of the business lifecycle, and statistics.

- Highlight how institutional set-ups and stakeholder engagement can facilitate the work of social economy entities.

In addition, the social economy contributes to Europe's diversity of business formats, enhancing consumer choice and product/service quality. The move to more beautiful, ecological, and inclusive living places and lifestyles will be aided by the social economy.

3.5.2. European Green Deal

The European Green Deal is a response to climate and environmental-related challenges. "The Green Deal will define and shape industrial policy making not only in the current mandate period of the Commission but also far thereafter and can only do so with a deep just transition policy in place. The proposed 1 trillion EUR, 10-year plan to put the EU on course to climate neutrality by 2050 could de facto become a better strategy for economic development in the EU, strengthening its position globally. However, this has to be complemented by a long-term industrial strategy that prepares industry for the digital and low-carbon economy and allows industry to remain competitive and just while decarbonizing" [51].

Figure 26: Elements of the Green Deal [8].

In addition to the climate neutral plan, the Commission also mention the concept of circular economy. In a communication report from the European Commission to the European Parliament, European Council and the European Economic and Social Committee, it was stated that "in March 2020, the Commission will adopt an EU industrial strategy to address the twin challenge of the green and the digital transformation. Europe must leverage the potential of the digital transformation, which is a key enabler for reaching the Green Deal objectives. Together with the industrial strategy, a new circular economy action plan will help modernize the EU's economy and draw benefit from the opportunities of the circular economy domestically and globally. A key aim of the new policy framework will be to stimulate the development of lead markets for climate neutral and circular products, in the EU and beyond" [8].

3.5.3. Europe fit for the Digital Age

Since 2014, the European Commission has taken a number of steps to facilitate the development of a data-agile economy. The EU's digital strategy aims to make the digital transformation work for people and businesses, while helping to achieve its target of a climate-neutral Europe by 2050 [51]. "On 10 March 2020, the Commission laid the foundations for an industrial strategy that would support the twin transition to a green and digital economy, make EU industry more competitive globally, and enhance Europe's open strategic autonomy" [93].

The pandemic has drastically affected the speed and scale of this digital transformation. To accelerate the twin transitions, the Commission has proposed:

- **Transition pathways:** co-create jointly with industry and stakeholders, transition pathways to identify the actions needed to achieve the twin transitions, giving a better understanding of the scale, benefits and conditions required.

- **Multi-country projects:** to support the recovery efforts and develop a digital and green capacities, the Commission will support Member States in joint projects to maximize investments under the Recovery and Resilience Facility.

- **Analysis of the steel sector**: to ensure a clean and competitive steel industry, the Commission analyses and addresses challenges for this sector.

- **Horizon Europe partnerships:** bringing together private and public funding to finance research and innovation on low-carbon technology and processes.

- **Abundant, accessible and affordable decarbonized energy:** the Commission will work with Member States to accelerate investments into renewables, grids and address barriers.

Small and Medium Enterprises (SMEs) must be considered in all efforts under the strategy as a main vehicle of innovation in many ecosystems. Increased attention to regulatory costs for SMEs reflects this is on a horizontal level. Whether it is a reinforced Single Market, decreased supply dependencies, or expedited green and digital transitions, new steps will benefit SMEs and start-ups significantly. The strategy also contains some initiatives aimed specifically at SMEs, such as greater resilience, late payment prevention, and solvency support [93].

4. MADE© – Competence Center I4.0

From a public-private partnership, MADE© was created in 2019 to support the enterprises in their digital transformation towards Industry 4.0. It is part of the Competence Center and the Digital Innovation Hub led by the *Politecnico di Milano* along with 43 companies as partners to exchange technological skills [44].

MADE©'s main goal is to provide companies in the manufacturing industry the necessary services (e.g., trainings and guidance, digital tools, applied research) that allow them to implement 4.0 tools and reshape their organizational and business models to keep competitive advantage. In an article published by the School of Management in 2019, Marco Taisch, President of the Competence Center, stated that "companies that turn to MADE will therefore be supported in a path of growth and adoption of new digital technologies to cover the entire life cycle of the product, allowing them to "touch" and understand how the solutions currently available can be used to improve their competitiveness" [45].

The visitors can have access to the latest digital technologies for the manufacturing industry, which are divided in 6 main areas:

1. Artificial Intelligence
2. Digital Factory
3. Collaborative Robotics
4. Additive Manufacturing
5. Smart Energy Monitoring & Control
6. Big Data Analytics and Industrial Cyber Security

In each area is presented some use cases related to the different technologies. The idea is to present each technology in in deep in each area, but also explain the potential of those technologies when combined. In the area of Artificial Intelligence "for example, it will be possible to understand how augmented reality can be used in the design phase or to support plant maintenance remotely" [45].

Given that Industry 5.0 is related to the return of the human touch to the manufacturing process, in this paper we will discuss more in deep the area related to the Digital Factory. In addition, this are representing the heart of the industry, since it where the human-machine process happens and where products are made, that is, where the business performance can be verified.

4.1. Digital Factory

The area of the Digital Factory reproduces the context of a small and medium manufacturing company - it simulates the production of mechanical valves for the oil & gas sector -, where its objective is to show that new technologies can be inserted in the factory to support work and company's performance.

The area exploits the advantages deriving from the use of digital tools, such as Industrial IoT, Cloud, Data Analytics, Collaborative Robotics, Virtual Commissioning, Product and Process Digital Twin. Inside the factory there is a production line, consisting of:

- Warehouse 4.0
- Mechanical processing station for customized components
- Manual assembly station 4.0
- Automatic assembly and quality control station

Inside the factory, handling is entrusted to 2 automated guided vehicles (AGVs) and a 4.0 roller conveyor. Two collaborative robots are integrated into the production cycle to support valve handling and assembly activities.

The software architecture of the Digital Factory supports the operational management of the factory in every activity and allows the extrapolation of information/data for strategic and operational choices.

The tracking of quality and progress are ensured by the real time monitoring platform of the product, with functionality also of reproduction and analysis of past flows. The warehouses are managed by a Warehouse Management System (WMS) in the cloud and are directly connected to the order requests from the end customer.

The Manufacturing Execution System (MES) schedules the activities of the workstations and coordinates the automatic transport provided by the AGVs to ensure that the workflow runs smoothly.

The technologies are at the service of operators even in the most manual activities, such as the pick-to-light that supports the picking of the material and the assembly of the product, the collaborative robot that support the operator in moving the heaviest loads. In this area, it is presented three use cases: Lean 4.0, Logistics 4.0 and Digital Twin.

4.1.1. Lean 4.0

The area demonstrates the potential of Lean to support the introduction of 4.0 technologies in operations and vice versa, where the Lean 4.0 methodical approach defines a lean and agile factory in which it is possible to implement and make the most of all 4.0 technologies without digitizing/automating waste. “At its core, the lean philosophy is to improve processes by removing *muda* (waste), muri (overburden) and *mura* (unevenness) from the process”, where waste can be considered as transportation, inventory, motion, waiting, overproduction, overprocessing and defects [37].

Lean for digital transformation demonstrate that 4.0 technology allows companies to collect individual requests from end customers and channel them directly into the factory optimizing the available resources. In addition, continuous improvement is essential to innovate, but time is required to devote to projects. New technologies make it possible by significantly reducing the time required to collect data intelligently and to pre-analyze the context.

For the Lean 4.0 use case, the area counts with the following technologies and partners:

- **Automatic Production Assistant - APAS (Bosch):**

The APAS was created to make robot technology simple to use, where any worker could utilize it without specialist expertise [82]. Cobots are flexible assistants in which its application in manufacturing helps on the reduction of setup time, supports human workers with repetitive methods or ergonomically demanding tasks or in tasks that require safety procedures. In addition, it helps to increase workers’ engagement by allowing them to apply their knowledge to enhancing the process rather than just operating it [37].

- **ActiveAssist (Bosch):**

The ActiveAssist is the evolution of manual workstations, as it is a freely configurable software that supports employees with targeted information and help functions and guides them intelligently through the assembly process. With ActiveAssist, the assistance system identifies the workpiece by RFID or barcode and loads the required work plan immediately onto the monitor, making it visible to the user. The work instructions are then projected directly onto the work surface using a projector and the correct grab container is marked. The employee's movements can also be tracked via 3D cameras, making it possible to automatically confirm individual work steps [84].

- **Extended Transportation System - XTS (Beckhoff):**

The XTS combines the advantages of the linear system with those of a rotary solution. With individual motion profiles for each individual product, whenever the slowest processing station determinates the speed of the complete production, the XTS can achieve higher throughput rate via variable product speed, hence, time losses can be absorbed by accelerated individual products transport between stations [86].

- **Active Cockpit (Bosch):**

The Active Cockpit is an interactive platform for processing and displaying production data in real time. Active Cockpit networked IT applications such as production planning, quality data management and e-mailing with the software functionality of machines and plants.

The information is the basis for decisions and process improvements. Its intelligent networking saves information processing time can be extended with other apps (e.g., Value Stream, Lean Indicator, Deviation Manager) [85].

- **Electronic Kanban (Modis):**

Sensor designed to improve the management of the supply of materials to production lines and to help companies make the supply chain more efficient; significantly reduces errors and delays in picking operations for the creation of assembly kits.

- **MindSphere (Siemens):**

Using advanced analytics and artificial intelligence, power IoT solutions from the edge to the cloud with data from connected products, plants and systems to streamline operations, create better quality products and implement new business models.

- **NX CAD-CAM (Siemens):**

Integrated solution that helps deliver better products faster and more efficiently, supporting every aspect of product development, from concept design to engineering and manufacturing.

4.1.2. Logistics 4.0

The Logistics 4.0 solutions exploit IoT, RFID and advanced automation technologies to create an efficient, coordinated material and information flow useful for the control and continuous improvement of the system.

The area demonstrates the potential of 4.0 technologies to support material handling in the company through automated handling of the material within the factory and real-time tracking of the product within the Digital Factory.

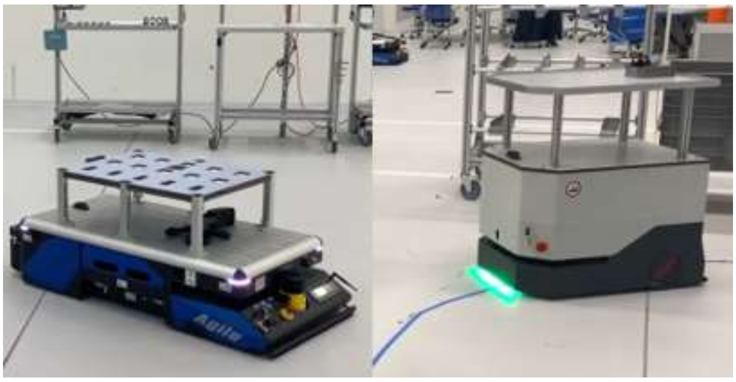
Hardware that supports physical material handling such as AGV and Collaborative-Robot. These technologies free operators to carry out activities with greater added value and represent handling systems with a high potential for reconfigurability.

Hardware supporting software. Fundamental for the acquisition of information, such as the use of assets, the real-time traceability of the product. All the information necessary for the optimization of resources.

- **Pick to light system (Modis):**

Allows the operator to be guided through a light signal to the locations from which to take the necessary material. Pick to Light is the technological and smart solution for picking, kitting, manufacturing - setup lines, material call, electronic Kanban, wireless button application. Pick to Light allows you to get the following benefits: reduction of wiring costs, precise picking operations, significant reduction of errors in picking operations, possibility of making several operators work, simultaneously, complete integration with systems MRP, ERP, MES, WMS of the customer.

- **Automated Guided Vehicles - AGV (SEW and Comau):**



Self-driving vehicles used for transport that allow the management of internal automatic material flows, where among its benefits are reduction of complexity, ability to adjust processes and paths so to respond quickly to changing requirements, reduction of travel distances and reduction of costs.

- **RTLS UWB (Siemens):**

Indoor localization system that allows the display of the positions of the transponders in real time and the history of the positions of a commodity and / or an AGV on which it is installed.

- **Bluetooth Low Energy - BLE (Italtel):**

The BLE allows proximity tracking (area tracking) to locate resources and know their movement / use statistics by dividing the environment into areas with dedicated receivers, small battery-powered tags and an integrated application platform.

- **RFID system (Siemens and Italtel):**

UHF RFID technology is used to manage and control material flows and obtain real-time and historical information to improve the planning and control of production and handling activities, through reading antennas, labels very low-cost adhesive and an integrated application platform.

- **Middleware "Connect" (Modis):**

Application software for integration of field systems and automation. The connection between the devices and the Connect is managed directly by the SW or it can be interfaced with the machine management SW through different protocols.

- **Business logic - LEA Orchestrator (Reply):**

Cloud microservices platform with the aim of orchestrating and tracing the physical flows of materials necessary for the production of the "valve".

4.1.3. Digital Twin

The Digital Twin allows you to thoroughly analyze the characteristics of the production process and the product, prevent design errors and predict final performance. At the same time, it becomes and enabling technology for new methods of analysis and business models.

The Digital Twin as a support to the design of the factory and of the machines: from virtual commissioning to performance analysis, system simulation and ergonomics of operations.

There are 4 levels of Digital Twins:

- **The Digital Twin of the operations system:** focused on overall performance, useful for cost and performance analysis, planning and control, evaluation of bottlenecks, investments (Siemens, HyperLean)

- **The Digital Twin of the machine:** virtual commissioning, thanks to the Digital Twin of the mechanical part of the machine, design errors can be recovered without having to test in the field. The Digital Twin of the machine integrates automation and mechanics, for higher quality in the start-up phase (Siemens Engine Soft).

- **The Digital twin of the manual station:** the digital twin replicates the working conditions of the manual station and stimulates the activities carried out by the operator. In this way, he can calculate compliance with safety and ergonomics parameters, as well as find the configuration of the activities and the workstation that optimizes his efforts.

- **The Digital Twin of the product (CAD-CAM):** from a technical drawing input, the digital twin is able to automatically (also virtually) simulate the part-program of the process necessary to produce the piece from a neutral machine. It is also able to integrate the machining part-program with the

Digital Twin of the machine, thus predicting any design errors and anticipating product performance and costs (PTC).

Among the technologies presented at MADE, there are:

- **Plant Simulation (Siemens):**

Discrete event simulator allows you to create digital models of logistics and production systems for exploring the characteristics of the systems and optimizing their performance.

- **Industrial Physics (Enginsoft):**

Software for the Virtual Commissioning and the Digital Twin of machines, cells, lines that allows to optimize the planning of the machine sequence, immediately verify the solutions, and reduce costs.

- **Robot Racer (Comau):**

Innovative articulated arm robot perfect for a wide range of assembly, handling, machining, and arc welding processes.

- **LeanCOST (Hyperlean):**

Software able to support the costing of products with an analytical approach; it automatically analyzes and extracts the geometric characteristics of the model and defines the necessary machining processes.

- **Creo Design Premium Plus PDMLink (PTC):**

Comprehensive 3D software that you can expand and upgrade at any time to meet the changing needs of your design and business requirements.

- **ThingWorx Connected PLM (PTC):**

Enables companies to extend their Windchill PLM environments by developing custom applications. Custom enhancements to a PLM system can help break down organizational silos and make stakeholders more productive.

- **AR Vuforia Studio Starter SAAS (PTC):**

Software that allows you to transform existing CAD and IoT data into detailed AR experiences that provide critical information to frontline workers when and where they need it most, allowing you to increase productivity and worker satisfaction, reduce costs of errors, waste and accidents and improve the customer experience.

- **MCD Virtual commissioning (Siemens):**

Mechatronics Concept Designer is a functional digital twin that provides a common tool for mechanical, electrical and automation disciplines, helping to deliver projects faster and with fewer integration issues at various stages of the design process.

5. Industry 5.0 in Digital Factory

Systemic industrial transformation requires research and innovation. Over several generations, societal and industry-led paradigm shifts have prompted substantial changes in skills and capabilities. The twenty-first century presents itself as a difficult moment that necessitates a unique set of talents that are sometimes disregarded in regular educational environments. The distinction between those born and raised in constant interaction with technology, and the older generations who must learn how to use technology later in life, is relevant since there is a significant difference on how information is received and processed [88]. Work on Industry 4.0 has increased awareness of skills gaps and the need for re-skilling and up-skilling across the board, notably in manufacturing and operations. From entry level employees to board of directors, Industry 5.0 implies mind-sets, skill and capabilities that are trained to understand complexity, think in systems, use complexity-friendly tools and methodologies, design principles, experimental learning, action and reflection cycles, and iterations to support the transformation of existing businesses, both small and large. "Massive change in a company isn't going to be brought about one person. It is not enough for one person to want to change", the whole company has to be on board [39]. A strengthening of public-private partnerships aimed at speeding up economic transformation and collaboration along sustainable lines could encourage European companies and universities to improve [7]. In addition, the shift on companies' mindset from adopting technology solely to increase efficiency and thus profit should also include the idea of adopting technology to collaborate with employees, increase operators' satisfaction, creativity, and decision-making power and ensure resilience in addition to the reduction environmental impact and waste.

The notion of sustainable development arose in the 1980s in response to increased concern about the depletion of Earth's resources and environmental challenges, such as global warming, deforestation, and desertification [36]. "The concept of 'sustainable manufacturing' defined by Bonvoisin J. (2017) aims to create manufactured products that fulfill their designed function throughout their lifecycle causing manageable number of impacts in society and nature while delivering the proposed socio-economic value" [36].

Figure 27: Triple Bottom Line of Sustainable Manufacturing [106].

Nonetheless, there are difficulties in terms of teaching sustainability and sustainable manufacturing, as well as the concepts and requirements of Industry 4.0 and 5.0. Hence, new approaches to education and learning, such as game-based learning and gamification, can be beneficial. Organizations can use the gamification strategy to produce benefits by increasing employee and general customer engagement and encouraging behavior change [36].

One might have come across also with the term serious game, which has a different meaning. Serious games are entire games with the intention of conveying a message to the player rather than having fun. Serious games are a subgenre of serious storytelling, where according to Michael D.R et al (as cited in Paravizo E., 2018), storytelling is applied "outside context of entertainment, where the narration progresses as a sequence of patterns impressive in quality, relates to a serious context, and is a matter of thoughtful process", as currently used by MADE to present the Digital Factory. However, this approach could be implemented in a wider scale, that is, involving the whole MADE in order to make the learning process towards Industry 4.0 and Industry 5.0 more attractive and maintain the players involved engaged from the beginning to the end.

The principles of Industry 5.0 are not a novelty. As previously mentioned, the idea of the concept is to bring back the lost dimensions from Industry 4.0, such as sustainability, human-centricity, and resilience. In terms of technology, some are already present at MADE, such as Cobots and Digital Twins, however, it will be necessary to integrate I5.0 vision to teach the companies that these principles bring nothing but whole new level of benefits for the company itself. For instance, according to Carol Cone (2019), member of the Forbes Councils, satisfied employees achieve a productive output of 100%, engaged employees achieve 144% and inspired employees over-achieve with a productivity rate of 225% [94]. "Organizations whose employees, communities, and customers are deeply engaged will outperform those that cannot engender authentic motivation. This is especially true in a world where competition is global, and technology has radically lowered barriers to entry. Engagement is your competitive advantage" [41].

Furthermore, Talal Rafi (2021), another member of the Forbes Councils, put together some of the main reasons why companies should care about sustainability strategies [95]:

- It adds brand value and increase competitive advantage, as millennials, baby boomers and generation Z are becoming increasingly concerned about sustainability.

- Meet consumer demands, given the change in the trend among consumers towards supporting sustainability.

- Increase efficiency, as sustainability strategies can reduce costs and affect operating profits, according to McKinsey.

- Attract talent and lead to employees being more motivated to work because they see value in what the company is doing.

- Create new opportunities, helping the companies to tap new markets and expand into existing ones.

Regarding resilience, Jim Purcell (2020), a Forbes contributor, presented its role in human well-being, stating that it "enables employees to protect against negative experiences which otherwise could be paralyzing. And it helps employees maintain emotional balance during the adversity we're experiencing today and reduces the likelihood of debilitating stress or depression" [96].

In addition, the European Union will promote a more appealing investment climate as well as growth that generates high-quality jobs, particularly for young people and small enterprises. By advocating multilateralism and a rules-based global order, the EU will increase its global voice. Some elements belonging to the Industry 5.0

concept are already part of some major Commission policy initiatives, such as the adoption of a human-centric approach for digital technologies which is part of the Proposal for AI regulation; the up-skilling and re-skilling of European workers which is part of the Skills Agenda and Digital Education Action plan; resource-efficient and sustainable industries which is part of the Green Deal; and the speeding up investment in research and innovation included in the Industrial Strategy [50].

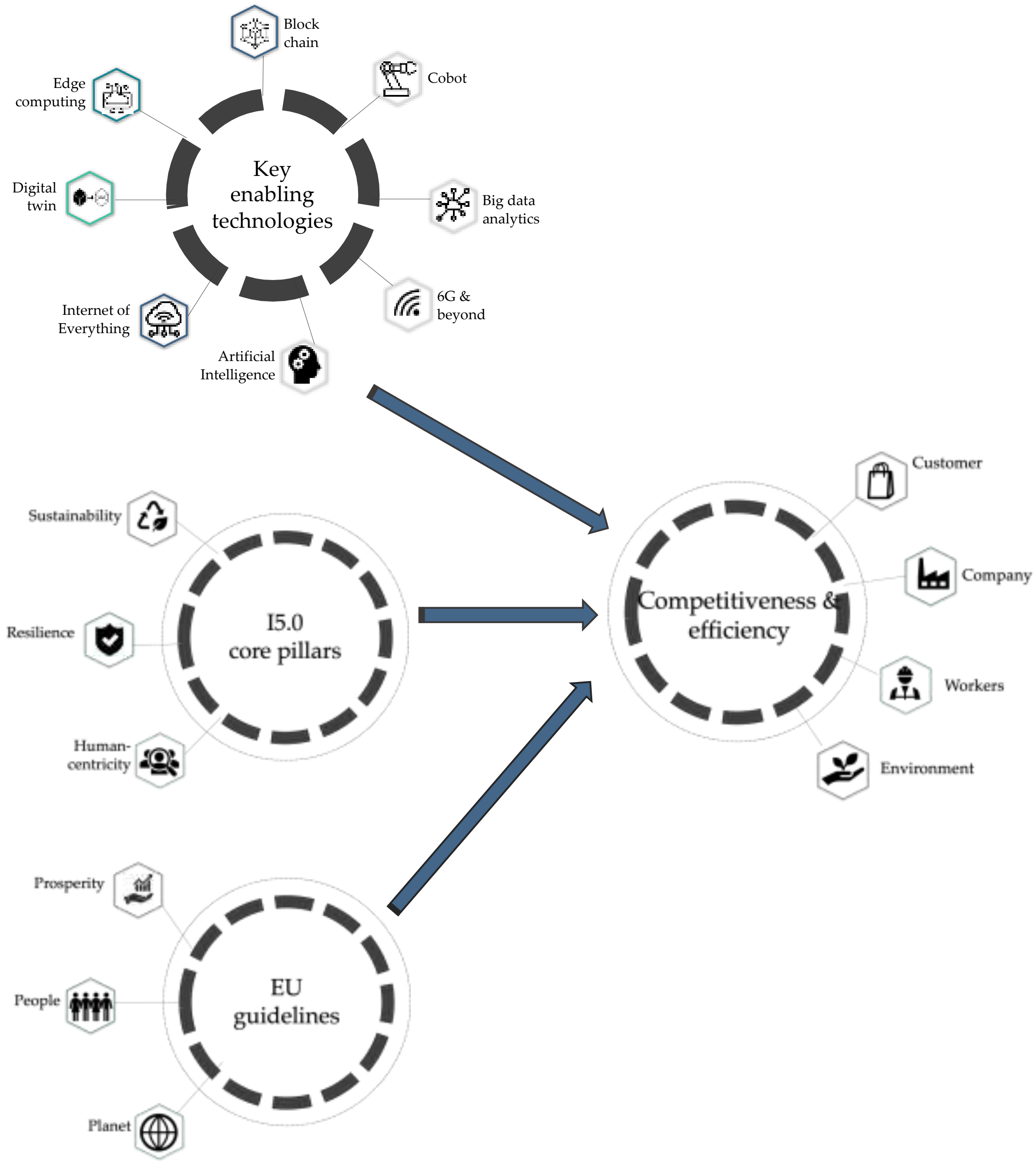


Figure 28: Elements towards Industry 5.0's companies.

5.1. Gamification to support change

MADE is the place where companies can go to learn what is Industry 4.0 and its technologies, how to start and/or proceed with their digital transformation in order to improve their productivity and efficiency, optimize operations, and increasing profits. In addition, sustainability is a topic that has been already covered in MADE and is embedded in some areas and technologies, for example the Smart Energy Monitoring & Control area, where the focus is on energy efficiency, that is, the use of less energy to perform the same task or produce the same result.

As learnt in the previous chapters, the concept of Industry 5.0 should be taken into consideration since the design phase of any transformation, which might happen at MADE, where it could be provided the big picture, which is not only the digital transformation as a protection against competitors and disruptions, such as the pandemic, but also the challenges the world is facing, what the public authorities are doing about it and how companies could contribute to keep competitiveness while not impacting on the environment, contributing with the society and becoming more innovative.

However, when it comes to changes, companies are usually concerned on what they will gain in return by changing. This is known as an extrinsic motivation, which according to Werbach K. and Hunter D. (2012) is when "you are motivated to do something by reasons that come from outside your enjoyment or engagement with the activity" (e.g., because you want to impress your boss, because other companies are doing so, and you don't want to stay behind). Opposite to extrinsic is the intrinsic motivation, when, "for the person involved, [motivation] lies inside the activity". One way to make an extrinsic motivation into an intrinsic motivation could be through gamification. "A well-designed game is a guided missile to the motivational heart of the human psyche" [41]. According to Deterding S. et al (as cited in Paravizo E., 2018), "gamification is defined as the use of game design elements in non-game contexts". Paravizo E. [28] published a study aiming to develop a conceptual framework for gamification implementation tackling sustainability awareness issues.

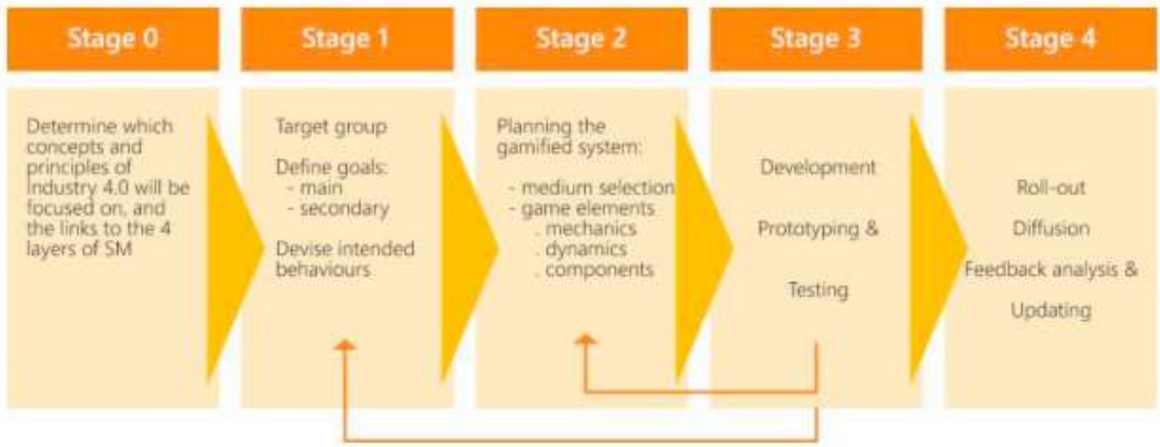


Figure 29: Elements of the Green Deal [8].

As a first step, MADE could be considered as the game designer, while the visitors are the main customers and partners are secondary customers. The objective is to engage the main customers in the learning process so they can be able to implement sustainable and social practices in their manufacturing processes, as well as incentive them to do the same with their employees (i.e., learn and engage). As well as engage the secondary customer in the activities proposed in MADE to the main customers. "Gamification is the process of manipulating fun to serve real-world objective" [41].

Game thinking asks why customers use your service in the first place. In other words, it asks, 'what motivates them?' and 'what is it about you that makes them want to do business with you?'. In the case of MADE, it is possible to apply the 6 steps for gamification implementation proposed by Werbach K. and Hunter D. [41], since they are more robust and also includes the proposed approach of Paravizo E.:

1. DEFINE business objectives

Objective	Benefit for MADE
Attract visitors Have the visitors engaged in the activities offered by MADE Have visitors making and finishing their projects	More visibility of MADE and its partners and increase of credibility.

2. DELINEATE target behaviors

- Visit MADE
- Attend the seminars
- Close deals for projects with partners
- Share information about the progress

3. DESCRIBE your players

What makes them less likely to complete a relevant task? Faculty - a perceived lack of capability → call for progression systems that gently walk the player up the difficulty curve [28].

4. DEVISE activity cycles

- Visit to the 6 areas
- Consultancy with MADE expert
- Consultancy with technology expert (partner)
- Seminars

According to Werbach K. and Hunter D. [41], there are two types of cycle to develop: engagement loops (i.e., players action result from motivation and in turn produce feedback, such as points) or progression stairs (i.e., it reflects the fact that the game experience changes as players move through it, which is the case of levelling up).

5. DON'T forget the fun

Main customers: autonomy to choose the building blocks of knowledge to achieve their main goal, sense of competition, sense of mastery after fining an activity, sense of being part of a group towards a better future.

Secondary customers: sense of competition.

6. DEPLOY the appropriate tools

Pick the appropriate mechanics and components and coding them into the system. In the case of MADE: Cooperation, feedback, rewards, badges, leaderboards. In addition, according to Werbach K. and Hunter D. [41], expertise in more than one area is needed, such as people who understand the business goals of the project, an understanding of the target group of players and the basic psychology, game designers, analytics experts, and technologists.

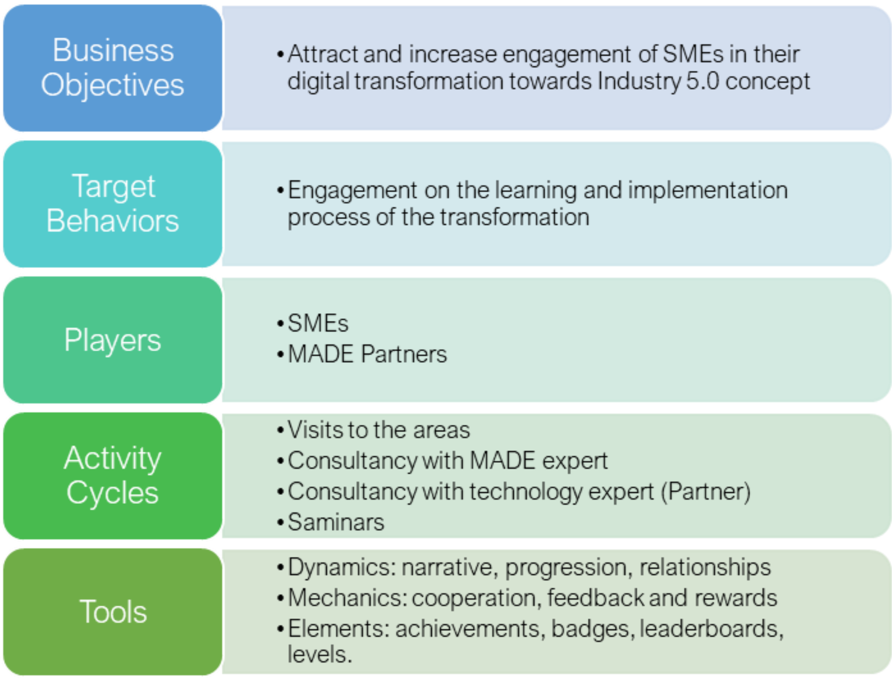


Figure 30: Gamification steps.

Given the type of the main player, which calls for progression systems that gently walk the player up the difficulty curve, that is, progressions in companies' digital transformation, the appropriate dynamics applied would be progression along with narrative and in combination with feedback, rewards, and levels. "This is one reason why many videogames involve levels. Players start at Level 2 and pass through increasingly challenging stages as they progress. Reaching a new level is an accomplishment that gamers call 'levelling up'. Levelling up signifies progress and offers opportunities for encouraging feedback. Without levels, players may lose interest because they have no measurable sense of progress" [41]. Leveling up or earning badges signals to the player that they are progressing toward mastery of a valuable skill [41].

In addition, a feedback loop might push players towards a desired behavior, especially when provided real-time feedback. For instance, "homeowners turn their thermostats down when given real-time feedback on what happens when they turn it up" [41].

Researchers Judd Antin and Elizabeth Churchill (as cited in Werbach K. and Hunter D., 2012) suggested that a well-designed badge system has five motivational characteristics:

1. Badges can provide a goal for users to strive toward, which has been shown to have positive effects on motivation.

2. Badges provide guidance as to what is possible within the system and generate a kind of short land of what the system is supposed to do. This is an important feature for 'onboarding', or getting the user engaged with the system.

3. Badges are a signal of what a user cares about and what he or she has performed. They are a kind of visual marker of a user's reputation, and users will often acquire badges to try to show other what they're capable of.

4. Badges operate as virtual status symbols and affirmations of the personal journey of the user through the gamification system.

5. Badges function as tribal markers. A user who has some of the same badges as other users will fell a sense of identify with that group, and a clever gamification design can connect the badges with a system of group identification".

Regarding the second player (i.e., the partners), given the different objective of the gamification system towards them, which is to provide them more visibility, the leaderboard would be the proper component, since players may find racking up a high score or topping the leaderboard inherently stimulating. “Players often want to know where they stand relative to their peers” [41].

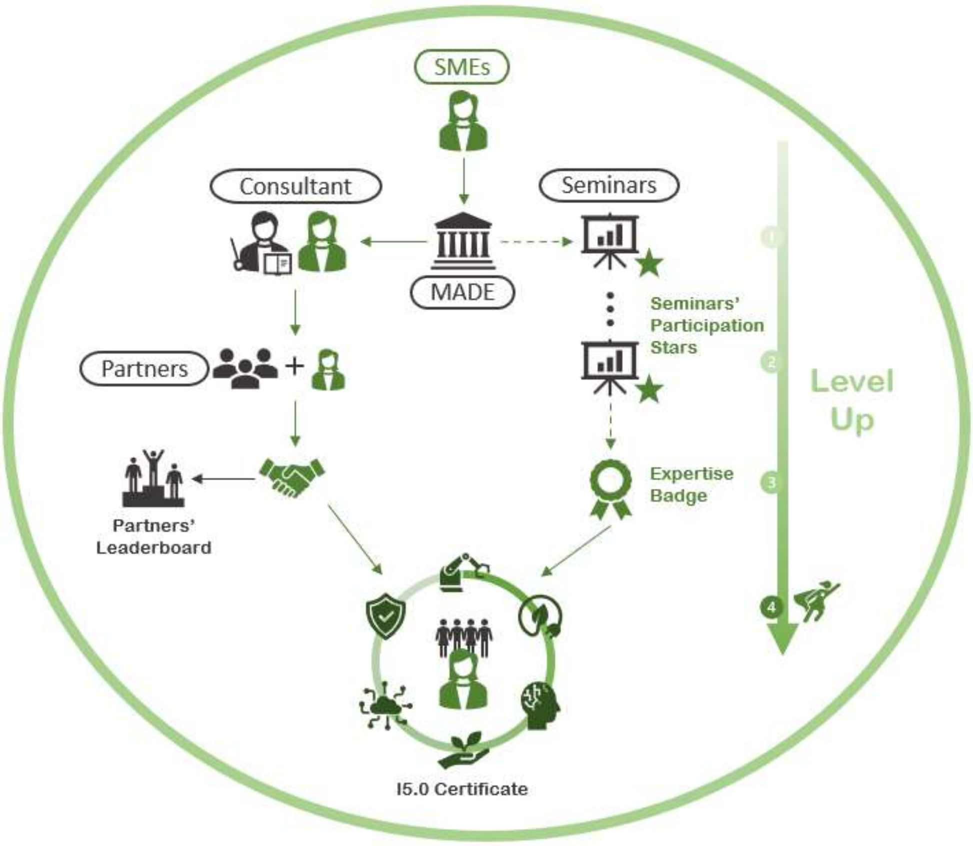


Figure 31: Gamification elements applied to MADE.

The final objective of the main player would be to obtain the expertise related to Industry 4.0 and 5.0 in order to have a successful digital transformation towards the main core pillars of human-centricity, sustainability, and resilience. “One important aspect is that games are voluntary. No one can force you to have fun. Second, games require those who play to make choices, and those choices have consequences that produce feedback. Those decisions affect your experience playing the game” [41]. So, through the trajectory of the company in MADE, they can choose which seminars are aligned with their vision, so they can build by themselves a strategy to accumulate the necessary knowledge to achieve their final goal.

5.2. Technologies, Techniques and I5.0 Core Pillars

As seen in chapter 4.1., MADE has been already presenting technologies which are in line with the Industry 5.0 concepts, such as the Cobots, ActiveAssist, Pick-to-Light, Automated Guided Vehicles and Extended Transportation System, which could assume as human-centric since these technologies can be seen as a mean to serve, support and adapt the production to the diverse needs of the worker, shifting from being a technology-driven process to a human-centric approach. In addition, those technologies should be seen as a prioritization of the physical health, mental health, and wellbeing of workers.

Technologies such as the ActiveAssist and Pick-to-light are very important when it comes to new workers, given that they guide the operator throughout the whole process of assembly or picking, respectively, and at the same time teaching the process to the operator and avoiding that mistake are done.

Digital Twins couple the physical and digital work enabling companies to monitor both systems, prevent issues, develop new opportunities, and simulate future outcomes, which could be used as powerful tool to become more resilient, hence, support key infrastructure in times of crisis.

Some of those technologies have already embedded the sustainability concept, however it is crucial, from the Industry 5.0 perspective, to provide a holistic view of this pillar, that is, not only present sustainable solution in the manufacturing processes, but also in the product lifecycle, as the latter is directly linked to the business strategy of companies.

Sustainable manufacturing was approached by Haapala K.R. (2013) "through looking at manufacturing processes employed in several industry contexts and manufacturing systems, which focus on the design of production systems environmentally aware and the design of closed loop supply chains that account for the whole product lifecycle" [36]. There are many activities across product lifecycle that can help achieve sustainable development targets, and according to Stark J. (2005, p. 67), "they include reducing the quantity of energy and materials used, reducing the quantity of energy and materials wasted, finding new ways to reuse materials, finding new ways to recycle material, improving energy-recovery rates of incineration, improving landfill productivity".

Techniques such as lifecycle design, lifecycle analysis and lifecycle assessment play an important role in sustainable manufacturing [36], and those techniques could be part of the path visitors make in MADE, given that the concept of Concurrent Engineering, which should be applied at the early stages of product development, and due to the fact that it considers the expertise of different people. If product design wants to avoid problems during manufacturing, the product development team needs to consider all the constraints in manufacturing since the beginning (and during all the lifecycle phases) by asking the manufacturing team. This multidisciplinary approach leads to consensus decision making, hence, providing relevance to all members of the team and stimulating personal and professional growth.

Furthermore, a methodology that has been introduced to guarantee that criteria is respected during the design phase, such as reliability, manufacturability, ergonomics, sustainability, and son on is known as Design for Excellence or simply Design for X, where X is a variable which can have one of many possible values and be directed to any lifecycle phase (i.e., beginning of life, middle of life and end or life). For instance, Design for Environment follow four simple rules [40]:

- Design products and processes with industrial materials that can be recycled continually with no loss in performance, thereby creating new industrial materials

- Design products and processes wit natural materials that can be fully returned to the earth's natural cycles, thereby creating new natural materials

- Design products and processes that do not produce unnatural, toxic materials that cannot be safely processed by either natural or industrial cycles

- Design products and processes with clean, renewable sources of energy, rather than fossil fuels

Design for Environment expands the traditional manufacturer's focus on the production and distribution of its products to a closed-loop lifecycle (i.e., where end-of-life products are recycled into the same product) [40].

Another important criterion which is relevant in the Industry 5.0 application context is the Design for Ergonomics, which involves designing the workplace to fit the needs of the worker rather than trying to make the worker adjust to the workplace.

Good ergonomic design increases work quality and production, as well as worker well-being.

In a manufacturing context there is an increasing awareness on the need of undertaking more responsible actions, circular economy is an emerging paradigm that is gaining the attention of governments and organizations across the world, being widely considered as a promising concept that allows a more sustainable development in a changing socio-economic world. In terms of technology, Industry 5.0 aspires to grasp the benefits of enhanced digitalization, big data, and artificial intelligence, while emphasizing the role these technologies can play in meeting new, emerging needs in the industrial, societal, and environmental landscapes. This involves deploying technology for circularity and sustainability [4,101]. "Technologies like AI and additive manufacturing can play a large role here, by optimizing resource-efficiency and minimizing waste" [4]. In addition to the environmental benefits, the circular economy model stimulate innovation, boost economic growth, and creates jobs [101].

In March 2022, the European Commission released the first package of measures to speed up the transition towards a circular economy, as part of the circular economy action plan.

Figure 32: Circular Economy approach [101].

It is valid to highlight that since 2005 the European Commission has been working on the "European Platform on Lifecycle Assessment" (LCA), which is a methodology that work along with the Product Lifecycle Management and Circular Economy. LCA is a structured, comprehensive, and internationally standardized method to help companies to avoid resolving one environmental problem while creating others. "The benefit of LCA is that it provides a single tool that is able to provide insights into upstream and downstream trade-offs associated with environmental pressures, human health, and the consumption of resources" [102].

Within Product Lifecycle Management, there is Product Data Management (PDM) and Collaborative Platforms, which software that aim to ensure that all stakeholders involved have a similar understanding, that there is no uncertainty throughout process execution, and that the highest standards of quality controls are maintained.

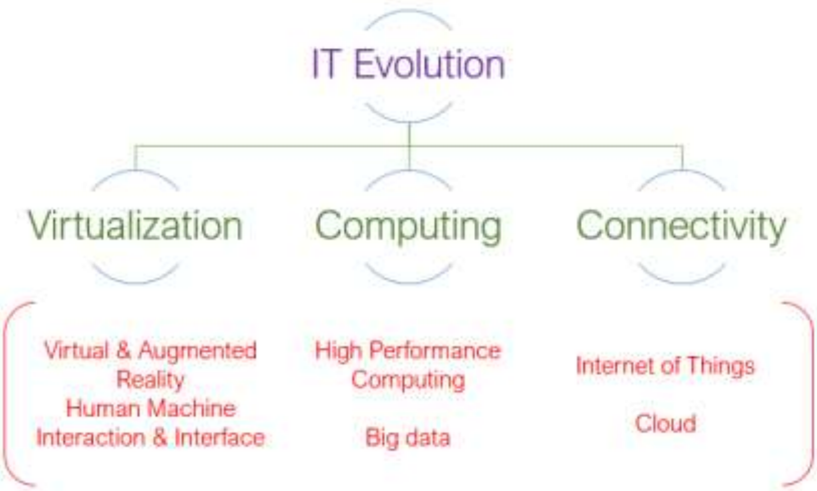


Figure 33: IT Evolution [11].

With PDM system it is possible to create manage and carry out automated workflow-driven processes that mirror industry-best practices for change planning (what-if analysis), change incorporation (execution), change verification, and change communication, which fits on the Industry 5.0 concepts, since it calls for the human-centricity, that is, the use of a collaborative platform that enables different departments to communicate – hence fitting the technology to a need of the company's workers, that is, find the correct data quickly -, in order to avoid late changes in product development and, consequently, reducing development errors and costs, improve productivity and reduce cycle times, improve operational resources, improve value chain orchestration, and so on. Furthermore, PDM can be an important tool in terms of sustainability, given that sustainability-related information could also be added in the system. Inside the system, entities are related through different relationships that allow also to describe different aspects of a product. "As an example, by linking product factory and sustainability through a relation, it is possible to declare different environmental indicators for the same product when it is produced in different factories" [20].

5.3. Partners & Industry 5.0

In January 2022, Siemens published in the blog section of the company's website an interview with Dr. Bert Pluymers, Senior Industrial Research Manager at the Department of Mechanical Engineering at KU Leuven, regarding the future of engineering, bringing the topic of Industry 5.0 which, according to the interviewer Jenn Schlegel, "encompass a couple of [Siemens'] major Simcenter[14] trends like digitalization, sustainability, innovation, and AI" [49].

In the interview, Dr. Pluymers starts talking about the evolution of simulation and testing and the increasing relevance of manufacturability, energy efficiency, ecology, and material usage since 2010. In addition, he said that "because of the environmental impact, there has been a trend towards lightweight materials and structures to reduce transportation and production emissions. There is a lot to take into account these days. As engineers we need to move away from component-level design and optimization toward full-system assessment and optimization where dynamics are still key drivers" [49]. And when questioned if this is where Industry 5.0 steps into the picture, Dr. Pluymers stated that "actually we are moving quickly toward Industry 5.0 because the human is always there. We are making machines and products that humans will sit, move with or operate. Engineering will have to become more human-centric".

[14] The Simcenter is a portfolio of predictive simulation and test applications that support one's digital journey through software and consulting services.

According to the interviewer, one of the main topics of Industry 5.0 is AI (Artificial Intelligence). By providing some insights on this topic, Dr. Pluymers agreed that AI is applied in many things, however in reality is not so simple, more specifically in mechanical engineering, especially on finding data when really needed, such as mechanical parts failure. "The issue with AI today is real data. Artificial data is abundant today and real data is quite scarce, especially real data which holds information about key events, and which is labelled accordingly" [49]. According to Dr. Pluymers, Digital Twins can be used to generate artificial data to train AI algorithms and AI can be used to represent parts that are difficult to capture by physical models in the Digital Twin [49].

When questioned about teaching complex engineering concepts, Dr. Pluymers agreed with the interviewer that continuous education or "the triple L (Life-Long-Learning) is going to be high on the academic agenda as a whole" [49].

In March 2022, Comau presented innovative strategies and technologies to accompany companies towards Industry 5.0 at the I-ESA[15] 2022 conference in Valencia [108]. In particular, Alessandro Piscioneri, Digital Solutions and Services Segment Leader of Comau, took part in the workshop "Artificial Intelligence Beyond Efficiency". He presented examples of the traits of an industry system that is always changing and lays the groundwork for the development of what is known as Industry 5.0. The Fourth Industrial Revolution's natural development into this new environment is characterized by an increasingly important role for workers in the factory, where Big Data and enabling technologies are used at the operator's disposal to improve and sustain business operations and the work of human resources [108].

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[15] Interoperability for Enterprise Systems and Applications, a conference organized by the Universidad Politécnica de Valencia on behalf INTERVAL (Spanish Pole of INTEROP-Vlab) and the Virtual Laboratory for Enterprise Interoperability, aims to fuel an international debate on tools and methodologies which companies can use to connect, internally and with its stakeholders, useful information and resources to optimize and rationalize the productive processes.

6. Conclusion and future development

Industry is the single largest contribution to the European economy, creating jobs and wealth throughout the continent. Industry consistently accounted for roughly 20% of EU GDP between 2009 and 2019, with manufacturing generating around 14.5% of value [4,42]. European industry is robust, yet it is constantly challenged, since it operates in a rapidly shifting geopolitical environment [4].

Industry must constantly adapt in order to meet these ever-changing problems if it is to continue to provide prosperity to Europe. Only continuous innovation can allow for long-term adaptability [4,42].

Unprecedented levels of competition and increased consumer expectations for speed and customization present challenges for modern organizations, leading to what became known as Digital Transformation, given the rapid advancement of technology and its applications in the industry to help overcoming those challenges. Efficiency, productivity, and cyber-physical systems are at the heart of the Industry 4.0 revolution. Artificial Intelligence (AI), Cloud Connection, and real-time Data Analytics are examples of 'smart' technology that Industry 4.0 has introduced to the manufacturing and industrial sectors. The goal of Industry 5.0 is to accelerate that Digital Transformation by fostering deeper and more effective human-machine and system-machine interactions. Humans and intelligent machines work together to combine industrial automation's accuracy and speed with human creativity and critical thinking abilities.

The nine enabling technologies of Industry 4.0 are expanded upon with Industry 5.0 in an effort to put human well-being at the center of industry. In fact, the first core pillar of Industry 5.0 is human centricity, followed by sustainability and resilience. By integrating Industry 5.0 value-driven efforts with Industry 4.0 technological changes, it will be possible to achieve a more seamless and customized interaction between humans and machines by using embedded sensors and machine learning to facilitate the adaptation of Cobots; AI-powered human/robot collaborations can help to reduce waste and increase sustainability compliance; data management and analysis systems can leverage machine learning to minimize inefficiency and optimize human talent; Digital Twins will allow for maximum innovation and creativity with minimal operational risk; and virtual reality can leverage creativity and problem-solving skills of human/robot partners.

To support the enterprises in their digital transformation towards Industry 4.0, a public-private partnership, MADE, was created. Along with 43 companies as partners to exchange technological skills, MADE's main goal is to provide companies in the manufacturing industry the necessary services that allow them to implement 4.0 tools and reshape their organizational and business models to keep competitive advantage. Through gamification and change in the mind-set regarding technologies application and techniques towards the core pillars of Industry 5.0, MADE could be the starting point for SMEs to become more value and technology-driven at the same time and more engaged in the change process. Furthermore, it is important to guide those companies through the current European Commission priorities, given that they are already in line with the Industry 5.0 concepts, and it is important that companies consider the long-term impacts of changes on all its assets, that is, physical assets, information, employees, suppliers and customer, as social, psychological, and ethical implications, changing role of human resources and information technology, learning and competition with robots might become a serious issue if not properly handled.

This scenario already presents itself as a difficult moment as work on Industry 4.0 that necessitates a unique set of talents, which has increased awareness of skills gaps and the need for re-skilling and up-skilling across the board, especially in manufacturing and operations. In addition, the distinction between those born and raised in constant interaction with technology, and the older generations who must learn how to use technology later in life, is relevant since there is a significant difference on how information is received and processed, which could be explored in further studies to understand and maybe develop a system that fits for both cases.

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Acknowledgements

My heartfelt gratitude goes to my entire family. I was able to attain a significant milestone in my life because of their efforts, and I may never know how to repay them.

A special recognition to my lovely husband Michele, my first supporter and safe guide on this adventure and who has always inspired me to give it my all.

Thanks to Tainara, with whom I collaborated on this thesis, who is not just a talented colleague but also a wonderful friend.

Finally, yet importantly, a special thanks to myself for always having faith in me and for never giving up.

Rebecca Savoretti

I would like to express my special thanks of gratitude to my parents, whose invaluable motivation and support helped me through difficult times.

Besides, I would like to thank my partner, Rebecca, who have been working with me since the IMLAB I and has become a dear good friend.

Tainara Marinho Kitamura