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Industry 5.0: Examining the Role of Human-Centric Approach through Learning Factories

Tesi di Laurea Magistrale in
Management Engineering

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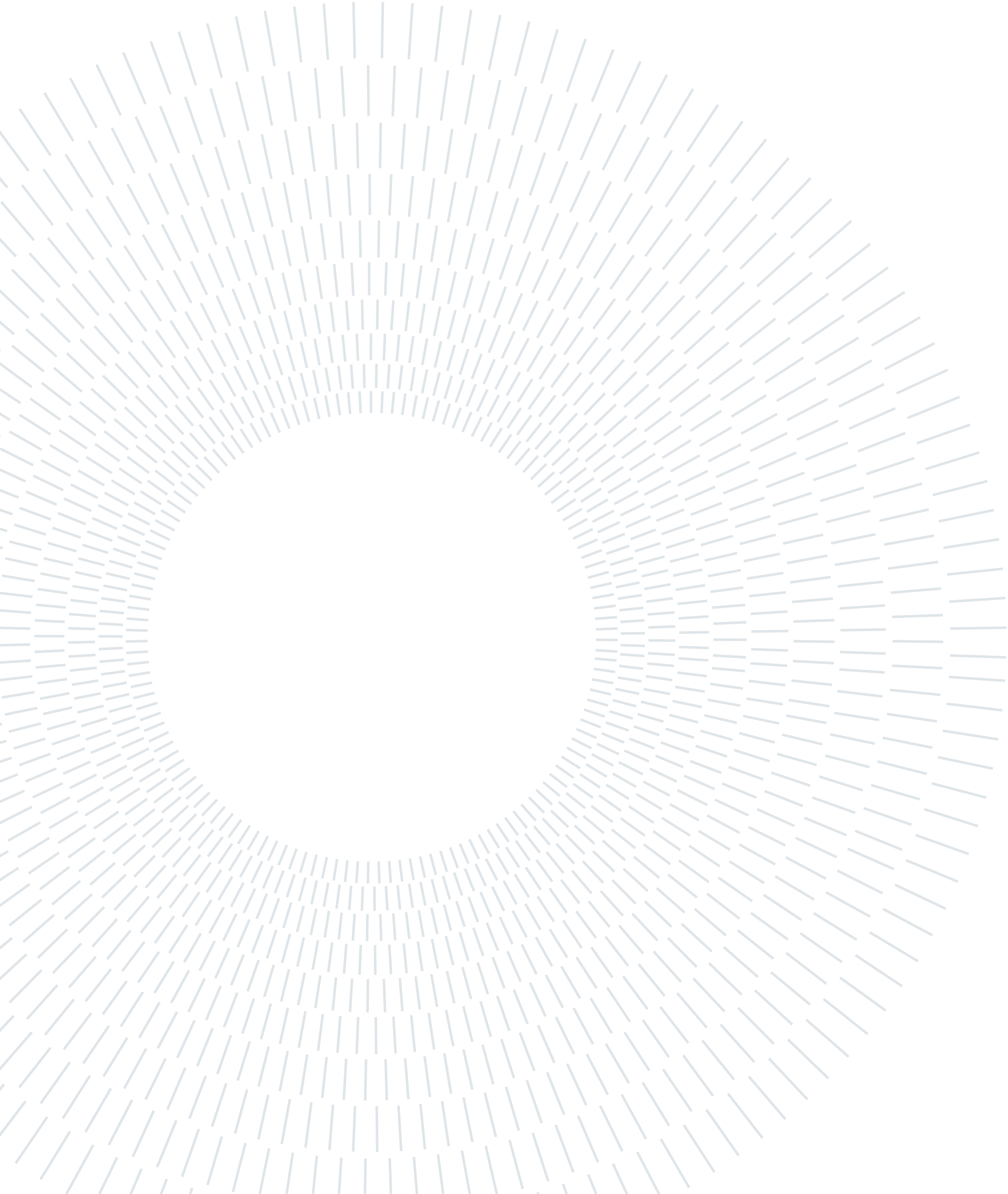


Abstract

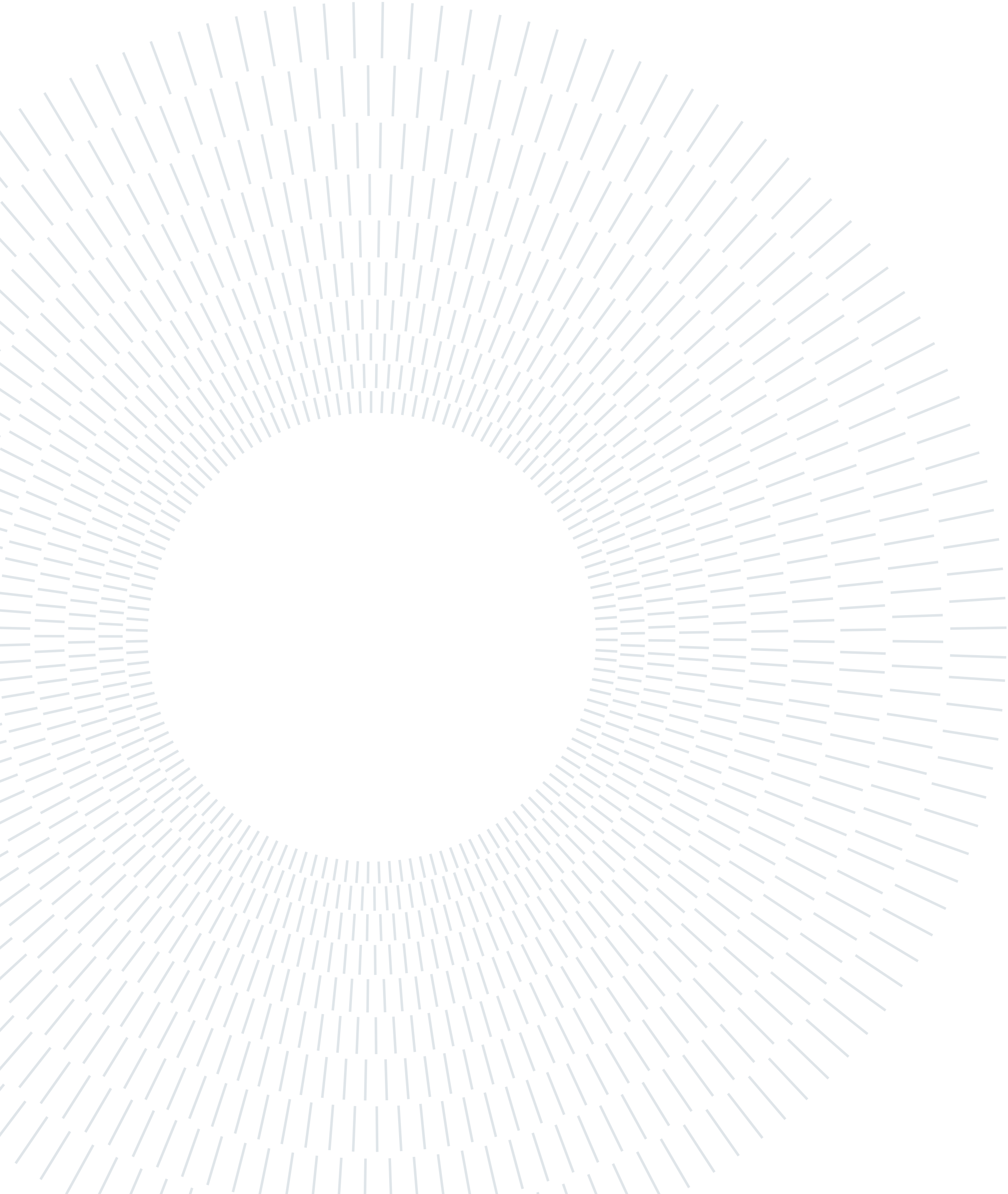
This study explores the human-centric dimension of Industry 5.0, aiming to decode its alignment with the current industry. Through a series of hands-on experiences conducted in a learning factory, it examines how the industry embraces this approach and assesses workers' reactions to novel tasks and advanced technologies.

These experiential learning opportunities were designed within the framework of Constructive Alignment, this methodological approach ensures a direct connection between the learning activities and learning outcomes, thereby departing from conventional lecture-based approaches to practical experiences conducted in a learning factory, which replicates a genuine production environment based on real industrial sites.

The research primarily concentrates on providing practical exposure to Industry 5.0 while soliciting invaluable feedback from industry experts regarding the fundamental values of a Human-centric manufacturing system, particularly emphasizing Safety, Inclusivity, and Empowerment. This research is an outcome of an extensive collaborative effort within the framework of the European Project DE4Human.

In essence, this study illuminates the transformative potential of Industry 5.0 in reshaping industrial practices through a human-centric lens, driving progress in safety, inclusivity, and empowerment. It showcases the adaptability and flexibility that technology can provide, emphasizing the role of collaboration and teamwork in realizing the vision of Industry 5.0.

Keywords: Industry 5.0, Human-centric, Safety, Empowerment, Inclusivity



Abstract in lingua italiana

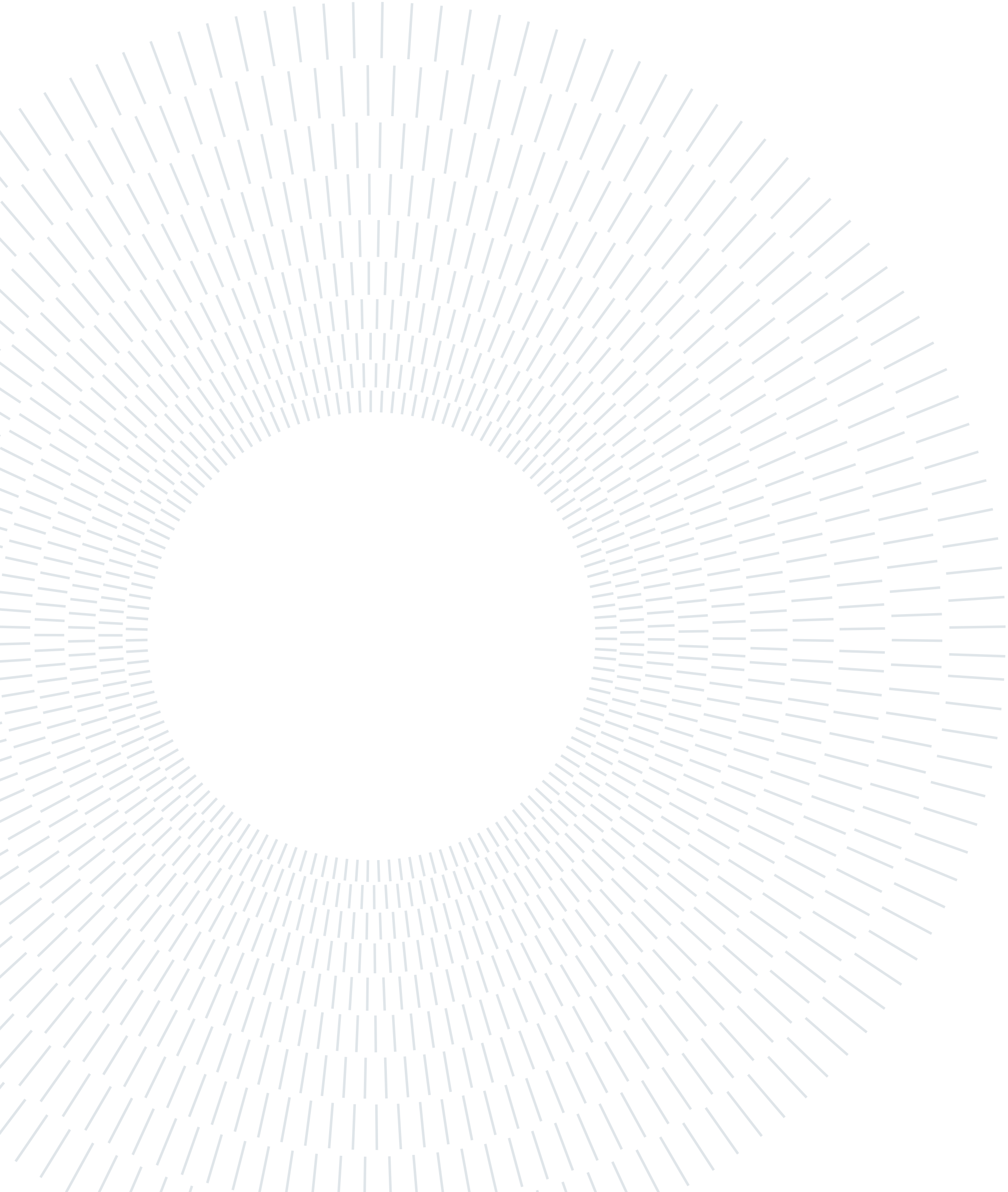
Questo studio esplora la Human-Centric dell'Industry 5.0, con l'obiettivo di decodificare il suo allineamento con l'industria attuale. Attraverso una serie di esperienze pratiche condotte in una learning factory, esamina come l'industria abbraccia questo approccio e valuta le reazioni dei lavoratori a compiti nuovi e tecnologie avanzate.

Queste opportunità di apprendimento esperienziale sono state progettate nell'ambito del Constructive Alignment, questo approccio metodologico garantisce una connessione diretta tra le attività di apprendimento e i risultati dell'apprendimento, discostandosi così dagli approcci convenzionali basati su lezioni frontali verso esperienze pratiche condotte in un Learning Factor, che replica un vero e propio ambiente produttivo basato su siti industriali reali.

La ricerca si concentra principalmente nel fornire un'esposizione pratica all'Industry 5.0, sollecitando al contempo preziosi feedback da parte di esperti del settore riguardo ai valori fondamentali di un sistema produttivo incentrato sull'uomo, sottolineando in particolare la sicurezza, l'inclusione e l'empowerment. Questa ricerca è il risultato di un ampio sforzo di collaborazione nell'ambito del progetto europeo DE4Human.

In sostanza, questo studio mette in luce il potenziale di trasformazione dell'Industry 5.0 nel rimodellare le pratiche industriali attraverso una lente incentrata sull'uomo, guidando il progresso nella sicurezza, nell'inclusione e nell'empowerment. Mette in mostra l'adattabilità e la flessibilità che la tecnologia può offrire, sottolineando il ruolo della collaborazione e del lavoro di squadra nella realizzazione della visione dell'Industria 5.0.

Parole chiave: Industry 5.0, Human-centric, Sicurezza, Empowerment, Inclusione



Contents

Introduction

The evolution of industry has been marked by a series of technological revolutions, each reshaping the landscape of production, employment, and society. From the mechanization of the first Industrial Revolution to the digitalization of Industry 4.0, these transformative waves have propelled humanity forward, altering the way we work, live, and interact with technology. In the current era, Industry 5.0 is the future evolution in this continuous narrative of technological progress, designed for human creativity to work in synergy with the efficiency and accuracy of machines. However, what sets this revolution apart is not merely the advancement of technology itself, but the profound shift in the perspective, that places human well-being and values at the center of industry [4].

Industry 5.0 establishes its basis in three core pillars Human-centric, Sustainability, and Resilience, emphasizing the importance of integrating social and environmental priorities into technological innovation. The objective is not just economic prosperity but a holistic and sustainable advancement that respects the boundaries of our planet [4]. It envisions an industry that thrives, not at the expense of its workers or the environment, but in harmony with them [4].

Industry 5.0 represents a departure from the technology-driven approaches of its predecessors. It advocates for a shift in the paradigm where the welfare of the worker takes precedence within the production system [4]. Safety, Inclusivity, and Empowerment are becoming guiding principles [7], and the relationship between humans and machines assume a harmonious and symbiotic nature [10]. In this vision, technology is not merely a tool to enhance efficiency; it is a means to elevate the human experience within the industrial landscape.

The workers' skills are crucial aspect within the context of Industry 5.0. The demands for skills are undergoing rapid evolution, paralleling the advancements in technologies. Industries confront shortages in skilled personnel, while educational and training institutions find it challenging to keep pace with this ever-growing demand [4]. Learning factories represent a viable approach for training and equipping individuals with the required skill set. By simulating authentic production environments based on real industrial sites, learning factories aim to facilitate experiential, hands-on learning for participants.

Research Objective

The current study seeks to explore the human-centric dimension of Industry 5.0. By immersing participants in a learning factory environment, it attempts to understand how the industry aligns with the principles of human-centric manufacturing. Via examining the reactions and feelings of workers when faced with new tasks and the integration of novel technologies, it aims to shed light on the practical implications of this visionary approach. Our primary objective is to convey and explain the concept of human-centric manufacturing through its three core pillars: Safety, Inclusivity, and Empowerment providing hands-on experiences conducted in a learning factory within the context of Industry 5.0. Our aim is to obtain industry feedback on these fundamental concepts, facilitating a comprehensive understanding of human-centric manufacturing in the evolving industrial landscape.

This research is an outcome of an extensive collaborative effort within the framework of the European Project DE4Human[1], involving participation from both academic and industrial experts. The DE4Human project has been funded by EIT Raw Materials and its mission is to upskill the manufacturing industry and operators on how to use design thinking to build a human-centric, healthy, and more inclusive factory in manufacturing shaping the relationship between humans and machines.

Research Methodology

In order to achieve this purpose, the initial step involved conducting an extensive literature review on the pertinent subjects. Subsequently, the development of two distinct learning factories was undertaken, each tailored to the utilization of different technologies, specifically Collaborative Robots and Exoskeletons. The didactic framework employed for these learning factories adhered to the principles of constructive alignment. This framework establishes a direct and cohesive link between the intended learning outcomes (ILOs) and

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[1] https://www.made-cc.eu/it/progetti-di-innovazione/de4human/

the teaching and learning activities, departing from the traditional lecture-based instructional approach. The learning activities within these learning factories were designed to engage participants and optimize their comprehension of the specified learning outcomes [3].

Figure 1: Constructive Alignment [14].

These learning experiences were structured into three distinct phases. Initially, The participants were presented with a challenging task that required collaborative problem-solving within a team dynamic. Subsequently, a facilitator introduced and discussed a relevant technology, providing a practical demonstration of its application in concert with the task. This demonstration purposefully emphasized key facets related to safety, inclusivity, and empowerment. Finally, the participants revisited the initial task, this time equipped with the technology, allowing them to apply their newly acquired knowledge. After each activity, the participants were encouraged to express their impressions and observations verbally. In addition to this, they were provided with a questionnaire, facilitating the collection of their reflective thoughts and emotional responses.

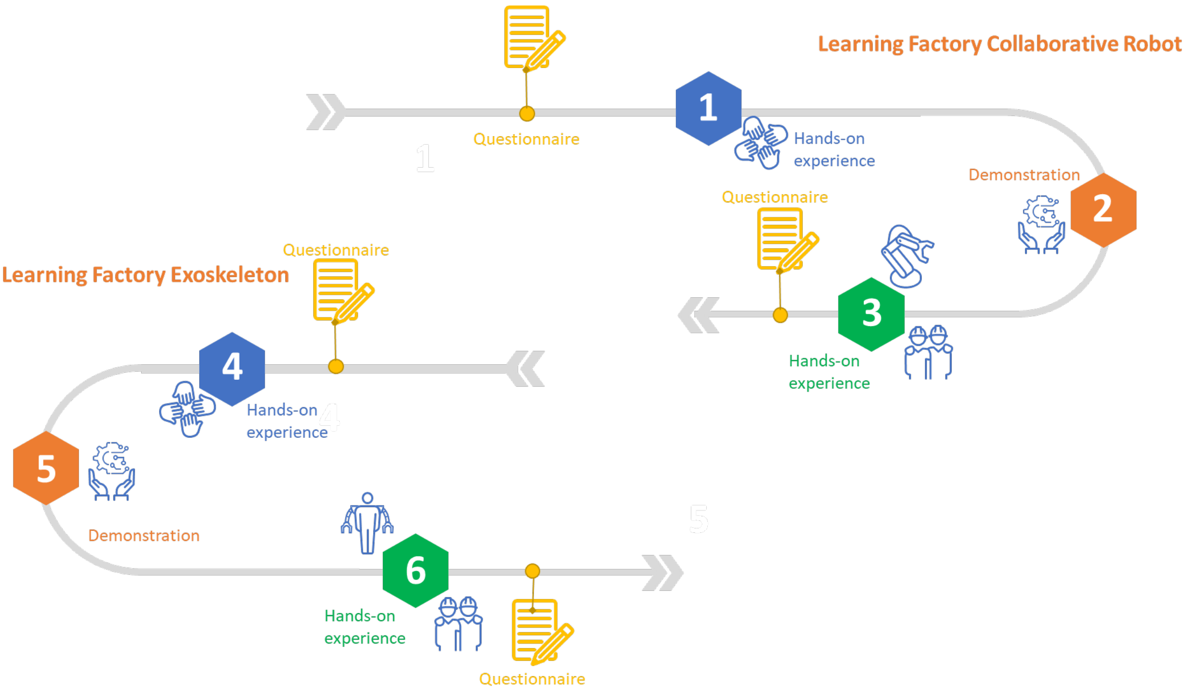


Figure 2: Learning Factories Journey.

In the first chapter, A concise historical overview of the Industrial Revolutions is presented to enhance comprehension of the technological progression and its corresponding cultural and socioeconomic implications. Furthermore, we provide a comprehensive exposition of Industry 5.0, with a particular emphasis on its fundamental pillars, along with a definition of learning factories. In chapter 2 we delve into the development of the learning factories, exploring each facet of the constructive alignment framework. Chapter 3 encapsulates a summary and an insightful analysis of the information gathered. Lastly, a chapter encompassing conclusions and future prospects is provided.

1 | Literature Review

1.1. Industrial Revolutions

An Industrial Revolution is the transition from one production process to another, driven by innovation and a change in technology. the first Industrial Revolution originated in Britain in the century 18th which involved the transition from creating goods by hand to using steam machines powered by coal as an energy source. In the mid-19th century the advances in steel production and the use of electricity, jointly with the introduction of mass production using assembly lines constituted the Second Industrial Revolution. Later in the second part of the 20th century the digital revolution or Third Industrial Revolution, which implies the shift from mechanical and analog technologies to digital electronics marking the beginning of the information age. Nowadays the introduction of connected devices, data analytics, and additive manufacturing technologies marked the fourth Industrial Revolution, which is characterized as the emergence of cyber-physical systems that bring entirely novel capabilities for both humans and machines, Examples include Artificial Intelligence, Augmented Reality, the Internet of Everything, and the Blockchain.

What characteristics have the Industrial Revolutions? The Encyclopedia Britannica denotes the features that mark an Industrial Revolution are three, technological developments, socioeconomic changes, and cultural transformations [5]. The technological advancements experimented in the first Industrial Revolution were based on the use of new energy sources such as coal and steam that provided more efficient manufacturing processes and goods could be produced regardless of the location or season not being tied up to natural energy sources. Technological growth was evident in different sectors including coal mining, glass, steam transportation, and textile industries for instance mechanized cotton spinning powered by steam increased the productivity of a single operator by 100 in the space of a generation and by 1000 in two generations [2].

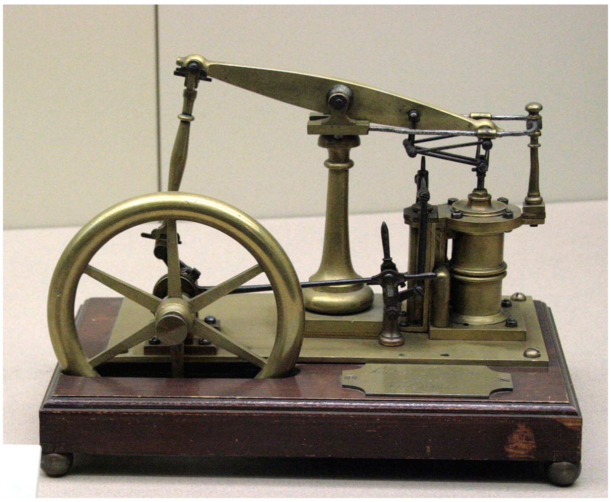


Figure 1.1: Steam Engine.

Furthermore, numerous changes emerged in nonindustrial domains, the peak in agricultural production liberated manpower that became available for work in the industry, transitioning from an agricultural economy to industrial production and shifting the power from land owners to industrial entrepreneurs. Similarly, industrialization led to a substantial migration of people from rural communities to new cities, driving a process of urbanization, one example is the city Manchester in Grain Britain that "experienced a six-times increase in its population between 1771 - 1831" [25], However, the rapid growth of cities led to deplorable living conditions. The high level of overcrowding in urban areas resulted in cramped living spaces and insufficient housing. Moreover, nonexistent drainage systems exacerbated the sanitation crisis, leading to the spread of diseases and unsanitary living conditions. Additionally, child labor became prevalent as industries sought a cheap workforce to meet the growing demands of production. only in the mid-19th century, did the European countries start to implement the first general laws against child labor.

The Second Industrial Revolution is identified by the emergence of petroleum and electricity to power the machinery as well as the technological advancements in the production of steel and iron, which depicts the building of railroads at a competitive cost marking a boost in the speed and cost of moving the raw materials and helping even to potentiate the construction of more railroads. for instance in the United States in the decade of 1850s were put into operation over 21.000 miles of railroad [6]. Another key point is the invention of the telegraph, with the use of electricity the telegraph allowed the share of ideas faster than ever before, but later it would be replaced by the telephone.

The period of the Second Industrial Revolution brought a major quantity of innovations and rapid changes in the living standards of the population. The expansion of urban centers and the growth of industries also led to significant migration from rural to urban areas in search of employment opportunities. Public health and sanitation became a topic in the cities impulsing initiatives such as the construction of sewerage systems and filtered water supplies that reduce the pollution in the environment and death rates from many diseases. In a similar manner, the growth in transportation networks facilitated the movement of people and ideas over longer distances, fostering cultural exchange on a global scale and the creation of a larger middle class.

The Third Industrial Revolution was marked by the development of the transistor which implicated an advantage in the building of complex electronic machines, The principal characteristic was the transformation of mechanical or analog electronic technologies to digital electronics opening the door to new devices such as computers or cell phones. The integrated circuit that carries in a single piece of semiconductor material multiple transistors revolutionized the electronics industry by allowing for the mass production of compact, reliable, and completely innovative devices.

Moore's Law played a significant role in driving the advancements during this historical period, which is an observation and projection proposed by Gordon Moore, the co-founder of Fairchild Semiconductors and Intel, who in 1965 stated that the number of transistors in a single piece of semiconductor material will double in number about every two years. For a considerable duration, the semiconductor industry employed Moore's law to guide their long-term strategies and establish objectives, consequently operating, to a certain degree, as a self-fulfilling prediction.

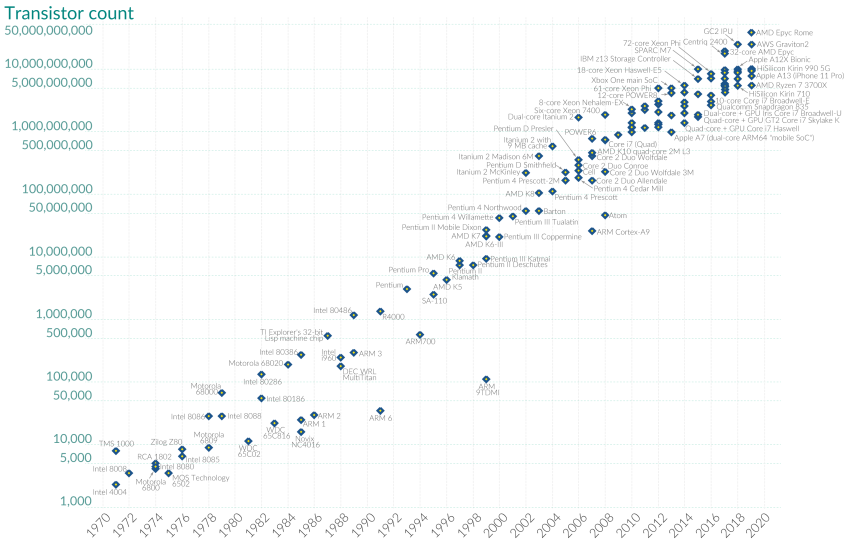


Figure 1.2: Moore's Law: from 1970 to 2020 [20].

Moore's law resulted in a major force in the miniaturization of electronics passing from computers such as the ENIAC in the mid-20th century that occupied about 100 square meters and weighed 30 tons to computers that fit on desks like the iMac in less than 50 years and then passing to portable devices such as the first smartphones and tablets in less than a couple of decades [11] and giving the opportunity to everyone to carry a computer in their own pocket and redefining how the society interacted with the technology.

(a) ENIAC.

(b) iMac.

Figure 1.3: Evolution of Computers [11].

The development of the Internet in the last decade of the 20th century radically changed the way companies interact with customers, allowing the companies access to much larger markets and receiving feedback from customers in real time. but also impulsing a process of globalization that strengthens the relationships between countries and favors the exchange of ideas, beliefs, and cultures.

Digitalization brought a boost to the economy significantly enhancing productivity, The miniaturization jointly the Internet led to improved efficiency and the creation of entirely new business models, however, one drawback is the impact on employment rates, While new ways to work are being created this also implies a shift in the skills that the workforce needs to have for not being displaced by the automation of some tasks, another challenge is the environmental impact generated by the rapid advancements in technology, leading to swift obsolescence and generate a lot of electronic waste.

The Fourth Industrial Revolution was introduced in 2011 at the Hannover fair from a project of the German government that advanced the concept of Cyber-Physical Systems into Cyber-Physical Production Systems (CPPS)[27], this involves the capacity for intelligent decision-making through real-time communication and collaboration among machines. The concept of Industry 4.0 was reinforced by Klaus Schwab, founder and executive president of the World Economic Forum at the Davos summit in 2016, where stated that the current revolution is evolving at an exponential rate, is disrupting almost every industry in every country and is deeply transforming the systems of production, management, and governance.[16].

The trend toward incorporating automation and data exchange is marking an essential shift in how global production and supply networks operate. The advancements in the machine to machine communication (M2M), the connectivity among devices inside and outside the production facilities, and the decision-making based on data acquired by sensors could only be possible due to the development of technologies such as the Industrial Internet of Things, artificial intelligence, robotics, 3-D printing, and big data analytics. for example in 2015 the Boston Consulting Group affirmed that the transformation is drove by nine foundational technologies (Figure 1.4) that will increase productivity, making processes be more efficient, reducing cost and transforming workforce profile.[21]

Figure 1.4: Nine Transforming Technologies Industry 4.0 [21].

This revolution is having an impact on industries and markets but in the same way, is leading a transformation in society by affecting the rules and norms of economic life, This shift could yield greater inequality, as automation substitutes labor across all industries, the gap between returns to capital and returns to labor will amplify.[22]

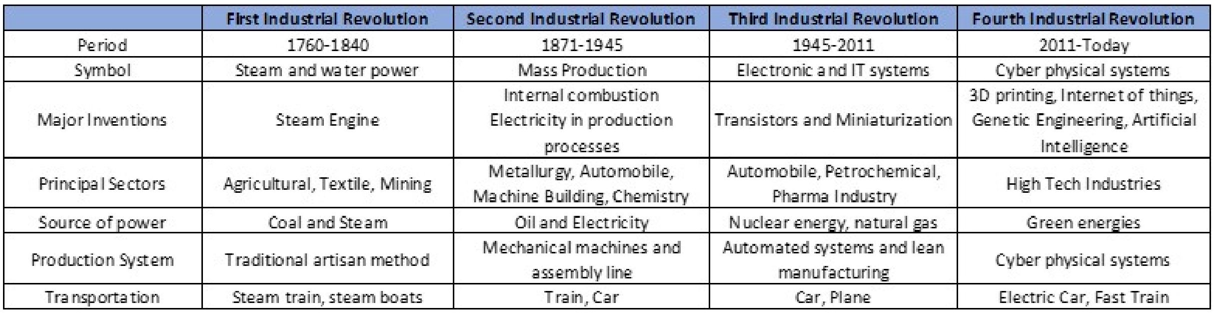
Each revolution previously discussed brought both positive and negative consequences. History illustrates how certain nations leveraged technology to increase their prosperity and elevate entire societies from poverty. However, alongside every transformation there also arise various challenges, nowadays the world is evolving faster than governments can legislate leaving a gap for risks such as misinformation at large scale, cybersecurity threats, and the illicit use of cryptocurrency. For instance, Cambridge Analytica a political consulting firm acquired and used personal data about Facebook users to identify the personalities of American Voters and influence their behavior for the Trump campaign in 2016.[19]. However, The danger also extends inside the factories, As connected devices increase, factories that are part of this network unintentionally become targets for cyber attackers seeking to disrupt operations, steal valuable information, or covertly observe processes in smart manufacturing environments.

Besides the rapid changes in technology and the improvements that this brings for people and industry, Presently the environment is suffering more than ever, resulting in climate change to a point from where there could be no return. Information and communication technology (ICT) devices play a significant role in generating greenhouse gas (GHG) emissions, They contribute to approximately 67% ± 15% of total lifetime emissions, without specific intervention, emissions from this sector are projected to double by 2030. In contrast, extending the useful lifespan of electronic devices with strategies such as eco-design, source reduction, repair, refurbishment, and reuse has the potential to alleviate up to half of the overall GHG emissions.[23]

Nonetheless, the challenges that arose from the fourth revolution make it imperative to proactively search for an option of industry human-centric, resilient, and sustainable, Michael Rada was among the pioneers who introduced the term Industry 5.0 in 2015 and named it "Industrial Upcycling". He emphasized that the tools and environment for this industry are not virtual but rather physical, similarly, he stressed that the tools should not work for us, but work with us in a symbiotic manner. "Industrial Upcycling" in this context, emerges as a concept that prioritizes environmental preservation, does not take the work and reason to live from people, but uses the best in every individual to contribute to the development.[17]

Furthermore, The European Commission in the lead of the Dictatorate "Prosperity" of Dictatorate-General for Research and Innovation conducted 2 virtual workshops in July 2020, where was discussed the concept of Industry 5.0 among participants from research and technology organizations as well as funding agencies across Europe. The primary goal was around facilitating technologies supporting Industry 5.0, there was a consensus on the necessity of effectively incorporating European social and environmental priorities into technological advancements, and transitioning the focus from individual technologies to a comprehensive systemic approach. During the workshops, six categories were identified, with each one being seen as capable of realizing its potential when synergized with the rest: Individualised Human-machine-interaction, Bio-inspired technologies and smart materials, Digital twins and simulation, Data transmission, storage, and analysis technologies, Artificial Intelligence, Technologies for energy efficiency, renewables, storage, and autonomy.[4]

As previously highlighted, the periods between revolutions are progressively shortening. Between the first and second revolutions a century elapsed. Similarly, the gap between the second and third revolutions was roughly 80 years, and notably, only 50 years separated the third and fourth revolutions. Moreover, less than a decade passed before discussions arose about the fifth revolution, which is not thought of as a replacement of the fourth but instead as a complement of the concept driving the endeavors toward a human-centric, sustainable, and resilient industry.



	First Industrial Revolution	**Second Industrial Revolution**	**Third Industrial Revolution**	**Fourth Industrial Revolution**
Period	1760-1840	1871-1945	1945-2011	2011-Today
Symbol	Steam and water power	Mass Production	Electronic and IT systems	Cyber physical systems
Major Inventions	Steam Engine	Internal combustion Electricity in production processes	Transistors and Miniaturization	3D printing, Internet of things, Genetic Engineering, Artificial Intelligence
Principal Sectors	Agricultural, Textile, Mining	Metallurgy, Automobile, Machine Building, Chemistry	Automobile, Petrochemical, Pharma Industry	High Tech Industries
Source of power	Coal and Steam	Oil and Electricity	Nuclear energy, natural gas	Green energies
Production System	Traditional artisan method	Mechanical machines and assembly line	Automated systems and lean manufacturing	Cyber physical systems
Transportation	Steam train, steam boats	Train, Car	Car, Plane	Electric Car, Fast Train

Figure 1.5: Industrial Revolutions.

1.2. Industry 5.0

The emergence of Industry 5.0 originates from the observation or presumption by the European Commission that Industry 4.0 has a limited implication on the core values of social equity and sustainability and instead prioritizes digitalization and AI-driven technologies to enhance production efficiency and flexibility. The concept of Industry 5.0 proposes a fundamental shift in our society and economy toward a new paradigm, underscoring the importance of research and innovation to support humanity in the long run within the limits of our planet's resources. [4]. It can be asserted while Industry 4.0 is considered technology-centric addressing social fairness, sustainability, and resilience as secondary concerns, alternative Industry 5.0 prominently centers around the workforce's welfare within the production process, with the aim of fortifying critical infrastructure for moments of adversity, respecting the planetary boundaries, making it value-oriented approach.

In the formulation of their concept of Industry 5.0 the European Commission considered various elements, one of those being the examination of the rapid societal transformation powered by increased connectivity and automation. A telling illustration of the growth of digital technology's importance can be found in Figure 1.6. In 2009, only one tech company (Microsoft) had a spot among the top-10 publicly traded corporations. However, in 2023, seven of the top-10 companies are technology-related, with only one non-technology company positioned within the first 5. Despite the benefits brought by technological advancements, society is now confronted with the negative aspects and risks that entail including inequality, the fragility of the supply chains, and threats to the environment [4].

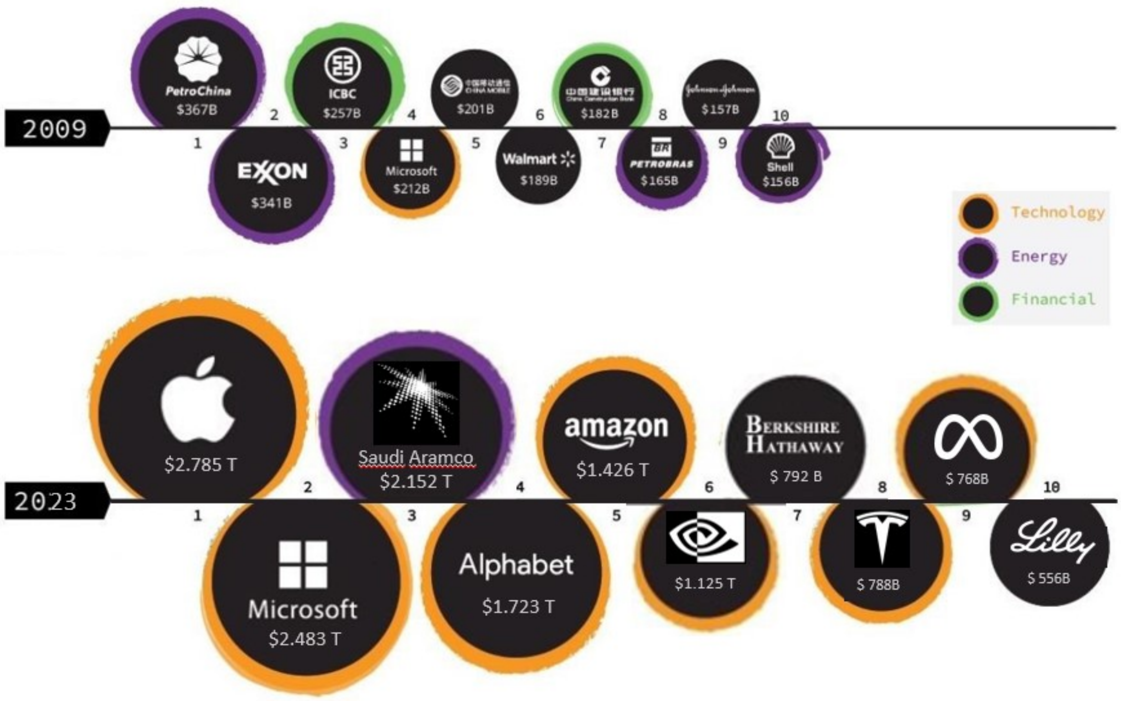


Figure 1.6: Largest companies by market cap (10/9/2023) [8].

Industry 5.0 remains an evolving concept, with considerable uncertainty about its precise implications and impact on business. the European Commission perspective highlights the inadequacy of a purely profit-oriented approach. to truly cultivate prosperity, the industry´s fundamental purpose must include social, environmental, and societal factors, enriching not only cost-effectiveness but also benefiting all stakeholders involved including investors, employees, consumers, society, and the environment.

Additional efforts to conceptualize Industry 5.0 have been made by J.Leng et al. who present an overview of the definition of Industry 5.0 from three perspectives, the first definition is based on the white paper of the European Commission, which envisions "Industry 5.0 is understood to recognize the power of industry to achieve societal goals beyond jobs and growth to become a resilient 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" [4]. The second definition is given by Nahavandi, who presents Industry 5.0 as a synergy between humans and robots, where the brainpower and creativity of the humans increase productivity and solve problems through the integration of workflows with intelligent systems, Nahavandi also includes that the new generation of robots will be aware of the human presence, supporting the concerns of safety and risk in the workplace[12]. The last definition comes from Friedman and Hendry which emphasizes the importance of prioritizing human elements when integrating novel technologies into industrial systems [10]. Reviewing the definitions, it becomes evident that they all intersect in the values of human-centric powered by collaboration with machines, sustainability, and resilience.

1.2.1. Core Values of Industry 5.0

Considering the previous literature, Industry 5.0 which is value-driven encompasses three fundamental elements: Human-centric, sustainability, and resilience.

Figure 1.7: Industry 5.0 Core Values [4].

Human-centric

The most important shift of Industry 5.0 is the transition from a technology-driven approach of Industry 4.0 to a value-oriented approach that puts the worker at the center of the production process, instead of requiring industry workers to adjust their skills to the demands of advancing technology, the objective is to utilize technology to adapt the production process to the needs of the worker [4]. In this manner, Industry 5.0 aims to avoid the replacement of humans by machines in the industry, instead, it envisions a synergy between humans and robots, fostering creativity and enhancing decision-making by providing essential information, while the machines work in a collaborative way increasing efficiency, improving quality control but also providing a safer workplace, for example, a human working on an assembly task could partner with a cobot equipped with cameras, initially, the cobot observes to identify patterns and once is confident in its predictions, it will attempt to help the worker, enhancing the overall process efficiency. Additionally, the robot could be used to detect possible hazards and prevent accidents, ensuring workplace safety [12].

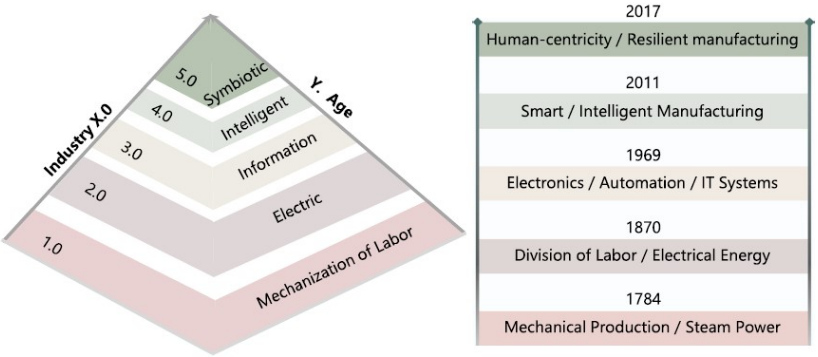


Figure 1.8: Industry X.0 [10].

Furthermore, a study conducted by the European project DE4Human proposes 3 pillars to pay particular attention to the aim to improve the well-being of the workers those are: Safety, Empowerment, and Inclusivity [7]. The objective of the study was to obtain a user-centric view of what comprises a human-centric manufacturing system and to obtain a skills-oriented view of the requirements for the facilitation and realization of a human-centric manufacturing system. To accomplish this goal two workshops were held with participants from academia and industry in which taking the role of designers of a human-centric system they defined the three main pillars and discussed the skills needed for its execution [7].

Safety

A strong connection exists between Industry 5.0 and safety, the incorporation of innovative technologies within Industry 5.0 holds promise for enhancing workplace safety in manufacturing processes. For example, mobile robots or exoskeletons hold the capacity to reduce the physical strain associated with specific tasks, on the other hand, a latent risk in mental health is present, with the new ways of working always-online or always-available the risk of burnout increased [4]. As a result of the study conducted in [7] identified 3 dimensions of safety:

Emotional Safety: Makes reference to how workers perceive themselves as valued team members. arises from being respected and recognized as integral to the organization, extending beyond their role as employees.

Professional Safety: Linked to the perception of the worker of their job as a source of livelihood, may emerge from the belief that their job is secure, otherwise, the worker performance may be undermined and lead them to take unwarranted risks to safeguard their employment.

Physical Safety: Refers to the comfort associated with job-related activities. Is fostered by working in an environment equipped with ergonomic furnishings that promote comfortable body positioning, maintaining suitable temperature conditions, and providing access to all necessary tools for task performance.

Inclusivity

An important aspect of the human-centric industry is inclusivity, new technologies such as virtual and augmented reality could be used to guide workers in more specialized tasks that typically demand specific expertise and training, this might create chances to incorporate individuals with different characteristics into the workplace. As a result of the study conducted in [7] identified 2 dimensions of inclusivity:

Personal Inclusivity: Linked to embracing inherent personal characteristics that have no bearing on an individual’s job performance. These attributes may encompass age, gender religion, ethnicity, disability, economic status, and more.

Work-Related Inclusivity: Associated with recognizing varying skill levels and competencies among employees within an organization. especially significant when existing employees take on more substantial roles in the organization or when new employees join, potentially being viewed as inexperienced.

Empowerment

The perception of the worker in Industry 5.0 is no longer seen as a "cost" but rather as an "investment" for the company [4], another study [18] proposes the "operator of the future", the operator 4.0 as an intelligent and capable worker who works in synergy with machines. It represents a new paradigm where the technology enhances the operator's capabilities, which could be, for instance, physical (operator + exoskeleton), sensorial (operator + wearable tracker), or cognitive (operator + augmented reality).As a result of the study conducted in [7] identified 2 dimensions of empowerment:

Individual Empowerment: linked to experiencing self-assurance regarding one's abilities, actions, and choices. attributed to recognizing the influence of self-actions in the organization.

Structural Empowerment: Associated with methodologies and arrangements established within a workplace to promote individual empowerment. In essence, it relates to the measures and protocols designed to encourage the distribution of power, decision-making authority, and resource control.

Sustainability

Sustainability means producing having on account the reduction of energy consumption and emissions, preventing the depletion and deterioration of natural resources, Industry 5.0 fosters the development of circular processes that extend the life cycle of a product such as leasing, reusing, repairing, refurbishing, and recycling, in practice, when a product reaches the end of its lifespan, efforts are made to retain its materials within the economic cycle through recycling. These materials can be repeatedly utilized, for example through additive manufacturing creating further value, optimizing resource efficiency, and minimizing waste.

The 2030 Agenda for Sustainable Development of the United Nations presents 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries, between them are "Make cities and human settlements inclusive, safe, resilient and sustainable" and "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation" [13]. These SDGs underscore the vital role of Industry 5.0 in advancing sustainability on a global scale.

Resilience

Resilience entails enhancing the strength of industrial production, making it more resistant to disruptions or able to recover fast and capable of maintaining critical infrastructure during crises. Events like geopolitical changes and natural disasters, exemplified by the Covid-19 pandemic or the war in Ukraine, expose the vulnerability of our current globalized production model. To counter this fragility, it's imperative to cultivate resilient strategic value chains, adaptable production capabilities, and flexible business processes. This emphasis is particularly critical in areas where these value chains cater to fundamental human necessities like healthcare and security [4].

1.3. Learning Factory

In 1994, the National Science Foundation (NSF) in the USA granted funding to a consortium led by Penn State University to pioneer the concept of a "learning factory." This marked the inception and patenting of the term, which denoted interdisciplinary, hands-on senior engineering design projects characterized by robust connections and collaboration with industry [1]. In recent times, the creation of learning factories has surged, especially in Europe. These learning factories could be found in different forms, differing in scale and complexity, but all with the same aim of enriching the educational journey of participants across various knowledge domains with hands-on experiences.

Numerous definitions of the term “Learning Factory” have been put forth and intensively discussed, one such interpretation, as proposed by Wagner [26], where dissects the composite nature of the term, comprising "learning" and "factory". From this vantage point, a learning factory should encompass a real learning environment adaptable for educational objectives targeting diverse audience segments and, additionally provide a real production environment based on real industrial sites.

The CIRP Encyclopedia of Production Engineering defines a Learning Factory in a narrow sense as a learning environment specified by:

- Processes that are authentic, include multiple stations and comprise technical as well as organizational aspects.
- A setting that is changeable and resembles a real value chain.
- A physical product being manufactured.
- A didactical concept that comprises formal, informal, and non-formal learning, enabled by own actions of the trainees in an on-site learning approach.

Depending on the purpose of the Learning Factory, learning takes place through teaching, training and/or research. Consequently, learning outcomes may be competency development and/or innovation [9].

Additionally, in the study by Abele [1], six distinct dimensions are outlined, which collectively define the parameters of a Learning Factory. These dimensions include Purpose, Process, Setting, Product, Didactics, and, Operating Model. Furthermore, the delineation is made between a Learning Factory in its narrow and broader sense (Figure 1.9), In the broader context, at least one dimension is modified, which may be the setting with virtual representations of value-added chains, or alternatively, it might concern the product, with the product taking the form of a service, or alternatively, it could involve adjustments in the didactics, connecting the participants to the learning virtually.

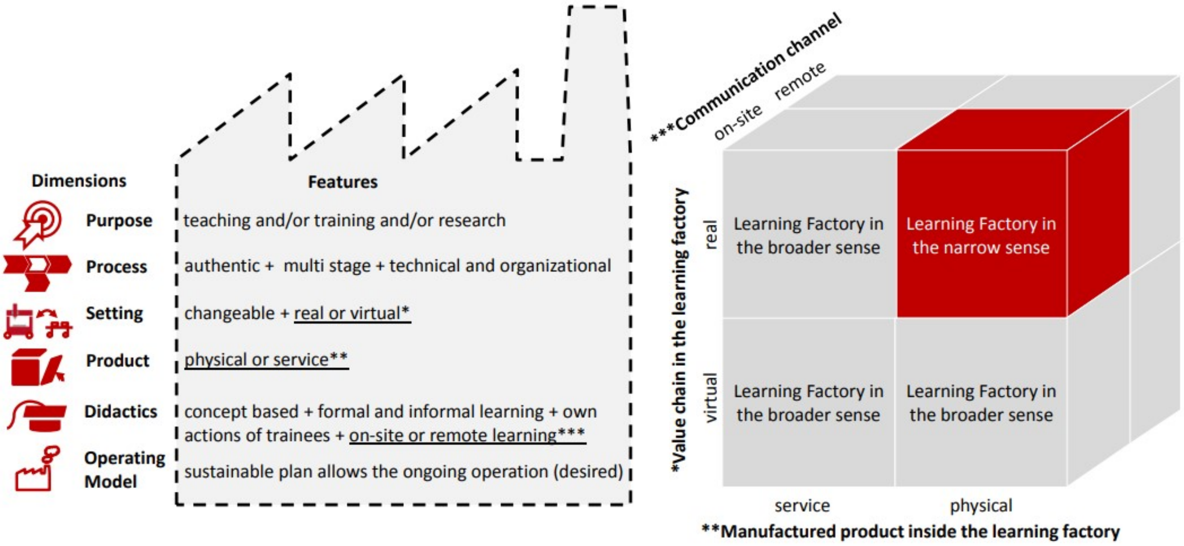
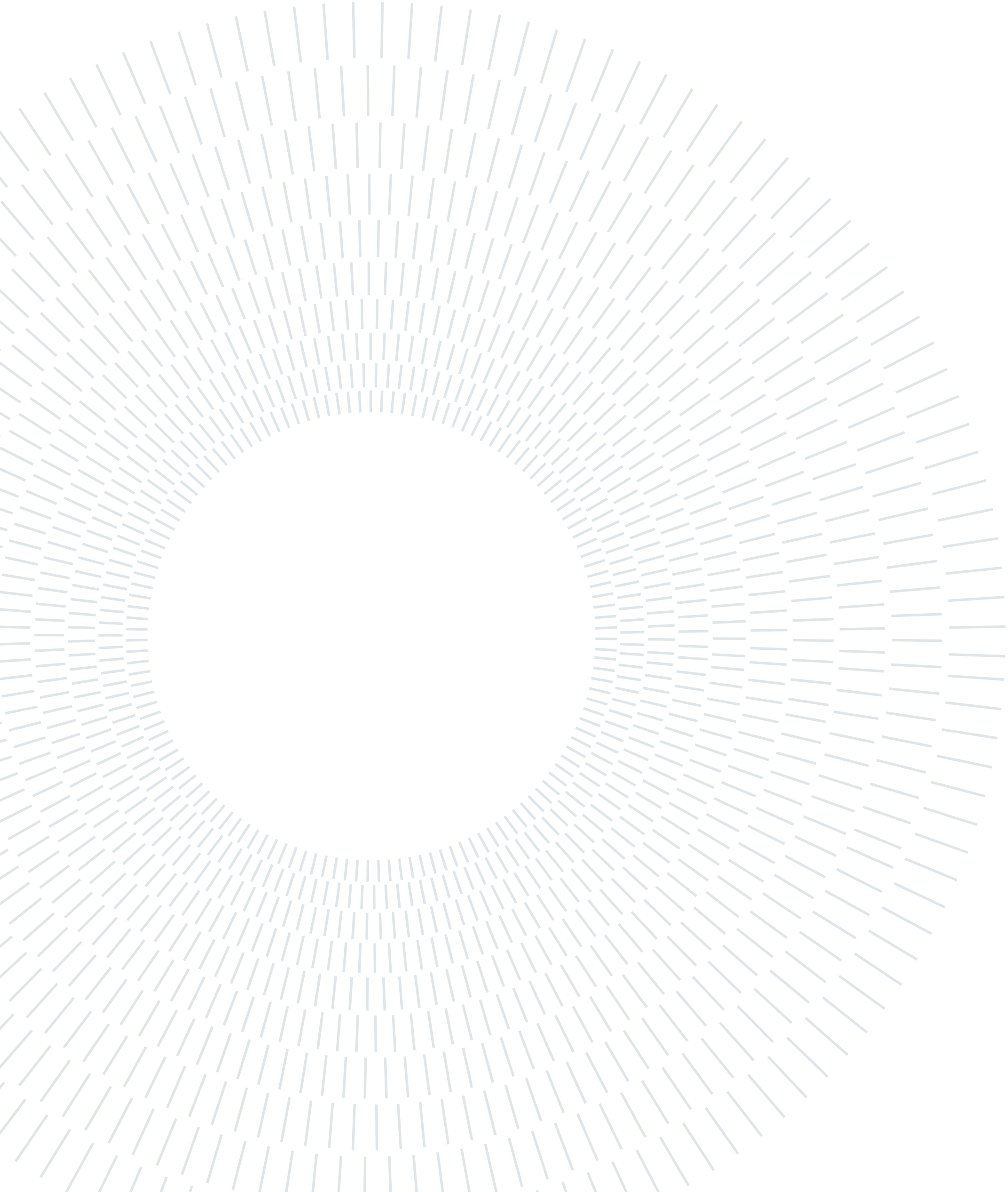


Figure 1.9: Dimensions of learning factories and the distinction between learning factories in the narrow (red cube) and in the broader sense (all grey fields) [1].



2 | Learning Factories Development

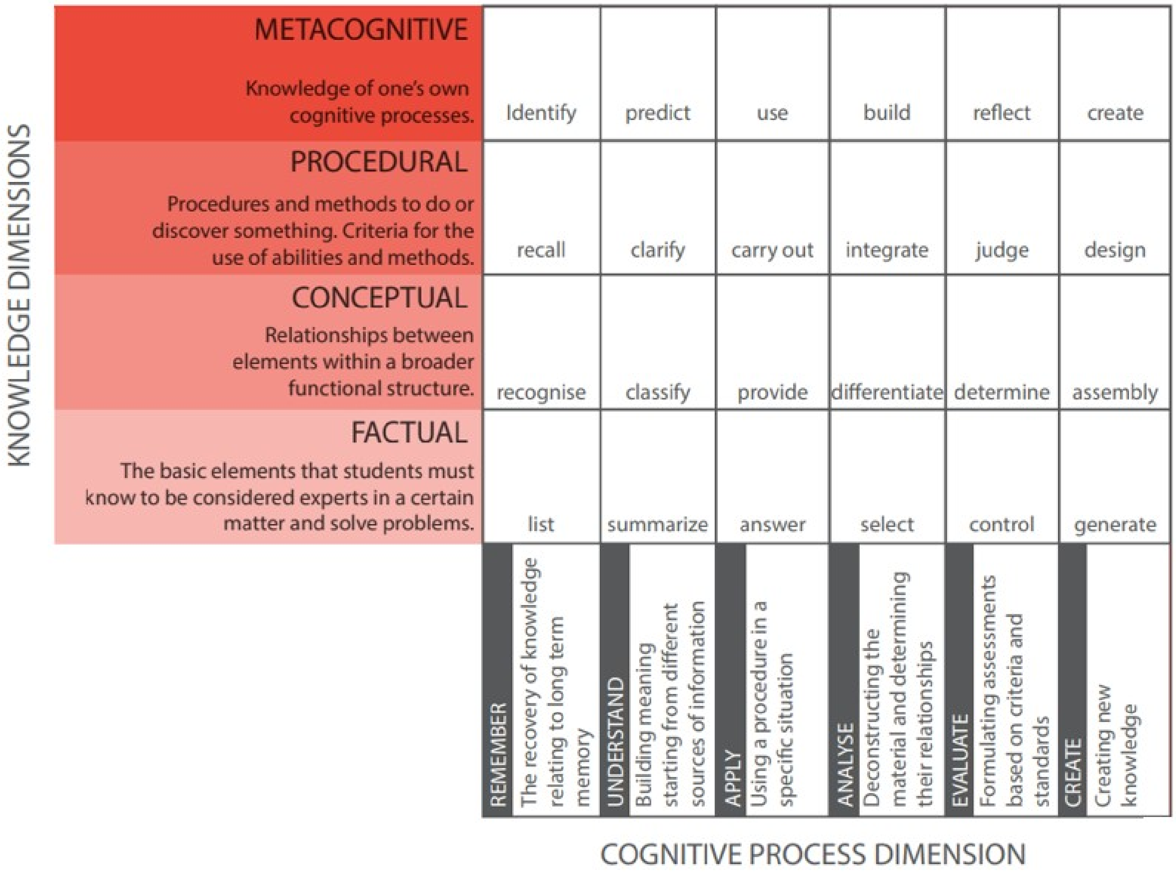
The learning factories were designed taking into account the principle of Constructive Alignment, which connects directly the intended learning outcomes (ILOs) with the teaching and learning activities in a way not typically achieved in traditional lectures, The Learning activities are designed to engage participants, and optimize their possibilities of understand the learning outcomes [3]. The term Constructive comes from the psychology of Constructivism which suggests that knowledge is constructed through the activities performed, In this way successful learning is where the participant engages in activities that are most appropriate for the ILOs. Similarly, the term Alignment derives from the link that must be between the learning activity, assessment, and ILOs [3].

Intended Learning Outcomes

Intended Learning Outcomes (ILOs) are statements of the accomplishments a participant will attain when they finish a unit of study. [15] These ILOs provide the groundwork from where the learning activities and assessments are designed. The first step in the Constructive Alignment framework is to set the ILOs, these should be described using one action verb or at most two and denoting the context of the performance and the field of application [3].

Figure 2.1: ILO Elements [15].

Usually, ILOs consist of four elements: verb, content, context, and clarity. A suggested way to state the ILOs is presented in [15], It starts with deciding the purpose, in the case of the study the purpose is aligned with the objective, secondly, identifying the content that is going to be taught, The content is the human-centric dimension of Industry 5.0, the pillars of safety, inclusivity, and empowerment, and the technology selected for the learning factory, then selecting the appropriate action verb regarding the level of cognitive engagement that is intended. For this task Bloom's Taxonomy is used which categorizes the verbs in two dimensions cognitive processes and knowledge that could be seen in Figure 2.2, the next step is to add the context, and finally ensure clarity avoiding unnecessary complex language.



KNOWLEDGE DIMENSIONS						
METACOGNITIVE Knowledge of one's own cognitive processes.	Identify	predict	use	build	reflect	create
PROCEDURAL Procedures and methods to do or discover something. Criteria for the use of abilities and methods.	recall	clarify	carry out	integrate	judge	design
CONCEPTUAL Relationships between elements within a broader functional structure.	recognise	classify	provide	differentiate	determine	assembly
FACTUAL The basic elements that students must know to be considered experts in a certain matter and solve problems.	list	summarize	answer	select	control	generate
COGNITIVE PROCESS DIMENSION	**REMEMBER** The recovery of knowledge relating to long term memory	**UNDERSTAND** Building meaning starting from different sources of information	**APPLY** Using a procedure in a specific situation	**ANALYSE** Deconstructing the material and determining their relationships	**EVALUATE** Formulating assessments based on criteria and standards	**CREATE** Creating new knowledge

Figure 2.2: Bloom's Taxonomy.

The Intended Learning Outcomes proposed for the study are:

- Participants should be able to recognize that building greater autonomy is closely linked to developing stronger decision-making skills and increased confidence and responsibility.
- Participants should be able to identify the changing circumstances and be open to new ideas and ways to execute the work.
- Participants should be able to outline how the technologies help in collaborating with their colleagues.
- Participants should recognize the challenges and opportunities presented by failure, including the need for resilience, adaptability, and continuous learning.

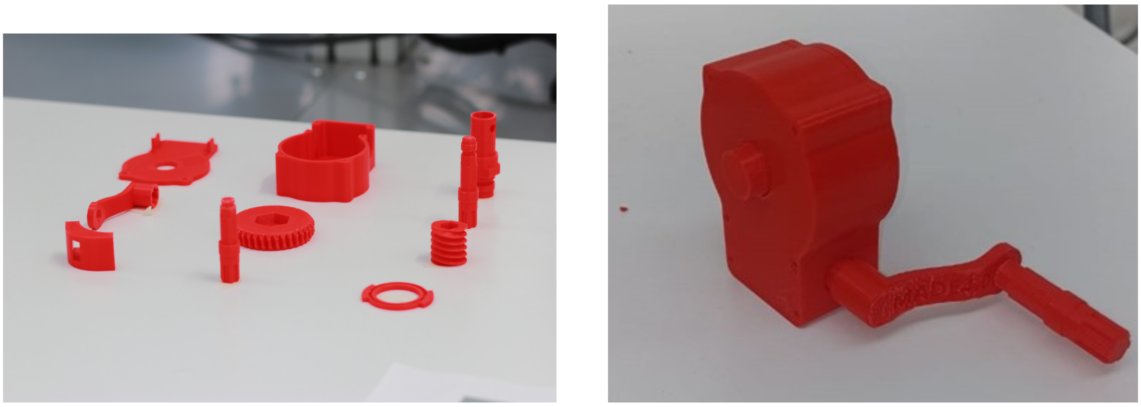
The first two ILOs are related to the dimension of Empowerment specifically with the skills of autonomy and flexibility, while the third and fourth are related to the dimensions of Inclusivity and Safety correspondingly.

Learning Experiences

The participants of the learning factories were industry workers experienced in Industry 4.0 technologies. The learning factories were scheduled each 30 minutes, After a brief introduction, the participants rotated between the two learning factories, with some attending one while others were in the other learning factory.

Learning Factory Collaborative Robots

The group facilitator provided participants with an overview of the activity. Each group was presented with a station containing various components, which they used to collaboratively assemble a Gearbox. To aid them in this task, participants were provided with an image displaying the fully assembled product as a reference. The Gearbox should move smoothly once assembled, and the facilitator indicated if it has been correctly assembled. Before starting the activity the group coordinator provided a first questionnaire to measure the feelings of the participants.



(a) Components.

(b) Gearbox Assembled

Figure 2.3: Overview components and final product

After executing the activity the facilitator instructed the participants in the use of the cobot and highlighted the importance of the 3 pillars, safety, inclusivity, and empowerment with this technology.

In the station, were present two cobots showcasing their capabilities. The cobot on the right has been ergonomically designed with the safety of the operator in mind (Figure 2.4). It features specially designed joints to prevent the operator's hands from getting caught, ensuring a secure working environment (Safety). Additionally, it is equipped with sensors that can detect something in its path, instantly stopping and entering safe mode.

Figure 2.4: Cobots Station.

One of the remarkable features of these cobots is how easy and intuitive they are to program. (Empowerment) The current technology allows us to program them in a simple and user-friendly manner. In fact, most of the operators who work with these cobots could provide them with the necessary instructions (Inclusivity). For example, the cobot on the right can be programmed to follow a specific route. All it takes is for the operator to physically guide the cobot along the desired path while holding a button. Once the route has been recorded, the cobot can repeat it accurately.

They can also be programmed to collaborate in assembly tasks. In this scenario the cobot brings the components in the correct order, patiently waiting for the operator to insert each piece into the assembly (Empowerment). This collaboration between humans and cobots can significantly enhance productivity and efficiency in manufacturing processes.

After the demonstration, the participants were invited to realize the activity again aided by the cobot, then the group coordinator provided a last questionnaire to measure the feelings of the participants.

Learning Factory Exoskeleton

The group facilitator provided participants with an overview of the activity. Each group was presented with a station containing a chassis of an oven with various screws with nuts, The objective of the activity was for the group members to work together to unscrew the nuts, show them to the facilitator, and then screw them back in place. Before starting the activity the group coordinator provided a first questionnaire to measure the feelings of the participants.

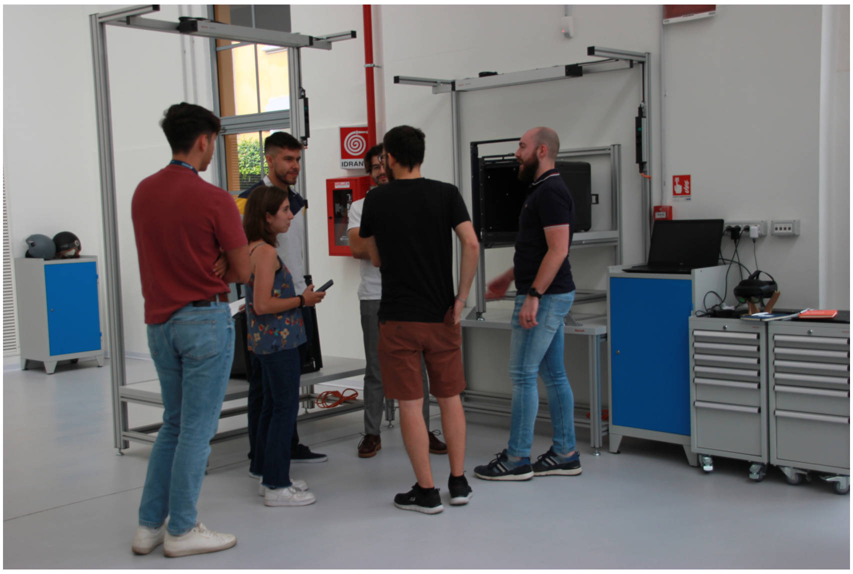


Figure 2.5: Facilitator explaining the demounting of the chassis.

After executing the activity the facilitator instructed the participants in the use of the Exoskeleton and highlighted the importance of the 3 pillars, safety, inclusivity, and empowerment with this technology.

In the station are presented 2 exoskeletons designed specifically for the upper body. These exoskeletons are aimed at supporting workers in repetitive tasks that demand prolonged use of their upper extremities. By doing so, they help reduce the strain and load on their joints, enhancing both comfort and productivity (Empowerment).

One example could be a scenario where an operator must spend an entire workday painting with their arms raised. This continuous strain on the body could lead at the long term to injuries. However, with the assistance of an exoskeleton, the operator is provided with the necessary support to mitigate the risk of such injuries (Safety).

Moreover, exoskeletons empower individuals who may not possess the physical strength required to perform demanding tasks for extended periods of time (Inclusivity).

By reducing the strain on workers' bodies, these devices can help prevent chronic injuries and promote a healthier work environment. Furthermore, exoskeletons enable individuals with varying physical abilities to actively participate in tasks that were once challenging or impossible for them (Inclusivity).

After the demonstration, the participants were invited to realize the activity again aided by the exoskeleton, then the group coordinator provided a last questionnaire to measure the feelings of the participants.

Figure 2.6: Participant using the Exoskeleton.

Assessment Tasks

The third element within the framework of Constructive Alignment is the Assessment Task, which serves the purpose of evaluating the extent to which participants' performance aligns with the Intended Learning Outcomes. However, it's important to note that the study's primary objective is not to assign grades to the participants. Instead, the emphasis is on assessing the participants' emotions and perceptions. This assessment is conducted by measuring their feelings both before and after they engage in the activity, initially without the assistance of technology and subsequently in conjunction with the technology. The intention behind this evaluation is to gain insights into the shift in participants' perceptions throughout the process. For this mission were designed four questionnaires, two for each learning factory, The complete questionnaires are given in Appendix A.

The methodology followed for crafting the questionnaires closely adhered to the framework outlined by Taherdoost in [24], The questionnaires were structured to maintain a specific and transparent sequence. Their primary aim was to discern the perceptions and emotions of the participants throughout the learning factory's execution. Each question was designed using a 5-point scale (ranging from 1 to 5), where 1 corresponded to a low value and 5 represented a high value. A concerted effort was made to ensure that the questions were concise, straightforward, devoid of bias, and devoid of vague quantifiers.

3 | Results and Discussion

The learning factories involved a total of eleven participants comprising three women and eight men, all employed in diverse sectors including industrial automation, metallurgic, and chemistry. Age-wise distribution revealed that seven were between 25-34 years, two fell between 45-54 years, one was aged 55-64 years, and one participant was older than 65 years. Before the learning factories, the participants were asked to associate terms with Human-centric Manufacturing, The word "customization" was the most commonly associated term, followed by "robotics" and "automation". Following is a concise overview of the key findings.

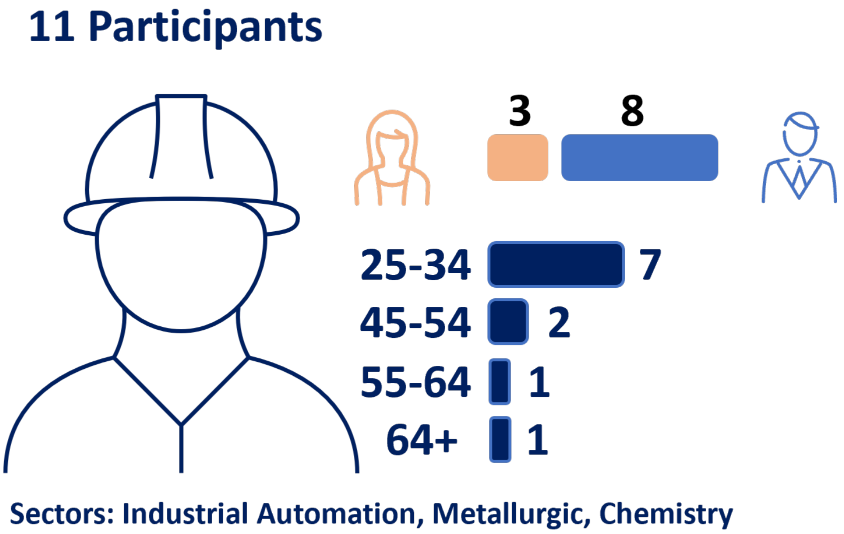


Figure 3.1: Demographics of participants.

3.1. Learning Factory Collaborative Robots

Questionnaire Learning Factory Cobot Before

Question 1: How confident are you in your ability to perform the work described?

Total Number 11

Standard deviation 0.75

Mean 2.82

Question 2: How would you rate the level of safety associated with the task described?

Total Number 11

Standard deviation 1.14

Mean 3.91

Question 3: To what extent do you perceive is important in this task the teamwork?

Total Number 11

Standard deviation 1.12

Mean 3.64

Question 4: On a scale of difficulty, how would you rate the assigned task?

Total Number 11

Standard deviation 0.87

Mean 3.18

Questionnaire Learning Factory Cobot After

Question 1: On a scale of difficulty, how would you rate the assembly without the Cobot?

Total Number 10

Standard deviation 1.07

Mean 3.6

Question 2: How confident do you feel to take control over job tasks with this technology?

Total Number 10

Standard deviation 1.35

Mean 3.6

Question 3: To what extent do you perceive this technology gives you the

freedom to perform the work at your own pace?

Total Number 10

Standard deviation 0.79

Mean 4.2

Question 4: How would you rate your level of worry during the assembly with the Cobot?

Total Number 10

Standard deviation 1.06

Mean 1.7

Question 5: To what extent do you perceive this task enhances performance and collaboration?

Total Number 10

Standard deviation 0.67

Mean 4

Question 6: How smooth was the assembly process of the gearbox using the cobot?

Total Number 10

Standard deviation 0.67

Mean 4.3

Question 7: On a scale of difficulty, how would you rate the assembly with the Cobot?

Total Number 10

Standard deviation 1.20

Mean 2.10

3.2. Learning Factory Exoskeleton

Questionnaire Learning Factory Exoskeleton Before

Question 1: How confident are you in your ability to perform the work described?

Total Number 11

Standard deviation 1.19

Mean 3.27

Question 2: How would you rate the level of safety associated with the task described?

Total Number 11

Standard deviation 0.83

Mean 3.91

Question 3: To what extent do you perceive is important in this task the teamwork?

Total Number 11

Standard deviation 1

Mean 3

Question 4: On a scale of difficulty, how would you rate the assigned task?

Total Number 11

Standard deviation 1.03

Mean 2.45

Questionnaire Learning Factory Exoskeleton After

Question 1: On a scale of difficulty, how would you rate the activity without the Exoskeleton?

Total Number 11

Standard deviation 1.21

Mean 2.54

Question 2: How confident do you feel to take control over job tasks with this technology?

Total Number 11

Standard deviation 1.08

Mean 4.18

Question 3: To what extent do you perceive this technology gives you the

freedom to perform the work at your own pace?

Total Number 11

Standard deviation 1

Mean 4

Question 4: How would you rate your level of physical effort perceived during the activity with the exoskeleton?

Total Number 11

Standard deviation 0.92

Mean 2.64

Question 5: To what extent do you believe this technology is suitable for a wide range of users?

Total Number 11

Standard deviation 0.69

Mean 3.45

Question 6: On a scale of difficulty, how would you rate the activity with the Exoskeleton?

Total Number 11

Standard deviation 1.42

Mean 2.73

3.3. Findings and Discussion

The concept of human-centric manufacturing was explored in detail, centering on its three core pillars: safety, inclusivity, and empowerment. Purposeful activities were designed to appear deceptively straightforward but, in reality, required a certain level of skill. For instance, in the case of the collaborative robot, assembling the gearbox components in the correct order and position was essential for proper functionality, while the exoskeleton posed challenges with hard-to-reach screw positions. In both learning factories, participants initially perceived the tasks as relatively easy before attempting them. However, upon making their first attempt, the perceived difficulty increased. Subsequently, participants were asked to assess the difficulty with the assistance of technology. For the assembly of the gearbox, the perception of difficulty decreased due to the cobot passing the components in the correct order and orientation, whereas for the exoskeleton, it remained unchanged. This discrepancy might be attributed to insufficient time for participants to experience the tension in their arms and the support provided by the exoskeleton.

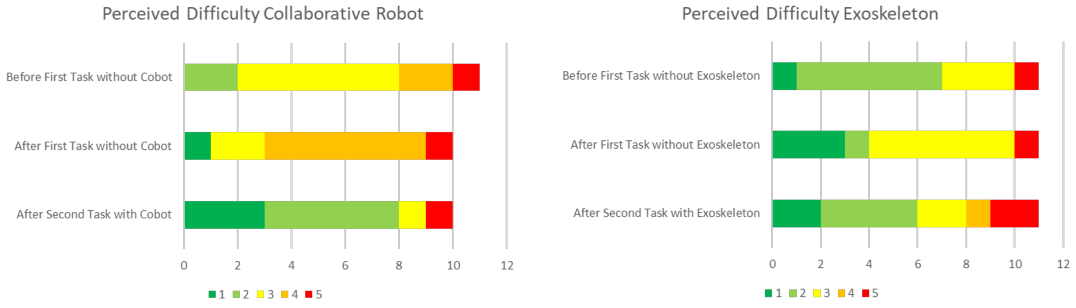


Figure 3.2: Perceived Difficulty.

Since the activities seemed straightforward participants initially displayed a medium to high level of confidence in their ability to accomplish the tasks before engaging with them. However, upon experiencing the actual difficulty of the tasks, their perception evolved. Despite recognizing the challenges, participants expressed that the technology equipped them with the capacity to successfully complete the tasks.

Figure 3.3: Level of Confidence.

Moreover, the technology allowed them to work at their own pace, contributing to a sense of flexibility and control during task execution. This transformation in perception underscores the significant role that technology plays in not only bolstering participants' confidence but also in significantly augmenting their overall efficiency when it comes to handling intricate and demanding tasks.

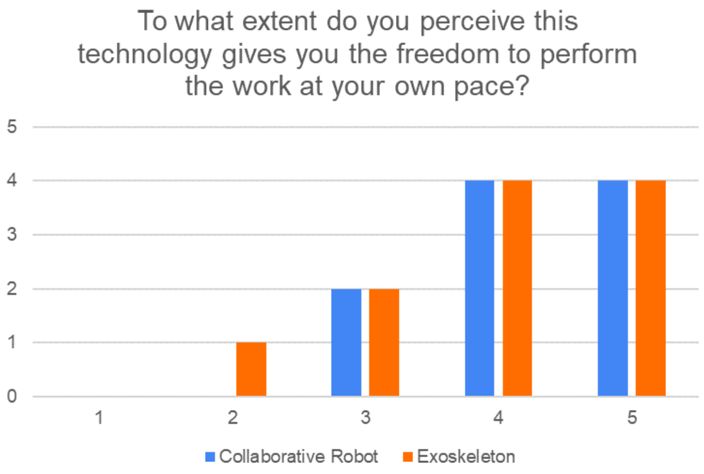


Figure 3.4: Perceived Flexibility.

The perception of safety among participants was high before embarking on the task, largely attributable to the absence of complex tools or machinery involved. This initial sense of safety was further reinforced during task execution with the collaborative robot, as participants were aware of its safety mode, which effectively prevented incidents that might occur. Similarly, when employing the exoskeleton, participants reported experiencing minimal physical strain during the task. What stands out is that both the collaborative robot and the exoskeleton instilled in participants a sense of control and agency over the activity. Rather than feeling as if the technology was completing the task on their behalf, participants perceived it as a valuable aid that enhanced their task management capabilities. This perception of technology as a supportive tool rather than a replacement for human effort granted them a degree of flexibility and the opportunity for experiential learning throughout the process

Figure 3.5: Perceived Safety.

The participants expressed the belief that teamwork played a pivotal role in the successful completion of the assigned tasks. It was particularly remarkable that despite hailing from diverse companies and spanning a range of ages, they seamlessly collaborated in the task execution. This collaborative spirit not only highlighted the universal significance of teamwork but also underscored the adaptability of the technology employed.

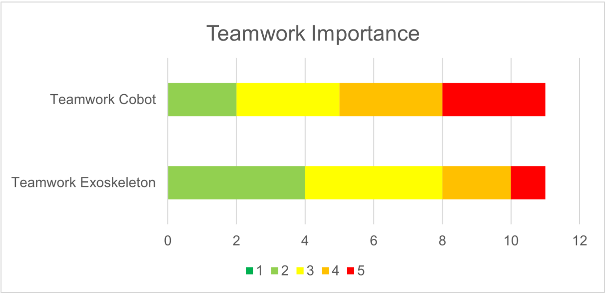


Figure 3.6: Teamwork Importance.

Finally, Participants shared the view that the technology was well-suited for a wide spectrum of operators, transcending gender and age boundaries. This adaptability ensured that the activity, when aided by technology, could be executed smoothly and efficiently, irrespective of individual demographics, reaffirming the technology's capacity to foster inclusivity and enhance the overall human-centric manufacturing experience.

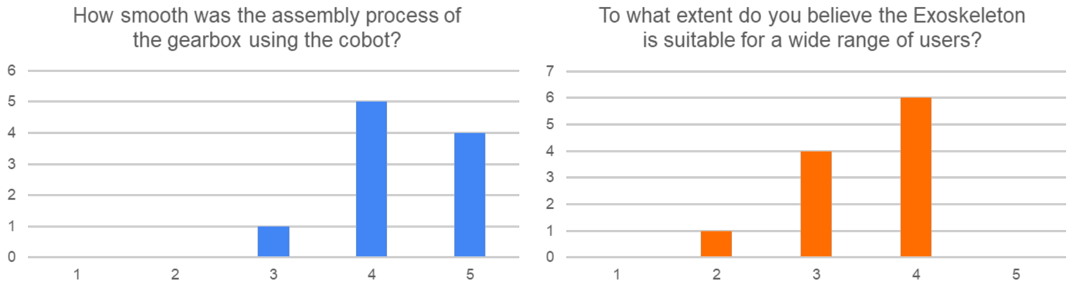
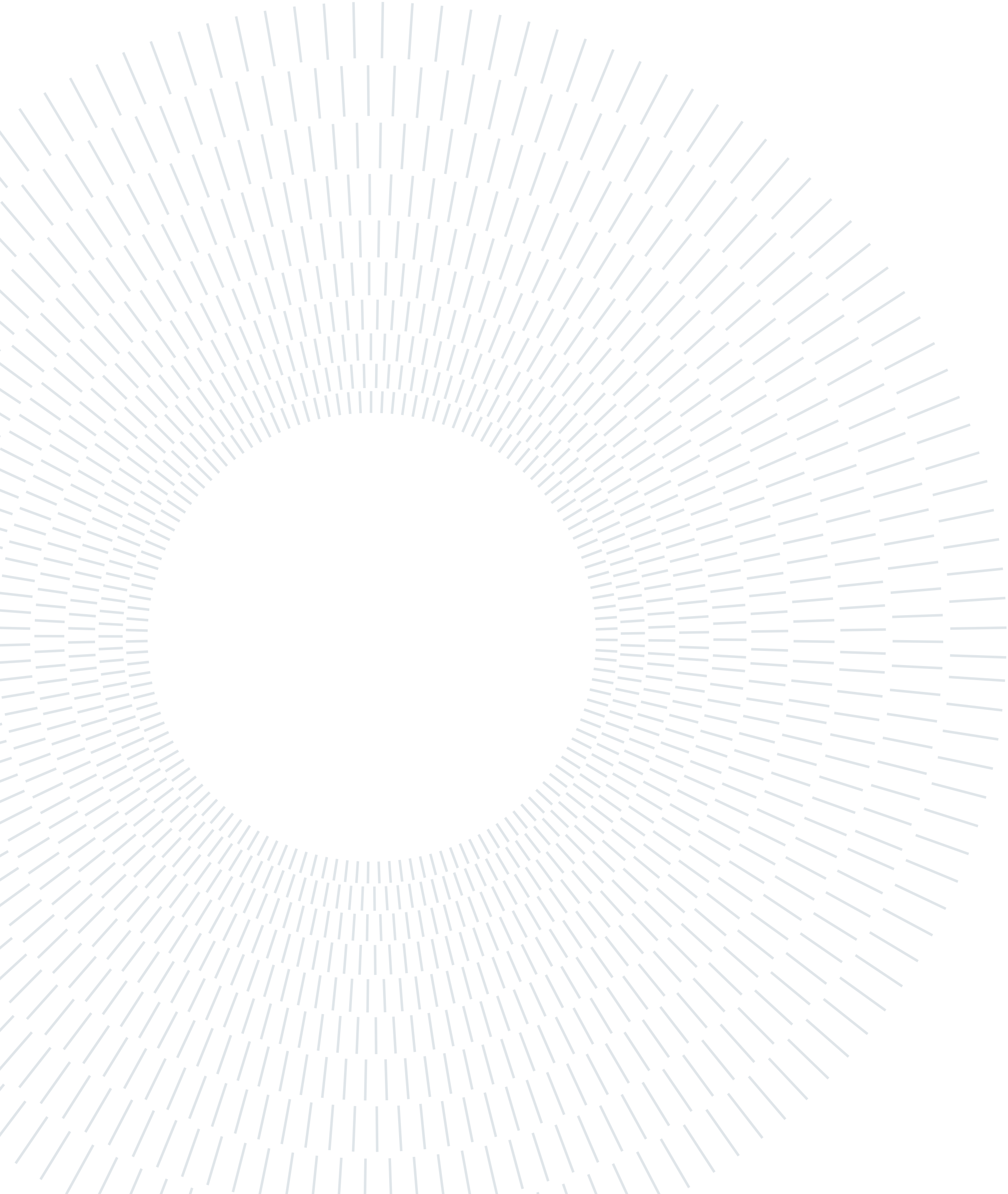


Figure 3.7: Inclusivity.



4 | Conclusions

History has demonstrated that each technological revolution has been accompanied by profound cultural and socioeconomic transformation, with the last one being a significant shift as disruptive technologies become increasingly integrated into industrial processes. The call of Industry 5.0 is to embrace this revolution but with a value-oriented perspective where the well-being of the worker takes precedence at the heart of the production system This approach, anchored in the principles of Safety, Inclusivity, and Empowerment, seeks to foster a harmonious and symbiotic relationship between humans and machines while simultaneously respecting the planet's boundaries. The ultimate goal is to transform the industry into a robust and resilient provider of prosperity [4].

The learning factories conducted in this study have provided valuable insights into the industry's alignment with the three pillars of human-centric manufacturing. Participants exhibited genuine enthusiasm during the practical learning factories, shedding light on how workers respond when confronted with new tasks or the integration of previously unfamiliar technologies within their workplace.

This study offers a valuable theoretical contribution by implementing the constructive alignment framework within the context of a learning factory. This innovative pedagogical approach serves as a novel method for crafting effective learning activities tailored specifically to the industrial domain. Moreover, it provides a practical and tangible illustration of learning factories, demonstrating its applicability in enhancing learning experiences within an industrial setting.

As a significant practical contribution, the utilization of learning factories has demonstrated substantial potential in addressing the up-skilling and re-skilling requirements essential for industrial workers to effectively adapt to the evolving industrial landscape. The study's inclusion of participants from various industrial sectors underscores the critical role that collaboration between industry and academia plays in this transformative process. This successful synergy is exemplified through the outcomes achieved within the learning factories highlighting its viability as a mechanism for fostering industry-academic cooperation and skill development.

4.1. Limitations and Future Developments

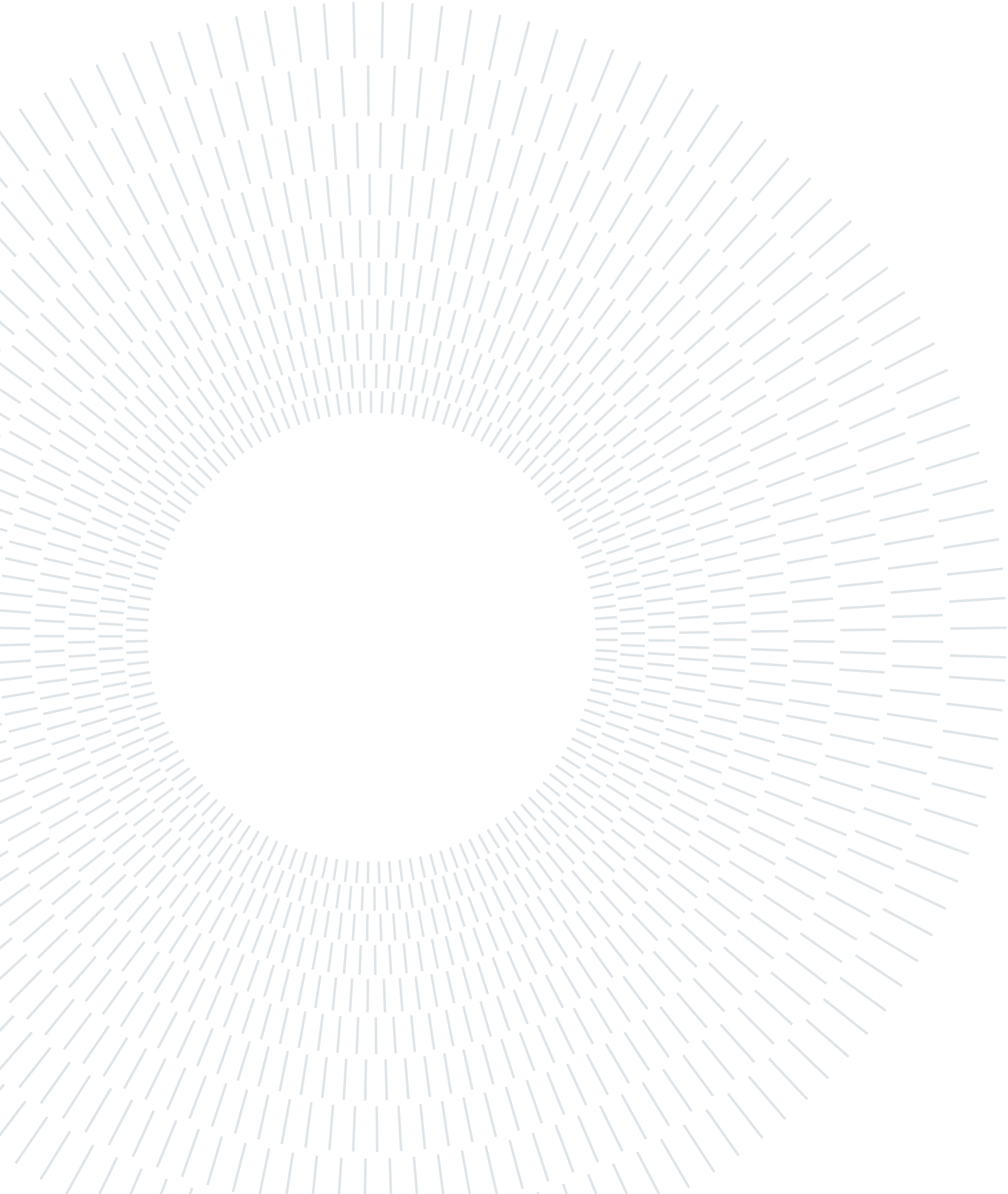
It is important to acknowledge certain limitations in the study. Firstly, the number of participants assessed was limited, which may impact the generalizability of the findings. However, the materials and questionnaires used in this research are readily available and can be employed in future studies with larger sample sizes.

The technologies employed in this study included Collaborative Robots and Exoskeletons. Conversely, a broader array of technologies can be integrated into the context of Industry 5.0 learning factory. As part of future developments, a learning factory could be conceptualized as an integrated value chain encompassing the utilization of multiple technologies. For example, a product's production process could involve the use of additive manufacturing for creating specific components. These components could then be transported to an assembly station through automated guided vehicles, where assembly tasks are facilitated with the assistance of Artificial Intelligence. This approach exemplifies the potential for expanding the scope and complexity of learning factories in facilitating comprehensive hands-on learning experiences.

Regarding the learning experiences crafted for the learning factories, in the context of collaborative robots, an alternative product configuration could be considered. This configuration might involve components requiring the cobot's assistance for assembly while one or more participants perform specific operations. For example, this scenario could encompass the assembly of a cumbersome part that necessitates support while participants secure it in place. For the exoskeleton, a modified activity setup could be proposed to either prolong the duration of the task by incorporating additional screws or intensify its complexity by introducing variations in heights and depths. This deliberate adjustment would create a more pronounced contrast between executing the activity with and without the exoskeleton.

In a general sense, the data collection process relied on participant questionnaires and verbal interactions, which may be susceptible to bias. To mitigate potential bias and enhance the assessment of participant sentiments, an alternative approach could involve the utilization of sensors. For instance, the incorporation of accelerometers attached to the participants' arms could facilitate the measurement of erratic movements, providing a more objective evaluation of their experiences.

Additionally, it is worth noting that the industrial landscape encompasses a wide spectrum of sectors. Future studies could expand on this research by incorporating different technologies and assessing the same values across diverse industrial sectors, providing a more comprehensive understanding of the implications of Industry 5.0 or possibly revealing other values of human-centric manufacturing.



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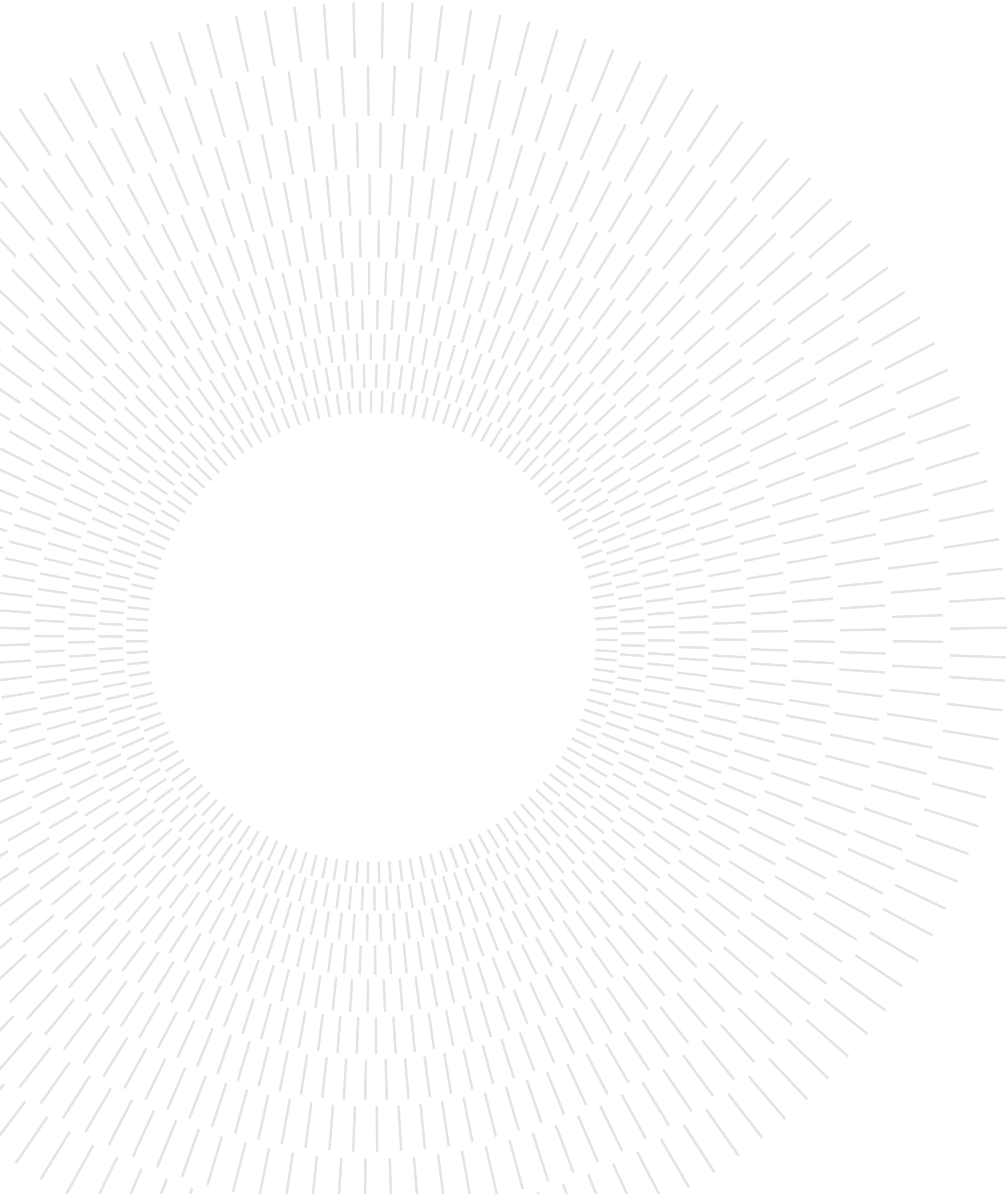

A | Appendix A

A.1. Questionnaire Learning Factory Cobot Before

1. How confident are you in your ability to perform the work described? (Scale 1 - 5).
2. How would you rate the level of safety associated with the task described? (Scale 1 - 5).
3. To what extent do you perceive is important in this task the teamwork? (Scale 1 – 5).
4. On a scale of difficulty, how would you rate the assigned task? (Scale 1 – 5).

A.2. Questionnaire Learning Factory Cobot After

1. On a scale of difficulty, how would you rate the assembly without the Cobot? (Scale 1 – 5).
2. How confident do you feel to take control over job tasks with this technology? (Scale 1 - 5).
3. To what extent do you perceive this technology gives you the freedom to perform the work at your own pace? (Scale 1 - 5).
4. How would you rate your level of worry during the assembly with the Cobot? (Scale 1 - 5).
5. To what extent do you perceive this task enhances performance and collaboration? (Scale 1 – 5).
6. How smooth was the assembly process of the gearbox using the cobot? (Scale 1 - 5).
7. On a scale of difficulty, how would you rate the assembly with the Cobot? (Scale 1 - 5).

A.3. Questionnaire Learning Factory Exoskeleton Before

1. How confident are you in your ability to perform the work described? (Scale 1 - 5).
2. How would you rate the level of safety associated with the task described? (Scale 1 - 5).
3. To what extent do you perceive is important in this task the teamwork? (Scale 1 – 5).
4. On a scale of difficulty, how would you rate the assigned task? (Scale 1 – 5).

A.4. Questionnaire Learning Factory Exoskeleton After

1. On a scale of difficulty, how would you rate the activity without the Exoskeleton? (Scale 1 – 5).
2. How confident do you feel to take control over job tasks with this technology? (Scale 1 - 5).
3. To what extent do you perceive this technology gives you the freedom to perform the work at your own pace? (Scale 1 - 5).
4. How would you rate your level of physical effort perceived during the activity with the exoskeleton? (Scale 1 - 5).
5. To what extent do you believe this technology is suitable for a wide range of users? (Scale 1 - 5).
6. On a scale of difficulty, how would you rate the activity with the Exoskeleton? (Scale 1 - 5).

List of Figures