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INDUSTRIAL ROBOTICS IN THE PROVINCE OF BRESCIA: ANALYSIS, ADVANCES AND OPPORTUNITIES

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Sommario

In un'epoca caratterizzata da rapidi cambiamenti nel panorama industriale, dove competitività e flessibilità rivestono un ruolo imprescindibile, la robotica industriale si afferma come una tecnologia strategica, integrandosi efficacemente con progressi quali l'intelligenza artificiale e la digitalizzazione. Il presente studio si focalizza sull'analisi della diffusione e dell'impatto della robotica all'interno del settore manifatturiero, con una particolare attenzione rivolta al settore della meccanica per parti nella Provincia di Brescia, una zona distintamente caratterizzata da un'intensa attività industriale. Mediante un'approfondita indagine economica, si è proceduto all'esame dell'adozione di soluzioni robotiche in imprese di dimensioni variabili, selezionando un campione rappresentativo e impiegando un questionario per investigare le tipologie di robot maggiormente utilizzate, le loro principali applicazioni, gli impatti a livello operativo e sul personale, nonché le competenze aziendali necessarie per la gestione di tali tecnologie. I risultati dell'indagine evidenziano una marcata presenza di soluzioni robotiche, in particolar modo di robot articolati, nelle maggiori imprese dell'area esaminata. Tale diffusione si correla positivamente a miglioramenti significativi in termini di produttività e qualità. Interessante risulta l'impatto sul mercato del lavoro: l'introduzione di robot si associa a un incremento degli indicatori di crescita aziendale, inclusa l'espansione del personale. Le imprese di maggiori dimensioni dimostrano una superiore capacità di adattamento a queste tecnologie, supportate da maggiori risorse finanziarie e da un'ampia gamma di competenze interne per la gestione dei robot. In generale, le aziende di tutte le dimensioni hanno espresso soddisfazione per i robot installati e manifestano l'intenzione di implementarne ulteriormente l'uso nel prossimo futuro. Un elemento di particolare rilievo è rappresentato dalle piccole imprese che, sebbene attualmente meno dotate di tali tecnologie, esibiscono un marcato interesse verso l'adozione futura della robotica, segnalando un'importante opportunità di crescita e innovazione in tale segmento. I risultati suggeriscono che l'integrazione della robotica nel settore manifatturiero non solo costituisce un mezzo efficace per potenziare le prestazioni operative, ma funge altresì da catalizzatore per lo sviluppo del capitale umano e per il rafforzamento dell'economia locale.

Abstract

In an era characterized by accelerated transformations in the industrial sector, where competitiveness and flexibility are of key importance, industrial robotics emerges as a strategic technology, seamlessly integrating with advancements like artificial intelligence and digitalization. This study focuses on the analysis of the deployment and impact of robotics within the manufacturing sector, with particular attention to the mechanics for parts industry in the Province of Brescia, a distinctly characterized area by intense industrial activity. Through a detailed economic investigation, we examined the adoption of robotic solutions in companies of varying sizes, selecting a representative sample and using a survey to investigate the most commonly used types of robots, their main applications, impacts at the operational and personnel level, as well as the corporate skills necessary for the management of such technologies. The results of the investigation highlight a marked presence of robotic solutions, particularly articulated robots, in the major enterprises of the examined area. Such diffusion positively correlates with significant improvements in terms of productivity and quality. The impact on the labour market is noteworthy: the introduction of robots is associated with an increase in corporate growth indicators, including staff expansion. Larger companies demonstrate a superior ability to adapt to these technologies, supported by greater financial resources and a wide range of internal competencies for the management of robots. Furthermore, larger companies are particularly proactive in hiring qualified personnel or initiating internal training courses. In general, companies of all sizes have expressed satisfaction with the installed robots and indicate the intention to further implement their use in the near future. A particularly notable element is represented by small businesses that, although currently less equipped with such technologies, exhibit a marked interest in the future adoption of robotics, signalling a significant opportunity for growth and innovation in this segment. The results suggest that the integration of robotics in the manufacturing sector not only constitutes an effective means to enhance operational performance but also acts as a catalyst for the development of human capital and the strengthening of the local economy.

Introduction

Problem Statement

Robot installations are rapidly growing globally, although their implementation in certain specific industries or companies is still limited. This is especially true for small and medium-sized enterprises (SMEs), where investments in this type of technology have traditionally been too expensive and inaccessible. This represents a significant opportunity in terms of productivity growth and business innovation for the entire existing production system. In this scenario, robotic installations in the manufacturing industry grew between 2011 and 2021 with an average annual global rate of 12%. From this perspective, the most active industrial sectors have been automotive, electronics, and mechanical processing. Traditionally, only large companies have employed extensive use of active robotic installations. This is because it required high capital costs and a high level of expertise to manage this type of technology; indeed, skilled workers are required to program robots to perform specific tasks under specific conditions. Both factors have led to a low adoption rate of robotic cells by small and medium-sized enterprises, which nonetheless represent a significant share globally.

This is beginning to evolve, as the cost of installing and running industrial robots decreases (this includes robotic equipment, peripherals, and system integration). The reduction in component costs, improvements in gripping, vision, and mobility technologies, integrated with developments in artificial intelligence, are translating into an expanding market, also for collaborative robots. These new devices work alongside humans instead of being confined in cages, being equipped with sensors and software that recognize and react to unexpected events.

At the same time, production facilities are transforming into extremely flexible factories, capable of rapidly changing assembly lines, allowing manufacturers to respond to customer demand for a greater variety of products, and maintaining high productivity indicators. This type of factory can swiftly switch between different productions, thus managing multiple product lines. Additionally, factory equipment is becoming increasingly digitalized. In this factory model, data is collected at every stage of production from sensors attached to machines. The data is then aggregated and processed with the aim of automatically optimizing the entire production process.

Automation, and digital technologies in general, are impacting not only machinery but also workers and job profiles. Repetitive or dangerous tasks are now largely carried out by robotic solutions, while human labour focuses on tasks related to managing production flows or handling unplanned exceptions. This leads to the need for greater integration between technological skills and soft skills, such as critical thinking, creativity, emotional intelligence, leadership, and change management. Emerging professional roles foresee greater use of technologies, not only from an applicative-procedural standpoint but also from a cognitive perspective.

Research Purpose and Research Questions

In the context of this research, an exploration of the state of the art is conducted through a systematic analysis of the diffusion of robotics, segmented by sector of use and geographic area. Additionally, a bibliographic review is carried out concerning the evolution of the workplace within companies, with particular attention to the related organizational and operational implications.

Despite the extensive documentation available, the analysis reveals the presence of two significant gaps in the literature. The first concerns the origin of robot sales statistics, which are commonly provided by manufacturers rather than end-users. This introduces uncertainty regarding the actual use of robotic equipment, as it may not accurately reflect the real trends of adoption and employment across different production realities. The second identified gap focuses on the lack of data stratification regarding the diffusion of robotics and the impacts of this technology on business dynamics. Specifically, the current literature does not adequately differentiate data based on company size. This gap is critical because the impact of robotics and adoption strategies can vary significantly between small and medium-sized enterprises (SMEs) and large corporations. SMEs may face specific barriers, such as prohibitive costs and a lack of technical skills, which differently affect their ability to integrate new technologies compared to larger entities, which usually have more extensive resources and greater capacity to invest in disruptive innovations.

The specific objectives of the project are summarized as follows:

- Examine the effects recorded in companies that have implemented robotic solutions, focusing on operational aspects and on dynamics related to human resources. In this context, both the challenges that have emerged following the introduction of robotics and the benefits derived are identified and evaluated.
- Deepen the understanding of the level of knowledge and skills related to robotics within the corporate fabric. This includes the perception of companies regarding the training of operators in the context of robotics management and the evolution of the production system.
- Investigate the state of diffusion of knowledge and skills related to robotics within companies, exploring the perception of companies regarding the training of operators in the context of robotics management.
- Assess the development and investment intentions in the field of robotics by companies, as well as evaluating the effectiveness of economic stimulus tools.

In order to achieve these objectives, the present work aims to address the following research questions:

- RQ1: To what extent is the adoption of industrial robotics prevalent within a mature market, and how does this prevalence vary with the size of the companies operating in such a market?
- RQ2: What is the impact of introducing industrial robotics on the operational outcomes and employment levels of companies within a mature market context, and how does this impact vary in relation to the size of the company?
- RQ3: Do companies operating in a mature market possess the necessary competencies to effectively implement and manage industrial robotics, and how do these competencies vary according to the size of the company?
- RQ4: What are the perspectives and expectations of companies regarding the future evolution of industrial robotics, and how do these perceptions differ based on the size of the company?

Research Methodology

The research methodology encompasses the procedures and techniques used in the identification, selection, organization, and analysis of information pertaining to a specific topic. Describing the research methodology enables readers to assess the rigor and reliability of the study's conclusions [1].

In this investigation, the adopted method included both qualitative and quantitative analysis, providing a solid foundation for the interpretation of the collected data. The focus of this inquiry is the field of industrial robotics, with particular emphasis on its development and impact on a global scale. Initially, a review of the existing literature is conducted to map the geographical distribution of robotics, analysing the number of installations, the most prevalent types of robots, the client industries, and the predominant applications. It is found that anthropomorphic robots are the most widespread, highlighting a global trend towards an acceleration in the adoption of robotics, especially in industrial applications. Subsequently, the study concentrated on the effects of introducing robotics into companies, considering operational, occupational, and social aspects.

To further refine the analysis, the research focused on the Italian context, one of the main users of robotic technologies, with a specific focus on the province of Brescia, known for its significance in the manufacturing industry. During this research, particular attention is paid to the sector of mechanical parts manufacturing, chosen for its relevance in the adoption and integration of robotic technologies. This sector stands out as one of the main areas where robotics has found extensive application, making it ideal for a detailed study on the use and impacts of such technologies. This allowed for an in-depth exploration of how the introduction of robotics alters production processes, affects labour dynamics, and leads to significant operational transformations. Regarding the investigative methodology, survey is chosen as the main tool to gather both qualitative and quantitative data. This approach enabled the comparison of the collected data with the state of the art, according to a stratification that considers the size of the enterprises.

Thesis Outline

The following work has been distributed in four chapters:

Chapter 1: This chapter delves into the dynamic interplay between innovation, learning, and technology in the workplace. It introduces Workplace Innovation (WPI) and examines its effects on work organization, human resources, and advanced technology use. The chapter discusses the challenges and opportunities of integrating industrial robotics, noting its role in economic growth and productivity, while acknowledging the complexities of automation. It emphasizes the need to develop cognitive and digital skills in the workforce and highlights the importance of ethical considerations and collaborative approaches in the technological transformation involving robotics, AI, and human labour.

Chapter 2: This chapter examines the evolution and significance of industrial robots, with a particular focus on the mechanical structure, actuators, sensors, and grippers of traditional industrial robots. It traces the development of industrial robots since the 1960s, highlighting how these critical components enable the execution of complex manufacturing tasks. Various types of industrial robots are explored, each with specific applications and technologies. The chapter then shifts to Collaborative Robots (COBOTs), describing their design for safe operation in proximity to human beings and discussing their applications across diverse sectors such as assembly and healthcare. Furthermore, it analyses how COBOTs incorporate advanced sensory technologies and adaptive grippers to dynamically respond and interact with human operators.

Chapter 3: this chapter focuses on the classification and growth of industrial robotics globally. It outlines the structural components of robots, categorizing them into Cartesian, SCARA, Delta, and Articulated types. The chapter emphasizes the significant increase in global installations and the widespread integration of robotics across various sectors, showcasing their essential role in the modern industrial environment.

Chapter 4: this chapter analyses the integration and impact of industrial robotics in the province of Brescia. It discusses the role of LLCs and Corporations in creating a competitive, technologically advanced environment, and the adaptability of SMEs and larger corporations. The chapter examines the mechanical discrete manufacturing sector in Brescia, focusing on company distribution, employment trends, and the influence of robotics on productivity and operational efficiency. It addresses the challenges of robotics integration and the need for specialized personnel and training, highlighting the future prospects of robotics in Brescia’s economic landscape.

Chapter 1

Workplace Transformation: Innovation, Learning, and Technology Integration

This chapter explores the intricate relationship between innovation, learning, and technological integration in modern work environments. It explores the concept of Workplace Learning and Innovation (WPLI), examining its impact on work organization, human resource management, and the utilization of advanced technologies. The discussion further extends to the challenges and opportunities presented by the integration of industrial robotics, highlighting its role in economic growth and productivity, while also acknowledging the complexities and potential drawbacks associated with automation. Additionally, the chapter addresses the critical need for developing cognitive and digital competencies in the workforce, emphasizing the importance of adapting educational strategies to meet the evolving demands of innovative workplaces. The role of worker participation in technological transformation is also scrutinized, underscoring the significance of ethical considerations and collaborative approaches in managing the intersection of robotics, artificial intelligence, and human labour. Ultimately, the chapter offers a comprehensive analysis of how innovation, learning, and technology converge to shape the future of work.

1.1 Embracing Change: Innovation Strategies in Modern Work Environments

1.1.1 Workplace learning and innovation: a critical perspective

The phenomenon of innovation, frequently evoked in various cultural, social, and professional contexts, is primarily associated with the notion of change or the desire to generate such change. Its applicability extends to different sectors, such as education, economics, and society; however, the exact definition of what it means to innovate a system or organization, regardless of its complexity, often remains ambiguous. Innovation is configured as an intentional process of transformation or radical renewal within an existing system [2]. This process is facilitated by the introduction of new and functional ideas, products, processes, or procedures that have a significant impact on roles, groups, and organizations. This definition provides a foundation for interpreting both the potential and the challenges inherent in innovative processes, highlighting the impossibility of standardizing innovation and its essential dependence on the specific environment in which it is applied.

The concept of change is a fundamental element in the process of innovation, where altering the status quo is indispensable. Nevertheless, transitioning beyond one's comfort zone to embrace change does not occur easily. Another important element is intentionality. To qualify an action as innovative, it is necessary to evolve from a realm of random or emergency circumstances to a deliberate and systematic strategy of approach to innovation, particularly in collective or organizational settings. Additionally, utility stands as an indispensable criterion. A change can only be qualified as innovative if it yields superior results compared to pre-existing methodologies. Consequently, innovation assumes the role of a catalyst for progress. This underscores the importance of a comparative analysis of the impact of innovation in the pre, during, and post-implementation phases of innovative processes. By evaluating the areas where innovation has had a positive impact and those where it has not met established objectives, the effectiveness of the innovative process can be measured. The systematic and rigorous collection, analysis, and interpretation of data play a strategic role in assessing the efficiency of an innovative process. Research and innovation are interpreted as interdependent and complementary processes [3]. This perspective emphasizes the importance of research activities and the collection of empirical data as indispensable elements in innovation processes.

Innovative processes involve examining fundamental issues such as change, intentionality, utility, and research, all of which are significant factors in human resource management. A superficial interpretation of innovation, particularly in the work context, both in companies and educational institutions, can lead to an underestimation of the time necessary for its implementation. This approach risks promoting the premature abandonment of innovative initiatives that could prove beneficial, even in environments originally resistant to change. A thorough reflection on these aspects is essential to ensure the effective introduction and support of innovative processes, considering the importance of a consistent commitment and an accurate assessment of the impact and needs related to such initiatives.

The investigation into the proposed themes focuses on the concept of Workplace Learning and Innovation (WPLI). This phenomenon has been outlined as the implementation of innovative interventions that influence both the organization of work and human resource management, potentially in connection with enabling technologies [4]. Within this scope, three main areas of intervention are distinguished: innovation in work organization, human resource management, and the use of advanced technologies. WPLI is characterized by its multidimensional and complex nature, being recognized not only as an economic process focused on investments and acquisitions but also as a social and participatory process aimed at restructuring work organization and work life. This process incorporates human, organizational, and technological dimensions. The aim of this approach is to improve not only the services and products offered but also the organizational performance and the quality of work life for employees at various levels of the organization [5].

Consequently, Workplace Learning and Innovation (WPLI) is often analysed as a mode of organizational innovation in companies, following the principles outlined by the Organisation for Economic Co-operation and Development (OECD) in 2005 [6] and other studies [6,7]. These studies examine management practices such as teamwork, knowledge management, flexible work, production techniques, and external relations, including outsourcing, networking, and interactions with customers. However, there is less attention in exploring and analysing the impact of WPLI on the competencies required of workers. Although the academic literature discusses a change in "knowledge management," it rarely investigates into how such knowledge should be developed before it can be effectively managed. Often, it is implicitly assumed that the introduction of an innovative process, such as the adoption of new technology, automatically entails the acquisition of new skills, which should subsequently be managed differently.

An in-depth investigation examined factors that foster Workplace Learning and Innovation (WPLI), including favourable legislation and the presence of research activities in the area [9]. However, the study does not specifically mention the processes of structured training within innovative companies, nor the cognitive skills required to support a renewed work environment. These analyses adopt an optimistic viewpoint, assuming an automatic improvement in business performance and an innate potential for innovation, capable of stimulating connections between different knowledge areas and promoting effective arguments. This perspective implies that the introduction of technologies in companies or training institutes automatically leads to an enrichment of skills, a renewed use of cognitive processes, and an increase in collaboration among the workers involved. Although positive, this approach requires a more critical and detailed evaluation of internal dynamics and the real impact on skills and cognitive processes.

Other studies interpret the concept of Workplace Learning and Innovation (WPLI) as a process that naturally facilitates the integration of different types of knowledge: strategic knowledge at the managerial level, professional skills of operational workers, and organizational knowledge of experts [10]. The intent is to involve all stakeholders in constructive dialogue, where the most valid arguments prevail. These studies highlight the importance of fostering interaction between different knowledge areas within organizations. However, they do not explicitly outline the need to develop new skills before they can be effectively integrated. This gap implies a need for further exploration of how organizations can not only promote the integration of existing knowledge but also facilitate the development of new skills necessary for innovation.

Despite this, Workplace Learning and Innovation (WPLI) highlights the need for a new integration of different forms of knowledge and the limitations of current training, which can sometimes be inadequate, excessively theoretical, practical, or self-taught [11]. Achieving this awareness will require a considerable commitment in terms of time and effort. The recent pandemic experience has not only accentuated the importance of having advanced technologies but has also highlighted the risk that these may be ineffective if managed by a workforce not adequately prepared to face innovative processes. Following a period of intense experimentation during the pandemic, it has been observed that some organizations are reverting to more routine processes, giving up the implementation of potentially innovative changes. Although various studies recognize the need for new workplace skills, and Brynjolfsson and McAfee in 2014, few researches focus on the specific identification of such skills, related cognitive actions, and how these can be developed and integrated into various work contexts [10,11].

1.1.2 Innovative dynamics and educational transformation in the workplace

To deeply explore the support for innovation in the workplace, it is central to refer to the theories of Joseph Schumpeter, who defined innovation as the engine of a "cycle of creative destruction" [12,13]. In this model, change, particularly in the industrial field, promotes a constant revolution of the economic structure, dismantling pre-existing configurations and replacing them with new ones. This concept of creative destruction, although interpreted differently from Schumpeter's original vision, emphasizes the need for radical renewal to realize the benefits of innovation. This perspective contrasts with the optimism that sometimes pervades the analysis of innovation in the workplace, where challenges related to the introduction of new methods of work or to educational and cognitive aspects are often overlooked. From an educational standpoint, embracing the destructive dimension of innovation involves investigating how learning models should be adapted in innovative contexts, what results in terms of knowledge, skills, and competencies are expected, and which teaching methodologies align or do not align with these objectives. It is essential to recognize that some teaching methods may be incompatible with the set objectives, regardless of the content. This implies a critical analysis of current educational methodologies and an evaluation of their effectiveness in the context of innovative environments.

The analysis of previous studies highlights how the debate surrounding Workplace Learning and Innovation (WPLI) may fall into the risk of focusing too much on who should manage the new knowledge and what this should imply, neglecting the process through which such knowledge is built and the consequent learning outcomes [6-[9]. Furthermore, an emphasis on "knowledge management" or "knowledge transfer" can lead to two substantial misconceptions: on the one hand, the idea that mere possession of knowledge (understood as the assimilation of information through learning) is sufficient to tackle innovation in a business context, ignoring the concept of competence; on the other hand, the idea that competence, reduced to mere knowledge, can be easily transferred rather than being actively and cognitively constructed. This perspective requires a more in-depth reflection on the role of the active construction of knowledge and competencies within innovative processes, as well as a reconsideration of the value and meaning of knowledge transfer in the workplace.

Adopting a perspective that incorporates the destructive component in innovation requires a detailed analysis of the necessary changes in existing processes, recognizing that such modifications should not be limited to equipment, business processes, technologies, or infrastructures. It is indispensable to understand that the training processes related to human resources must also be subject to review and updating.

When examining classifications of enabling technologies, such as those associated with Industry 4.0 or Smart Industry and comparing them with the most demanded competencies in sectors heavily influenced by innovative processes, it becomes clear that for the modern worker, mere theoretical knowledge of concepts such as augmented reality, cloud systems, or data analytics is not sufficient. Instead, there is a need for the ability to confer meaning to varying data and situations, as well as the capability to analyse and compare different contexts, evaluating the best course of action based on specific data or particular scenarios made accessible through the use of advanced technologies. This underscores the necessity for a training approach that extends beyond theoretical learning, integrating analytical and applicable skills suited to modern work contexts and the dynamic needs of WPLI.

In the contemporary work environment, technology plays a key role in the functions of storage, application, analysis, and transmission of information, often characterized by a high degree of processing. Despite this, it remains the task of individuals to optimally utilize these technologies, making appropriate decisions that vary from operational to strategic [15]. The "The Future of Jobs Report 2020" by the World Economic Forum highlights significant gaps in skills considered essential in the current work landscape, such as critical thinking, analytical ability, problem-solving, and self-management [16]. These skills are deemed indispensable for addressing the challenges that society will face in the coming years. Therefore, in the perspective of WPLI, there emerges a need for strengthening and expanding individual competencies to effectively embrace the opportunities and challenges presented by technological advancement and the continuous transformation of the labour market.

1.2 Cognitive and digital skills development in innovative work environments

1.2.1 Developing cognitive competencies for organizational innovation

In the current context, it is important to define educational objectives relevant to innovative processes, preferably adopting hierarchical and sequential classification systems of the cognitive processes involved in the competencies most demanded by innovation. The use of a reference taxonomy often proves useful in the design of coherent educational and evaluative interventions, capable of encompassing a wide spectrum of cognitive activities [17]. These taxonomies reflect the manifestations of human activity in knowledge creation, a fundamental aspect in an organization or enterprise pursuing innovation. Other works focus on thought processes rather than on learning outcomes. These analysis seem particularly appropriate for investigating which mental dispositions are necessary to competently manage the changes anticipated in Workplace Learning and Innovation (WPLI) [18]. The thought processes identified (remembering, understanding, applying, analysing, evaluating, creating) can be applied to different forms of knowledge (factual, conceptual, procedural, metacognitive), which constitute both the content of learning and the outcomes of thought processes.

It is possible to identify cognitive processes that are particularly relevant in WPLI. While in the past there has been a strong emphasis on basic cognitive processes (such as remembering, understanding, and applying), it is increasingly necessary to engage in higher-order cognitive processes such as analysis, evaluation, and creation. This need is clearly manifested in organizations that require advanced competencies in problem-solving, problem analysis, and critical thinking.

In literature, there is unanimous consensus regarding the importance of critical thinking as a prerequisite for conscious interventions, decision-making processes, and actions based on methodical processes rather than improvisation in the context of Workplace Learning and Innovation (WPLI) [19]. Critical thinking is conceptualized as a set of competencies that enable the analysis, comparison, evaluation, and objective interpretation of collected information, in order to arrive at clear and verifiable conclusions [20]. Other studies emphasize the role of critical thinking in decision-making, defining it as the reflection and reasoning that guide choices and beliefs [21]. Other research, however, emphasize its function in fact-checking and belief evaluation, describing critical thinking as a disciplined intellectual process actively involved in conceptualization, application, analysis, synthesis, and evaluation of information derived from observation, experience, reflection, reasoning, or communication, which guide beliefs and actions [22].

Scholars agree that critical thinking comprises various cognitive dimensions, which must be clearly identified and understood before proceeding to its full development and mastery within an organization. This deep understanding facilitates the implementation of targeted training strategies aimed at strengthening these critical competencies, essential for effective and innovative navigation in modern work contexts.

In the context of Workplace Learning and Innovation (WPLI), it is useful to consider the revision of Bloom's taxonomy made by Anderson and Krathwohl in 2001 and the further expansion proposed by Andrew Churches in 2008. Churches extended the taxonomy of Anderson and Krathwohl, and consequently Bloom's original taxonomy, by including reflections on digital technologies. He associated various aspects related to the use of digital technologies with the categories of the taxonomy, such as web navigation, information overload, the growth of ubiquitous and personal technologies in professional contexts, cloud computing, media production, and the online publication of materials with potential impacts on context, reputation, and business, as explained by Grower and Wedlock in 2017 and by Marini in 2021, as well as by Churches himself in 2008.

In developing learning objectives in contexts influenced by innovative processes, it is advantageous to undertake a critical reflection on previous educational initiatives aimed at supporting innovation. It is necessary to distinguish between initiatives that focus on basic cognitive processes and those oriented toward higher-order cognitive processes. Such critical analysis can be conducted effectively when educational proposals communicate learning objectives in a clear and detailed manner. Where educational proposals are limited to a list of topics and content to be covered in training sessions, without explicit reference to learning objectives, this could reflect a lack of adaptability or suitability for the ongoing innovation. This consideration underscores the importance of a targeted and well-structured educational design to meet the dynamic needs and expectations of WPLI.

1.2.2 Digital competence in the modern workplace: training for innovation

The digitalization of work has opened up opportunities to explore new working models and has enhanced individual capacity for collaborating in solving complex problems [23]. In this context of Workplace Learning and Innovation (WPLI), a study by the European Business Innovation Observatory revealed that worker skills represent a fundamental element in implementing innovative practices in the workplace [24]. The acquisition of new skills is intrinsically connected to the ability to face and solve emerging problems related to innovation. This type of learning should be based on training methods that prefer unconventional, cooperative situations subject to critical reflection, in line with innovation objectives.

The European Commission's Digital Competence Framework for Citizens emphasizes that digital competence requires a conscious, critical, and responsible approach to the use of digital technologies [24,25]. The document enumerates various levels of competence (basic, intermediate, advanced, highly specialized) and corresponding functionalities in the field of learning, establishing a causal link between levels of competence mastery and learning outcomes. The five competence areas identified include: Information and data literacy; Communication and collaboration; Digital content creation; Security; Problem-solving.

In these areas, 21 specific competencies have been identified. For example, in the area of Information and data literacy, competencies include navigating, searching, and filtering information; evaluating data, information, and digital content; managing data, information, and digital content. In the area of Communication and collaboration, competencies involve interaction, sharing, digital citizenship, collaboration, netiquette, and managing digital identity. The third area, Digital content creation, includes competencies such as developing, integrating, and reprocessing digital content, as well as issues of copyright, licensing, and programming. This complex framework underscores the importance of continuous and targeted training in the context of WPLI, ensuring that workers are adequately equipped to contribute effectively in an increasingly digitalized and innovative work environment. In the fourth area, named Security, four competencies are developed: safeguarding devices, protecting personal data and privacy, ensuring health and wellbeing, and preserving the environment. In the last area, Problem-solving, four competencies are identified: resolving technical problems, identifying needs and technological solutions, creatively using digital technologies, and identifying gaps in digital skills. Each level of mastery in the model represents an advancement in the acquisition of competencies in relation to cognitive challenges, the complexity of manageable activities, and autonomy in task performance.

Digital competencies can be acquired through an experiential learning program focused on problem-solving situations. The adoption of this pedagogical approach, focused on practice and experimentation, facilitates a more efficient development and distribution of competencies in learning activities [27]. These competencies are increasingly demanded in the job market, and the main obstacles to the development and acquisition of such skills are the high costs of technological training, the scarcity of candidates with adequate basic skills, and a mismatch between training supply and demand.

Thus, there emerges a need for greater integration between technological skills and soft skills, such as critical thinking, creativity, emotional intelligence, leadership, and change management. Emerging professional roles foresee a greater use of ICT-Enabled Technologies (ICT-ET), not only from an applicative-procedural perspective but also from a cognitive standpoint. This implies learning competencies such as self-sufficiency in technology use, flexibility, and resilience [28].

1.3 The role of worker involvement in technological transformation

1.3.1 Integrating robotics: transforming workplaces and human-machine synergy

The manifestation of robotics in the work context has been accelerated by technological transformation, particularly within large organizations equipped with significant financial resources to invest in advanced automation. These entities, capable of acquiring and implementing such systems, have recognized the economic and organizational benefits offered by robots [29]. This has facilitated the development of production processes that integrate human skills with robotic capabilities, promoting a synergistic approach to production [30].

Concurrently, the increase in the adoption of robots by small and medium-sized enterprises (SMEs) introduces specific challenges, particularly related to the acquisition of new skills and the development of new work practices [29,30]. The introduction of robots into the workplace is not merely a technical challenge but significantly impacts the daily lives of workers and internal relational dynamics [33]. These aspects transcend production, touching also on the relational and existential dimensions emerging in the workplace. Instead of being perceived as mere tools, robots are now considered active partners in the work process. This radically changes how individuals perform their tasks, the nature of interactions between employees, and the organization and management of companies. Consequently, collaborative robotics in the manufacturing sector not only demands the acquisition of new skills by workers but also the development of new work practices, rules, and values, generating complex strategies for appropriation and reinterpretation of values related to work.

When implementing robots in work environments, it is essential to recognize this process as a complex and multidimensional learning journey. This journey transcends the mere training of individual operators and involves the entire work ecosystem. Understanding this aspect is necessary to appreciate the scope of innovation introduced by robotics. It is essential to recognize that the principles and values guiding the restructuring of work contexts in response to robotics innovation, especially collaborative robotics, should not be imposed in an authoritarian or unilateral manner [34]. Instead, they should emerge through a process of negotiation among individuals and groups. This highlights not just a quantitative or qualitative change, but also a conceptual shift in the nature of work and human-robot interaction. Robots should be considered partners in the work process, rather than mere tools or machinery physically and conceptually separate from human workers.

These technological innovations radically transform how individuals perform their tasks, influence the relational dynamics among employees, and alter the operational and managerial methods of organizations. Consequently, the increasing adoption of robots in the manufacturing sector transcends the mere necessity for workers to acquire new skills. Instead, it involves the development of new work practices, the adoption of new regulations and values, and gives rise to complex strategies for appropriation and reinterpretation of the intrinsic values of work.

1.3.2 Redefining workplace safety and ergonomics

In the industrial workshops, traditional robots generally operate at high speeds in areas isolated and inaccessible to operators, as highlighted in several studies [33,34,35]. In contrast, cobots function in areas accessible to humans, usually operating at reduced speeds. The expansion of cobot applications is supported by technological advancements that enhance their capabilities and lower their costs. Moreover, cobots generally tend to increase productivity, speed, and precision, while simultaneously reducing defects and errors [38]. These developments highlight the importance and potential impact of cobots in the modern work environment, not only in terms of production efficiency but also in the realm of worker safety and well-being [39]. In various industrial sectors, the degree of collaboration between humans and robots presents a considerable variety. There are scenarios where operators and cobots operate independently, sharing only the same workspace. Conversely, in other cases, they actively collaborate and support each other in a joint operation [38].

This versatility of cobots highlights their potential in optimizing safety in production processes. Their ability to adapt to different needs and work contexts makes them valuable tools for industrial automation. Their integration into productive activities not only enhances operational efficiency but also offers the opportunity to reduce the physical and cognitive load on human operators, contributing to creating a safer and more sustainable work environment. Common commercial statements suggest that collaborative robots contribute to the improvement of worker health and safety, and in many cases, this claim is accurate. However, it is often presumed that operators can interact with cobots without the need for specific training, overlooking the necessity to adopt different cognitive or educational models from those traditionally used in a business context. Among the benefits associated with the use of cobots is the ability to fully automate repetitive or dangerous tasks, freeing workers from potentially alienating and risky duties. Additionally, cobots enable greater precision and speed in operations, as well as production characterized by high versatility and flexibility. Cobots also offer social benefits, making work more accessible to elderly people or those with disabilities. Despite this, it is essential to recognize that each digitalization process introduces new risks that can negatively impact the health and safety of individuals [40].

In the academic and industrial fields, there is an increasing systematic and in-depth analysis of issues such as "prevention through design", ergonomics, and the design of collaborative work environments. This research aims to anticipate the effects of new technologies to prevent and manage emerging risks, supporting workers through adequate information and training processes. This allows workers to evolve into "operators 4.0", who are competent, aware, and ready for change [41]. The primary goal is to minimize the negative impact of digital transformation on individuals and the entire organization, promoting inclusivity and continuous worker engagement. This approach aims for a harmonious integration of technology into the work fabric, ensuring that technological progress advances sustainably and responsibly.

Initially, traditional risks such as mechanical, electrical, thermal, chemical, and biological risks, as well as those arising from noise, vibrations, and radiation, already contemplated by current machine safety regulations (e.g., ISO 12100:2010 standard), must be considered. Although the use of cobots maintains many of these risk categories, aspects such as the sharing of tasks, tools, and workspaces, as well as the anthropomorphic interfaces of machines, introduce new emerging risks of an organizational and psychological nature [42]. Organizational risks can arise from the procedures, methods, and criteria adopted by the organization, such as the incorrect assignment of objectives to the operator in relation to the duration of the work shift. Psychological risks, on the other hand, are connected to the subjective perception of the worker interacting with the machine, including fears such as the fear of being replaced or the mental and physical fatigue linked to performance [43]. Specifically, mechanical risks can arise from the movement of moving parts, such as the arms of cobots, the presence of sharp edges or parts, the poor reactivity of machines in collaborative activities, the obstruction of vision systems, or the inability of operators to distance themselves from cobots. A significant problem is the difficulty in recognizing and predicting the trajectories of both humans and cobots, which can lead to collisions and injuries caused by imbalances and falls. Additionally, there are occasional problems related to maintaining large cobots in elevated positions, which can pose the risk of falls [44].

Regarding electrical risks, potential hazards stem from electromagnetic interferences between devices, which can cause malfunctions, power outages, or the unexpected release of stored energy, resulting in injuries to operators. Additionally, contact with live electrical parts or connections represents an added risk. Thermal risks in the use of cobots mainly derive from device overheating, with the consequence of possible burns and injuries to operators. Concurrently, there are risks associated with exposure to various environmental factors, such as vibrations and noise generated by the devices, ionizing radiation, laser sources, and corrosive or acidic substances present in batteries. These elements can cause damage to the skin, eyes, and respiratory system. Such issues underscore the necessity for a thorough assessment and the adoption of adequate safety measures in the context of cobot use. From an ergonomic perspective, the introduction of non-intuitive user interfaces can create discomfort and work stress, while the positions assumed during collaborative work can cause postural damage.

Furthermore, it is important to consider the wide range of organizational risks associated with the use of cobots. These risks are connected to adapting to the work rhythms imposed by cobots, which can lead to fatigue, musculoskeletal stress, psychological pressure, and physical overload for workers, consequently reducing their vigilance [31].

Another factor to consider is the cognitive overload resulting from simultaneously monitoring multiple cobots, which can lead to a decrease in attention and work effectiveness. Reduced concentration can potentially increase the risk of accidents and damage, both for operators and the work environment. Effective management of such risks requires a holistic approach that includes both physical and cognitive safety, ensuring that the implementation and use of cobots are carried out safely and responsibly for the overall well-being of workers. A concern is the implementation of collaborative robots in environments different from those for which they were originally designed. This practice can be risky, as it may lead to damage caused by unexpected machine behaviours or collisions due to the inadequacy of the workspaces where the devices are implemented. For this reason, a thorough assessment of the design and adaptability of cobots to specific work contexts is essential to prevent such risks [45].

The outsourcing of construction, configuration, installation, and programming phases of machines is leading to a significant reduction in internal technical knowledge about them. This lack of familiarity increases the likelihood of collisions and reduces the capacity for effective reaction in emergency situations. Without adequate training, workers may develop a perception of threat or overwhelm from the cobots, generating fears such as job loss, a poor understanding of machine behaviours, and increasing dependence on external personnel for maintenance and repairs. Recent technological advances have introduced machines capable of autonomous learning, increasing the risk of unpredictable behaviours. Furthermore, vulnerability to cyberattacks due to inadequate cybersecurity systems further heightens the danger of direct and indirect collisions, such as the falling of containers with hazardous substances [46].

The absence of safety fences around machines can generate stress and insecurity in workers. The psychological risks are significant: interaction with devices and the reduction of human contact can lead to social isolation. Workers may perceive a sense of inferiority or subordination to machines, which are faster and more efficient. Excessive trust in the cobots' ability to recognize and interact with humans can increase the risk of collisions [47].

Consequently, integrating a cobot into a work environment is not a simple matter. The diversity of risks that workers are exposed to, coupled with the increasingly complex and evolving nature of new work processes, suggests that traditional methods of risk analysis might no longer be adequate or effective. In the era of cobots, effective management of health and safety at work assumes fundamental importance.

1.3.3 Ethical principles in the age of Robotics and AI

When regulating the implementation of advanced technologies such as robotics and artificial intelligence, it is imperative to adopt a multidisciplinary approach that includes multiple stakeholders. In line with the European Commission's 2020 White Paper, the involvement of social parties plays an essential role in ensuring an anthropocentric direction in managing such innovations. In this rapidly evolving environment, unions are called to play a proactive role, innovating their strategies to respond to new protection needs. This involves promoting active worker involvement in restructuring and revising business practices impacted by technological transformation.

Simultaneously, a thorough theoretical analysis is necessary to explore the issues and challenges related to the use of collaborative robotics in the workplace. Currently, despite an active debate among specialists from various disciplines at national and international levels on managing technological innovation, there is a lack of comprehensive and integrated studies by labour lawyers, sociologists, legal philosophers, and union representatives regarding the impact of these technologies in the workplace.

The adoption of ethical and legal principles becomes fundamental to regulate these new dynamics, with the aim of mitigating risks and uncertainties and allowing individuals to protect themselves, while promoting a decorous work environment. Moreover, in interactions between workers and robotics, the benefits in terms of efficiency can complicate the reconfiguration of traditional trust relationships in the workplace. This scenario tends to amplify human vulnerabilities and inefficiencies, influencing both individual and corporate decisions and goals. The absence of empathy and emotional closeness, typical of interactions with non-human entities, can have repercussions on the behaviour of individuals and workers, potentially undermining their ability to manage risks and uncertainties [48]. This complexity requires careful reflection and an appropriate regulatory response to ensure that technological innovation advances ethically, sustainably, and socially responsibly.

However, the extent and manner in which robots can influence the behavior of the individuals they interact with, as well as the implications of this interaction, are still under investigation. The relevance of this topic is emphasized by studies regarding the innate human tendency to attribute intentions to robots to interpret their behaviours [49]. This psychological predisposition can be utilized from the design phase to increase the acceptance of robots in the social sphere of their users [50]. Consequently, it becomes essential to reflect on this human inclination, the existential nature of human-robot relationships, and the potential deceptions and risks associated with this interspecies trust.

The unconscious and innate tendency to trust technological infrastructures implies the need to restructure workers' routines and acquire new behaviours and competencies to support and validate this trust, both in individual and collective contexts [51]. The increased use of robots in the workplace thus implies learning new skills and developing innovative work practices. The ethical and legal issues that emerge evolve parallel to the introduction of these new technologies, making individuals' living and working environments particularly dynamic. Assuming that robots can be both a factor in accelerating the erosion of trust and a catalyst for reorganizing work relationships, it is critical, from a regulatory perspective, to identify principles and practices that can promote effective trust relationships. Trust and reliability in robotics, if mediated by a solid framework of ethical and legal principles, can represent reasonable goals for future work relationships. In this context, at least three aspects emerge that require in-depth analysis by regulatory bodies, with the aim of supporting trust relationships in these environments.

In the regulatory context concerning collaborative robots, three aspects are fundamental: transparency, identifiability, and predictability. Regarding transparency, it is particularly relevant to consider that robots, with their ability to perform multiple tasks simultaneously, can be opaque to users. Although this characteristic may be advantageous in certain contexts, it has the potential to erode trust in a human-robot interaction environment, making the actions of the robotic partner less evident. In terms of identifiability, in human interactions, each partner is clearly recognizable, a condition that does not necessarily occur (or is not indispensable) in interactions with robots. The possibility of replacing one robot with another of the same model can raise questions about reliability and the human partner's predisposition to establish a trust relationship. Finally, regarding predictability, a key element in human relationships, this is based on the knowledge or assumption of an individual's decision-making mechanisms (their values, preferences, attitudes, commitments), allowing anticipation of their behaviour [52].

However, this expectation might not be applicable to Cobots due to the "black box" problem, namely the impossibility of understanding the decision-making process behind their actions. This aspect raises significant questions about the possibility of establishing a trust relationship with entities whose actions are not fully understandable or predictable, underscoring the need for careful regulatory and ethical consideration in this emerging field.

1.3.4 Involving Workers in the Ethical Integration of Workplace Technology

Worker participation and involvement can be a means to mitigate the negative impacts of artificial intelligence and collaborative robotics on occupational health and safety. This approach, focused on shared awareness, fosters the identification of emerging opportunities from these technologies. Conscious management of technologies in the workplace requires active worker participation in all stages of design, development, implementation, and evaluation of the introduced systems. From this perspective, workers should not be mere passive recipients of information provided by the company but should be actively involved in the decision-making process, especially regarding issues that directly affect their health, such as privacy protection, data security, surveillance, tracking, monitoring, and the transparency of artificial intelligence algorithms [53]. Recently, various authors have analysed the participatory management of algorithms for worker well-being and methods to develop models of workplace well-being. While these approaches are generally considered positive, in practice, examples of transparent communication and active worker involvement are more the exception than the norm.

Limiting the provision of information to workers only after integrating these systems into their work environment, reducing their role to merely receiving may lack the necessary skills to fully understand the new technologies and the potential risks associated with them. Consequently, it is imperative to move beyond mere circumstantial statements regarding worker involvement and training enhancement. It would be appropriate to establish a mechanism where "work councils" or other forms of worker representation can consult internal and external experts to discuss the use of data and the functioning of algorithmic and artificial intelligence systems [54]. Simultaneously, it is necessary to develop an ethical framework at the European Union level, specifically targeting digitalization. Such a framework should outline criteria and methods for the use of robotics and AI-based systems in the workplace, considering the unique characteristics of each work environment. In this context, the focus is on work organization, with the aim of providing clear and universal guidelines, adaptable to the specific "ities of each work environment. This intends to effectively guide the adoption and integration of these advanced technologies into the European workforce, ensuring that the process is conducted ethically, transparently, and inclusively.

1.4 Robotics Deployment

1.4.1 Automation and robotics: a strategic approach

Academic research highlights a range of benefits from automating processes through robotics, identified by the acronym ARI ("Automation Robotics Integration"). These benefits, although interconnected, can be categorized into different thematic areas: economic gains, simplicity, flexibility and scalability, reliability and consistency, compliance and governance, customer benefits, worker benefits, long-term organizational improvements, efficiency, and increased productivity[55].

The primary advantages of automation, highlighted in a wide range of literature, are economic in nature: they represent cost savings compared to traditional process optimization methods and offer a quick return on investment. These savings manifest in terms of both operational expense reduction and personnel costs. These economic gains are characterized by short payback periods, attributable to the rapid implementation of ARI [56]. The second primary advantage is simplicity. The adoption of automated robotic solutions is non-invasive, integrating with and complementing the existing infrastructure without the need to replace or reconfigure entire production systems [57]. The installation and management of industrial robots do not require significant effort from the IT department thanks to configurations, controls, and interfaces that are simple and accessible even to personnel not specialized in IT. Moreover, deployment does not interfere with the organization's daily operations, making automation a low-risk option [58]. Automation systems represent an interface for integrating data from multiple sources. This integration capability facilitates the automation of interconnected processes across different technologies, promoting collaboration and data exchange both within individual organizational units and between external organizations [59]. This phenomenon is emphasizes how such systems encourage the standardization of process elements, as well as limit activities of low added value for the organization [60].

The integration and standardization lead to another advantage of Automation Robotics Integration (ARI): flexibility and scalability. Robotics can be implemented at various levels, allowing organizations to start with tests and experiments on specific processes or sub-processes [61]. Once the system's effectiveness is confirmed, it can be easily expanded and adapted to changing business needs [62]. This aspect is particularly relevant for organizations that need to navigate contexts characterized by seasonal variations, fluctuations in activity, data flow dynamics, variable labour availability, or uncertain environments [63]. The ability to rapidly reposition a robot significantly contributes to organizational agility and resilience, providing a versatile response to the changing needs of the operational environment. This factor is recognized as a key element in increasing the efficiency and effectiveness of business operations [64]. The reliability and consistency of Automation Robotics Integration (ARI) systems emerge from their ability to operate with constant precision, unlike human operators who can experience lapses in concentration. This aspect translates into a reduction of errors and rework needs, significantly improving the quality of the results produced [65]. Robots are equipped with a superior processing capacity compared to humans, allowing them to simultaneously manage multiple systems and process large volumes of data in real-time. These data can be automatically entered into corporate databases and reports, facilitating the smooth integration of information from different IT systems [66]. The resulting accessibility to accurate and timely managerial information supports forecasting, planning, decision-making, and resource allocation, which are key elements for organizational effectiveness. These accurate pieces of information are further employable to enhance compliance and governance. The processes automated by ARI are documented transparently, providing additional data useful for reporting and monitoring.[67]. ARI significantly reduces risks related to compliance, such as human errors and data losses, and monitors human transactions for unusual activities. By offering precision in processes, ARI increases the ability of organizations to adhere to regulations and governance requirements, while also reducing the costs and time needed to manage non-compliance. ARI's flexibility allows it to quickly adapt to regulatory changes, offering a competitive advantage in industries subject to frequent regulatory updates [68]. Organizations that comply with regulations provide superior quality service to their customers, an aspect that Automation Robotics Integration (ARI) amplifies by increasing customer satisfaction and service quality. ARI supports organizations in renewing and improving the customer experience, not only by accelerating direct processes but also by offering customized solutions [69].

From the employee's perspective, ARI represents a significant benefit. It takes on the burden of repetitive, low-value tasks, freeing workers to focus on activities that require specific human capabilities such as exception handling, interpersonal relations, intelligence, judgment, and interpretation. This shift in focus towards more stimulating and interesting activities not only improves working conditions and the balance between professional and private life but also increases employee motivation. This positive impact on employee motivation translates into greater engagement and well-being in the workplace. The reallocation of employees to higher-value activities further adds to the customer benefit [70]. Additionally, ARI stimulates innovation in talent, as it requires organizations to restructure job roles and offers employees opportunities for professional development. This evolution of roles enhances their value in the long-term job market [71]. Finally, the benefits of ARI extend beyond the immediate scope, contributing to digital transformation and lean production. These processes support organizational growth, competitive advantage, and the development of new capabilities, allowing organizations to compete effectively with natively digital startups. The adoption of RPA (Robotic Process Automation) by organizations is perceived as a sign of innovation and quality in the services offered, bringing reputational benefits and consolidating their position in the market [72].

1.4.2 Technological transformation: the role of robotics in economic progress

Industrial robotics has emerged as a sector of importance, getting widespread attention due to its multifaceted impacts, which are the subject of an evolving academic debate. A considerable body of research has empirically supported the hypothesis that the deployment of robots in the industrial realm can act as a catalyst for economic growth [73]. These studies emphasize the potential of industrial robots in reducing reliance on low-skilled labour and, concurrently, in promoting an increase in the demand for highly specialized labour a phenomenon analysed and documented in various publications [74] [3, 4]. According to this research, this transition is accompanied by an increase in average wages. However, it is important to note that there exists a contrasting school of thought, which highlights the potential negative effects of industrial robotics on the labour market. Some studies have found that the introduction of robots in the industrial field can have unfavourable repercussions on employment rates [77]. This dichotomy in research findings underscores the complexity and multifaceted nature of the impact of industrial robotics in the contemporary economic and labour context, necessitating further investigations for a more comprehensive and nuanced understanding of this phenomenon. In the academic literature, there is a systematic differentiation of the determinants of total factor productivity (TFP) in businesses, categorized into two essential groups: external factors and internal factors. External factors include variables such as political uncertainty and environmental regulation [78]. Another significant aspect in this category is the efficiency of resource allocation, highlighting how optimization in resource usage can influence productivity at the company level [79]. Concurrently, internal factors focus on elements intrinsic to the corporate organization, including investments in research and development (R&D), and the behavioural dynamics of staff and management [80]. These internal aspects are indispensable for a comprehensive understanding of corporate productivity.

In this context, technological progress stands out as a predominant internal factor, exerting a significant influence on productivity. However, it is important to acknowledge the existence of an academic debate regarding the efficacy of specific new technologies in enhancing productivity. Some researchers argue that not all technological innovations automatically translate into productivity improvements, leading to what has been termed the "productivity paradox." This critical perspective raises fundamental questions about the conventional assumption of technology as a universal catalyst for efficiency and productive growth. Therefore, there is a need for a more nuanced and critical analysis of the relationship between technological innovation and corporate productivity, taking into account the contextual and operational specificities of individual businesses.

For instance, there are research supporting a critical perspective, postulating that the adoption of advanced technologies has not produced a significant increase in the productivity of production factors in the United States [81]. This position emphasizes a disconnection between technological innovation and productivity gains. Concurrently, other studies offer a further facet to this theme, suggesting that the rapidity of automation, combined with the difficulty of workforce adaptation, may actually constitute an obstacle to the growth of total factor productivity [82]. This research alludes to an intrinsic complexity in the interaction between automation and labour dynamics, which could mitigate the potential benefits of technology.

Despite these critical perspectives, a considerable part of the scientific community has identified a positive impact of the use of industrial robots on productivity and the economy at various levels, thereby contradicting the so-called productivity paradox. These empirical and theoretical investigations have contributed to a broader debate, highlighting how the integration of robots in industrial contexts can actually lead to significant improvements in terms of productive efficiency and economic growth. This school of thought argues that, despite the challenges and complexities inherent in adopting new technologies, there is concrete evidence attesting to their beneficial potential in promoting increased productivity.

Over the past decade, a series of studies have provided consistent evidence supporting the significant contribution of industrial robotics to economic growth. An example of this trend is represented by the research of Graetz and Michaels [73], who identified that the use of robotic applications in the industrial sector has led to an increase in labour productivity and economic growth rates. These results have been corroborated through the analysis of country-level data, which confirmed that the use of industrial robots has contributed to economic growth, increasing productivity from both a theoretical and empirical perspective [83]. In a similar context, other works have examined data from French manufacturing companies, finding that the adoption of industrial robots can effectively enhance production and productivity growth in the manufacturing sector [82]. Concurrently, it has been demonstrated by Kromann et al. (2020) that industrial robots have a positive impact on productivity, considering various aspects and perspectives [70].

The use of industrial robotics thus exhibits a significantly positive correlation with corporate productivity. Further academic research has highlighted that industrial robotics can contribute to optimizing the industrial structure, promote industrial aggregation, and act as a catalyst in enhancing technologies related to exports and in specializing roles within the global value chain. From a technological standpoint, industrial robotics introduces innovative methods of processing, new production processes, and advanced control methods. The adoption of industrial robots within companies entails the need for investment in learning for innovation and research and development, as well as the development of absorption and management capabilities suitable for integration with the existing production system.

The integration of industrial robotic technology within companies necessitates the development of an innovative production system, which implies a phase of autonomous learning by the company. This process may lead to an increase in investments in research and development funds, both for product design and for management systems [84]. Furthermore, it has been observed that the use of industrial robotics at the corporate level facilitates the transfer of work between different industries and regions, encouraging the flow of talent to related sectors, as well as the integration of high-quality human capital into the production process. This phenomenon produces a direct effect of technological diffusion, enhancing the company's innovation capacity. This process can accelerate the flow of knowledge, stimulate technological transfer, eliminate technical barriers, and indirectly improve product quality and management efficiency of companies [85].

1.4.3 Challenges and complexities in automation robotics integration

Despite its numerous advantages, Automation Robotics Integration(ARI) presents challenges that can be categorized as follows: awareness and perception of ARI, uncertainties in preparation for ARI implementation, change management challenges during implementation, and issues associated with ARI providers [86]. The awareness and perception of ARI among stakeholders constitute a significant challenge for companies considering its implementation. Many organizations exhibit limited awareness of ARI and its range of benefits and drawbacks. Others express diverse perceptions ranging from extremely negative opinions, fearing that ARI may pose a threat, to sceptical traditionalist views questioning its benefits compared to offshoring production systems. Some even consider ARI as a panacea for standardized automation of organizational processes [87]. Despite growing interest in ARI in recent years, there remains a certain misunderstanding regarding its practical reality. This can lead to mistrust, negative attitudes, and active resistance to adopting ARI among those with contrary opinions. On the other hand, it can also lead to incorrect, unclear, or unmet expectations and inadequate decisions among those with a positive view of ARI. This disparity in perceptions and understandings represents a significant obstacle that must be addressed for the successful implementation of ARI and the full exploitation of its benefits [88]. An insufficient understanding of Automation Robotics Integration (ARI) implies that many decision-makers are not adequately informed about how to prepare for its implementation. Organizations need to consider ARI as part of a holistic strategy, which integrates and aligns with their overall strategy, requiring detailed planning. During the preparation for ARI, it is critical for organizations to identify which processes are susceptible to automation, select the appropriate ARI solutions, and determine the stakeholders to be involved in the process [87]. There is also a growing shortage of qualified ARI specialists to design and implement large-scale solutions, adding an additional challenge for organizations in the implementation of ARI [89].

With the implementation of ARI, various challenges arise, particularly in terms of change management, robot installation, and, more recently, cybersecurity issues, to which robots are not immune [90]. Change management represents an essential element in any ARI process, requiring a significant mindset shift for many and influencing workforce management. In this context, human resource management processes, in terms of recruitment and training, must be adequately modified to align with the new requirements brought by the adoption of ARI [91]. These aspects highlight the need for a comprehensive and well-considered approach to introducing ARI within organizations.

The implementation of Automation Robotics Integration (ARI) represents a significant challenge for organizations, especially in terms of the commitment and costs associated with internal development. The alternative, which involves employing external providers to assist organizations in selecting, implementing, and maintaining ARI, presents a different set of considerations. The choice between a "do-it-yourself” approach and a "done-for-you" approach largely depends on the pre-existing competencies within the organization and its ability to understand the relevant processes.

Despite Automated Robotic Integration appearing straightforward in its general operation, it requires qualified ARI specialists for the management and maintenance of robots, especially when errors or technical issues arise [92]. This need for specialized knowledge in ARI must be carefully considered by organizations when formulating their implementation strategy, as it directly impacts decisions regarding internal development versus outsourcing the necessary expertise.

Chapter 2

Industrial robotics and COBOTs

This chapter explores the fundamentals of industrial robotics and the integration of Collaborative Robots (COBOTs) within this domain, emphasizing their transformative roles in modern industrial and service sectors. It begins by tracing the historical development of industrial robots since the 1960s, highlighting mechanical structure, actuators, sensors, and control units that enable these machines to perform complex manufacturing tasks. The discussion then shifts to COBOTs, detailing their design for safe and effective operation in close proximity to human workers. Various classifications of COBOTs are examined, including their applications in assembly, handling, personal assistance, security, and healthcare settings. A critical analysis of the integration of advanced sensing technologies and end effectors shows how COBOTs adapt to dynamic environments and respond interactively to human operators. Additionally, the chapter delves into the programming paradigms and learning mechanisms that empower COBOTs to autonomously execute intricate tasks while prioritizing human safety. Through a synthesis of recent research and practical case studies, this chapter underscores the pivotal role of COBOTs in enhancing manufacturing processes, minimizing operational risks, and promoting ergonomic work conditions, paving the way for future innovations in robotic cognition and interaction.

2.1 Industrial Robots

2.1.1 Introduction

Robotics, a technology now established in the industrial context since the 1960s, embodies an innovative integration of numerical control machine tools (CNC) and teleoperators, which are remotely controlled manipulators used for handling hazardous materials. Robotics is thus positioned as a subset of mechatronic engineering, which itself amalgamates expertise in mechanics, electronics, and computer science. This discipline is bifurcated into two primary directions: service robotics, aimed at developing autonomous systems and humanoid robots to support human activities such as exploration and ambulation; and industrial robotics, which seeks to automate traditional manual processes [93]. Specifically, within industrial robotics, the focus is on the technical details governing the development of robotic industrial systems, from design and realization to practical application, and particularly on the integration of industrial robots for the automated execution of operations in production processes. This field introduces the role of the systems engineer, a multidisciplinary professional capable of synergistically orchestrating specific functions of industrial robots and auxiliary machines, with the goal of designing robotic applications for the industrial sector.

Regarding production processes, two main categories of industrial robotics applications can be distinguished: the industrial robotic cell, which denotes a space bounded by perimeter protections within which one or more robotic systems operate, along with other machinery and safety measures; and the industrial robotic line, which consists of a complex system composed of multiple robotic cells performing similar or specific operations, sometimes grouped within dedicated or shared protective areas [94]. A practical example of such technology can be observed in the automotive sector, where welding lines for bodywork illustrate the use of industrial robotic lines, composed of various cells that sequentially assemble.

From a regulatory perspective, the international standard ISO 8373:2012 provides a precise definition of an industrial robot: it is a multifunctional manipulator, automatically controlled, reprogrammable, with three or more degrees of freedom, either fixed or mobile, used for the automation of industrial applications. This manipulator is a machine equipped with a mechanism consisting of a sequence of rigid segments connected through rotating or translational joints, actuated by motors, enabling it to manipulate objects across multiple degrees of freedom. Such a device must be multifunctional, capable of performing various applications, automatically controlled by a controller that autonomously regulates the actions based on information from internal or external sensors, and must be reprogrammable, able to adapt programmed movements and auxiliary functions without direct mechanical modifications.

2.1.2 Mechanical Structure

The mechanical structure of a robotic system is designed for sustainability and the movement of loads through a device known as a manipulator, which consists of a series of rigid bodies, referred to as links, connected by joints. This assembly is thus defined as a mechanism. The initial configuration of the kinematic chain originates from the base, or frame, which is typically anchored to the ground, although some manipulator models can also be mounted on walls or ceilings. The terminal element of this chain is called the robotic flange, onto which a tool or gripper, known as the “end effector”, is mounted depending on the specific application the robot is intended to perform. It is common for the kinematic chain of industrial manipulators to be open, meaning there is a single path of links from the base to the flange. A second category of robots is parallel robots. They are less common than serial robots and have complementary characteristics to them. Parallel robots consist of members that form closed kinematic chains and potentially have a higher load capacity than normal robots and are stiffer because the base and the element to be moved are connected by multiple members. However, they often have reduced mobility, meaning the volume of the reachable space is smaller compared to that of serial robots. The particular kinematic structure of parallel robots sometimes allows for the placement of motors on the ground, lightening the structure and allowing for very high speeds and accelerations, although in this case, the load capacity is greatly reduced [95].

Joints are classified based on the type of movement they impose on the connected pair of links. In industrial manipulators, there are predominantly two fundamental types of kinematic pairs:

1. Prismatic joints (P), which allows exclusively for linear translational movement, comparable to the motion of a train on tracks, limited to a single direction, with a single degree of linear mobility. The relative position of the links in this case is defined by a parameter expressed in millimetres.

2. Rotoidal joints (R), which allows rotation between the two links, similar to the joint movement of the phalanges of the fingers, where each segment can rotate only relative to adjacent ones, ensuring a single degree of angular mobility. The relative position is defined by an angular parameter expressed in degrees.

Both types of kinematic joints restrict the motion of two adjacent links, ensuring a specific mobility: translation along a predetermined direction for the prismatic joints and rotation around a specific axis for the rotoidal joints. Although both allow only one degree of mobility per link, they differ in the parameters used to control position. The selection of joint types and their sequence of use are closely related to the rigidity of the manipulator, a property that directly affects precision and determines the system's field of application. Analogous to the human body, where the skeleton represents the mechanical structure supporting the system and muscles function as actuators, in the manipulator, the links represent the bones and the joints the articulations. Focusing on the analysis of the human thumb as a model, it can be considered a manipulator composed of four links, including a base, connected by joints of which one is a rotoidal joint, allowing only relative rotation between adjacent links. The number and type of joints used in the kinematic chain define the mobility of the flange, or the degree of freedom (DOF) of the manipulator. There are six parameters to define the position and orientation of a rigid body in space: three translational parameters and three rotational parameters [96].

2.1.3 Actuators

Actuators are fundamental elements in the operation of manipulators, analogous to the muscles of a biological system, as they are responsible for providing torque and speed, and thus power, to the kinematic pairs of the manipulator itself. Each joint of the robot is equipped with a specific actuator that converts signals, typically electrical, into mechanical energy. Servomotors, commonly used as actuators in robotic systems, receive positioning commands from the controller and act on the joints to position them according to operational needs, serving as the musculature of the manipulator.

The servomotor is a type of motor characterized by its ability to precisely control position, speed, and acceleration. To achieve these results, it is essential that the motor's mechanical structure integrates sensors and emergency brakes, as well as electronic components dedicated to motion regulation. Servomotors predominantly employed in industrial contexts are classified into three categories, distinguished by their regulatory capabilities. Pneumatic motors use compressed air as the primary energy source, transforming the energy derived from the expansion of compressed air, contained in tanks powered by compressors, into mechanical energy through the use of pistons or air turbines. While economically advantageous, these motors have limitations in control due to the compressibility of air, resulting in variable performance, high energy consumption, and noise.

Hydraulic motors, on the other hand, utilize the hydraulic energy of pressurized fluids, converted into mechanical energy. These systems require tanks for the fluid used, typically oil, and devices such as pumps or cylinders to activate the fluid. Despite their high power-to-weight ratios, hydraulic motors are complex to control and not suitable for food environments. Electric motors are the prevalent solution in industry, employing continuous current servomotors, stepper motors, and brushless motors. The latter are particularly valued for their accurate control, precision, and speed of movement, in addition to their ease of availability and low cost. Finally, transmission organs in industrial robots have the task of converting the speed and torque provided by the motor. Such transmission systems commonly include gears with high reduction ratios and significant precision, as well as transmissions with toothed belts, bevel gears, and drive shafts, especially when it is necessary to position the servomotor in a location not coincident with the joint [97].

2.1.4 Sensors

Sensors constitute essential devices for the acquisition of data concerning the constituent components of the robot, the tools connected to it, and the surrounding environment. Specifically, the transducer acts as a converter of a physical quantity of interest into an electrical signal, while the sensor transforms this physical quantity into a form that is simple to detect and electronically process.

Within the context of industrial robotics, sensors can be categorized into two main types. Proprioceptive sensors are employed to monitor intrinsic quantities of the robot, such as the speed of joints, forces, torques, and the status of internal elements, for example, the battery charge level. Among the internally used sensors, those dedicated to measuring angular position are pivotal for determining the position of the manipulator. These include encoders, which are optical sensors based on the photoelectric principle and capable of converting angular position into a digital code through the use of photoreceptors that emit a digital signal in response to incident light; and resolvers, which utilize the principle of magnetic induction to provide a voltage proportional to angular position, behaving akin to small electrical generators with rotor and stator windings that generate a magnetic flux.

Exteroceptive sensors, on the other hand, are used to measure external quantities relative to the robot, concerning the state of external devices or environmental elements surrounding it. Typically, these sensors detect distances between the robot and objects or the forces and torques exchanged with the environment and are necessary for enhancing the robot's perceptual capabilities. They increase the robot's autonomy in performing its tasks, enabling it to adapt to variations in environmental conditions [98].

2.1.5 Control Unit

The control unit, often referred to as the controller, constitutes the neural element of the robotic system. This unit is tasked with overseeing the operations conducted by the manipulator. The ability to manage these operations is ensured through the implementation of specific functions:

- Manipulation: the capability to relocate physical objects within the operational area
- Sensory capability: the ability to gather information about the state of the system through proprioceptive sensors and the state of the operational environment via exteroceptive sensors
- Intelligence: the capability to utilize the collected information to adapt the system's behavior
- Data processing: the capability to store, process, and distribute data related to the activities carried out by the system.

The implementation of these functions is achieved through an architecture organized into hierarchical levels. Each level is permeated by an informational flow that propagates to adjacent levels, including the transmission of measured signals to upper levels and the issuance of operational directives to lower levels. Each level incorporates three main functional modules, defined as follows: sensory module: responsible for processing data from sensors; model module: tasked with defining the system's behavior based on mathematical models; decisional module: in charge of managing and assigning elementary actions, as well as planning and executing tasks.

The hierarchical order of the levels is determined by the nature of the function performed by the decisional module. In controllers used in industrial robotics, three essential hierarchical levels are distinguished:

1. Action level: deals with translating commands defined by the user through a high-level programming language into sequences of intermediate positions that outline the elementary paths of point movement.
2. Primitive level: tasked with interpolating positions set at the higher level in order to define possible trajectories and articulate the control strategy.
3. Servomechanism level: responsible for formulating control algorithms aimed at generating the necessary signals for the operation of servomotors.

The process of achieving a specified spatial configuration by a terminal robotic device can be implemented through various control strategies, depending on the importance placed on just the final position or also the trajectory followed. The control mode called "positional" or "point-to-point" requires that each movement be executed based on instructions that exclusively specify the desired final position. In this scenario, the movements of different axes can be independent of each other and carried out simultaneously or sequentially. The input data may omit the specification of the movement speed. In contrast, the continuous trajectory control mode necessitates that the various axes of the robot be coordinated to ensure that the terminal reaches the final position following a predefined trajectory; generally, in this case, the trajectory's travel speed is also specified.

The sensor-based control mode implies that both the robot's movement and the force exerted are regulated based on data detected by sensors and transducers. Adaptive control represents an advanced technique of controller management that automatically adjusts certain control system parameters based on conditions observed during operation, aiming to optimize system performance. Intelligent control is a management strategy where experience gained during the execution of specific movements is automatically used to refine control parameters and algorithms for future operations. Moreover, control with active adaptation allows for the modification of pre-programmed movements based on data detected by sensors, for example, halting the robot's activity when detected forces exceed preset thresholds. Finally, compliance describes a robot's responsiveness to external forces or torques. If this responsiveness is influenced by sensor feedback, it is referred to as active compliance. Conversely, passive compliance relates to the response that depends solely on the robot's mechanical deformability properties.

The practical implementation of the functions previously outlined is achieved through the organization of specialized physical units integrated within the controller. The power unit is responsible for supplying the necessary energy to the manipulator's actuators, enabling the movement of the joints. This unit comprises a computer dedicated to analysing the positions of the axes in relation to predefined coordinates and a servo unit tasked with delivering the required power for the control of servomotors. Therefore, the power unit facilitates the regulation of servomotors in accordance with the trajectories established by the control unit. The control unit, represented by an industrial computer equipped with a microprocessor, takes on the role of coordinator of the manipulator's movements, determining the positions that must be achieved by the actuators. The necessary parameters are derived from the selected robotic program, which is stored in the internal memory of the control unit. Moreover, this unit is equipped with communication cards for the exchange of data and signals with the external environment, including other machines, auxiliary devices, and the robot's end-effector. The operator interface, a device connected to the main computer, allows users to manually move the manipulator and program the required movements. This tool facilitates a direct and intuitive interaction with the robotic system, enabling operators to effectively intervene in the management of operations [99].

2.1.6 End Effector

The term "end effector" refers to the component mounted on the robot flange, representing the final link of the manipulator. This term is synonymous with "EOAT" (End Of Arm Tooling), which generically describes any device installed at the end of the robot's arm. The end effector is crucial for an industrial robot as it forms the interface through which the robot interacts with the external environment, determining the nature of the task performed by the robot itself. The composition of the end effector generally includes a mechanical part and a control part: the mechanical part varies in complexity depending on the task of the manipulator and always includes a connection element, the mechanical interface, which facilitates attachment to the robot's flange and the transmission of energy and signals. The control part is responsible for activating the mechanical part and collecting data from connected sensors, incorporating a control interface for communication with the robot's controller.

Robot tools are primarily categorized into two classes: gripping organs and working organs. The gripping organs are designed to grasp objects in order to perform manipulation operations, such as picking up and releasing objects at predetermined positions, exploiting various physical principles such as friction force, differential pressure force, and magnetic force.

The classification of gripping organs can be based on the number of surfaces involved: bilateral grips: require contact with at least two opposing surfaces. Unilateral grips: require contact on a single surface. Grips that utilize friction force are generally bilateral, while those that operate on differential pressure or magnetic principles are examples of unilateral grips. Three main types of grips are distinguished: pliers, use the friction force between contact surfaces and are common in industrial robotics; suction cups: operate on the principle of pneumatic vacuum to generate a depression that allows attachment; magnets: employ the magnetic properties of materials using electromagnets for attachment. The working organs include specific tools for determined functions, such as welding torches, painting devices, machining spindles, screwdrivers, and measurement instruments such as cameras and laser scanners [100].

Choosing a specific tool specializes the task of the robot, limiting its flexibility. To mitigate this limitation, tool change units can be used that allow for the automatic replacement of the tool, thereby maximizing the operational flexibility of the manipulator [101].

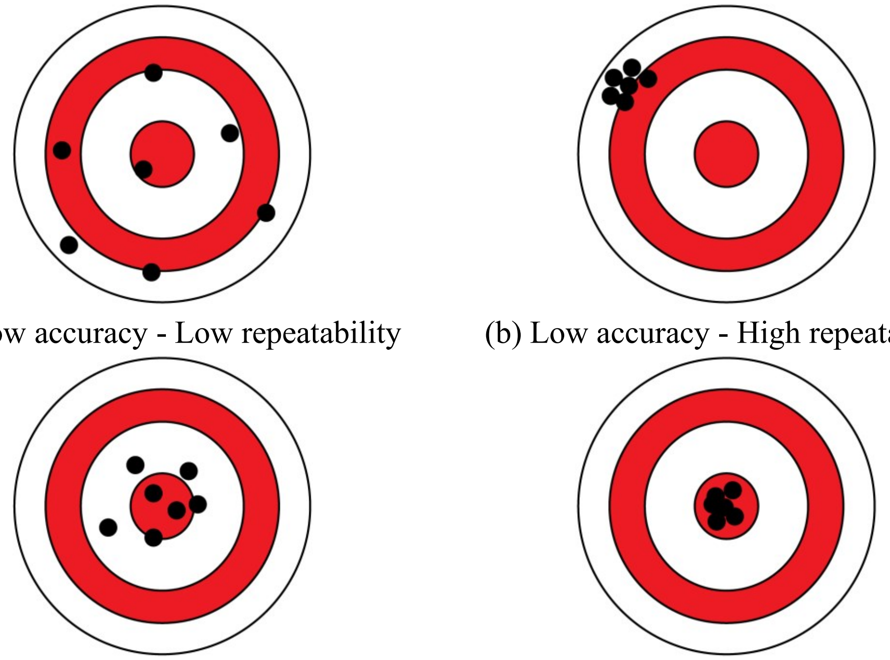
2.1.7 Characteristics of Industrial Robots

During the operations of a robot, various mechanical components reach different points in space, determined by specific objectives such as task optimization and safety checks. It is often essential to identify different volumes or spatial areas for safety reasons and to analyse and prevent possible collisions between the robot and human operators. Within the robot's working environment, the following critical spaces are defined:

- Movement Space: This space encompasses all points that can be reached by any moving part of the robot, excluding the end-effector and the workpiece. Thus, it represents an intrinsic characteristic of the machine itself.
- Maximum Space: This space includes the movement space plus areas accessible by the end-effector and the workpiece. It constitutes a characteristic specific to a particular installation or configuration of the robot. In certain contexts, it may be prudent to install safety devices such as limit switches, which restrict the movement of some robot axes in the event of unforeseen malfunctions. In these scenarios, the maximum space is reduced to a more confined area.

- Operational Space: Corresponds to the portion of the restricted space that is actually used to perform the programmed movements.

Additionally, there are two other fundamental characteristics that distinguish robotic manipulators: accuracy and repeatability.



(a) Low accuracy - Low repeatability (b) Low accuracy - High repeatability

(c) High accuracy - Low repeatability (d) High accuracy - High repeatability

Figure 1. Accuracy and repeatability

Accuracy is a parameter that indicates proximity to the programmed reference point, thus measuring the distance between the point actually reached and the intended one. Repeatability, on the other hand, refers to the robot's ability to replicate a movement consistently, measuring the repositioning distance to repeatedly reach the same point [102].

2.1.8 Industrial Robots Performance

When discussing the performance of a robot, reference is made to its operation under normal working conditions, that is, within specifically defined standard contexts. These conditions include environmental variables such as temperature and humidity, as well as potentially disruptive factors such as instability in power supply and electromagnetic fields.

The concept of "payload" refers to the force and torque that the robot can exert through its mechanical interface along various axes of movement. The payload is influenced by the static forces and torques exerted, as well as by the dynamic characteristics—mass and moments of inertia—of the body connected to the mechanical interface. These characteristics are, in turn, dependent on the conditions of speed and acceleration. The "nominal load" and "maximum load" refer to the load limits under which the robot can operate while maintaining its declared performance, including the weights and masses of the end effector, accessories, and processing components. The "limit load", on the other hand, identifies the boundary beyond which permanent damage or structural failures of the robot may occur.

Regarding the maximum thrust (and maximum torque), these terms describe the force and torque values that can be continuously applied to the robot's mechanical interface, excluding any inertial effects, without causing permanent damage to the structure.

Finally, the description of the performance of individual axes of motion of the robot typically focuses on the speed and acceleration of a specific axis, generally measured at the tool center or the center of the mechanical interface. Conversely, the terms "trajectory speed" and "acceleration" refer to the speed and acceleration along a trajectory that involves continuous control and coordinated movement of at least two axes [103].

2.1.9 Programming

Robot programming entails the creation of an algorithm that directs the operations of the robot. This process can be implemented through various methodologies:

- Manual Programming: This method involves entering data directly into the robot's control system using devices such as keyboards, switches, or pin programmers. This approach is known as inline programming, where the user directly interacts with the robot's control system to define operational sequences.
- Training-Based Programming: This method consists of instructing the robot through the direct demonstration of tasks to be performed. The operator moves an object following the trajectories that they want the robot to replicate, recording these movements, for example, by pressing a button. This approach allows the robot to learn the sequences of movements to be executed.
- Explicit Programming: In this technique, the positions of the end effector or the desired trajectories are defined precisely, often using CAD/CAM software. This type of programming is known as offline programming and allows for detailed planning of the robot's operational path before actual activation.
- Goal-Oriented Programming: This programming style enables assigning tasks to the robot without the need to specify the movements in detail. It is based on issuing high-level commands, leaving it to the robot's control system to determine the specific actions needed to achieve the set goal.

Each of these methodologies presents specific advantages and limitations, and the choice of one over another can depend on various factors such as the complexity of the task, the required precision, and the configuration of the robotic system [104].

2.2 Industrial Robot classification

2.2.1 Cartesian

Cartesian robots are distinguished by their movement based on an orthogonal spatial configuration, aligned with the cartesian coordinate system. These robots move in space through sliding joints, arranged orthogonally to each other and connected by metallic arms. The peculiarity of this type of robot lies in its ability to perform movements along linear axes, which makes the programming of movements relatively simple and straightforward. Not requiring excessive flexibility, the movements of Cartesian robots are standardized and can be pre-programmed at the time of installation. A significant advantage of Cartesian robots is their reliability and high precision in positioning and transitional movements.

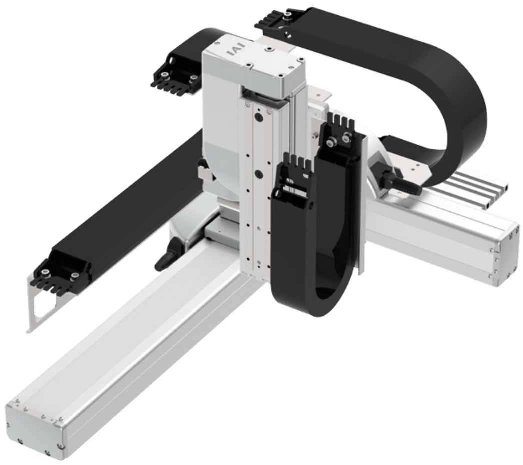


Figure 2. Cartesian robot – Bosch Rexroth CKK

This results from their simple construction and the limited number of degrees of freedom. The simple structure and movements confined to a single axis for each joint allow for the transport of large masses and the execution of wide movements, making these robots ideal for servicing machinery in production contexts. In the industrial field, Cartesian robots are employed in various applications. They are frequently used in production lines for operations such as machine unloading or palletizing, especially in large-scale automated lines where heavy load transport is required. Similarly, their high precision makes them suitable for assembly tasks and assisting machine tools in loading and unloading operations. Furthermore, Cartesian robots are effectively employed in Pick and Place activities and in 3D printing, leveraging their ability to execute precise and controlled movements in a defined work environment [105].

2.2.2 SCARA

SCARA robots, an acronym for "Selective Compliance Assembly Robot Arm," hold a prominent position due to their unique structure and functionality. These robots are characterized by two articulated arms capable of moving in the horizontal plane and are equipped with a prismatic coupling that allows for vertical movement. The configuration of SCARA robots includes two rotary joints for horizontal movements and a prismatic joint located at the end of the arms. In some cases, there is also an additional rotary joint that enables the rotation of the robot's terminal element.

Figure 3. SCARA robot diagram and workspace

The SCARA robot configuration, which can have three or four degrees of freedom depending on the presence of the terminal rotary joint, is designed to ensure rapid movements and flexible programming, facilitating integration with the human operator. The mechanical structure of these robots makes it rare to encounter configurations where positioning is impractical. SCARA robots find wide application in the industrial sector, especially in the assembly of delicate components and in the loading and unloading of components [106]. Depending on the specific operational requirements and the dimensions of the application, the end effector, which can be a tool or a gripper, is attached to the end of the last arm controlled by the prismatic joint. This feature makes SCARA robots particularly suitable for pick and place operations, where their ability to perform precise and controlled movements is critical for the efficiency of the production process [107].

2.2.3 Delta

Delta robots, also known as parallel type robots, are distinguished by their unique mechanical architecture and operational mode. These robots use arms connected to a fixed base to manipulate a terminal platform that moves within a defined area. The distinctive feature of Delta robots lies in their configuration, where the base is typically anchored to the ceiling or the top part of a structure, allowing the end effector to operate in a space below. This differs from the typical arrangement of parallel robots, where the spatial configuration is reversed. The structure of Delta robots is based on three arms with joints converging at the base, offering the advantage of keeping the platform, on which the end effector is placed, always parallel to the robot's base itself.

Figure 4. Delta robot – ABB IRB 390

Originally conceived in the 1980s for handling small objects in the manufacturing industry, particularly in the electronics and electrical sectors, Delta robots have stood out for their ability to perform rapid and precise movements, essential in mass production. With technological evolution, especially due to the introduction of more powerful motors and the construction of larger structures, Delta robots have expanded their capabilities, allowing for the movement of heavier loads at higher speeds. The most common applications of these robots include Pick and Place operations and assembly in mass production chains. They are also used in packaging and positioning of components. In recent years, the use of Delta robots has also extended to the field of 3D printing, where their ability to rapidly and precisely move the end effector proves particularly advantageous [108].

2.2.4 Articulated

Articulated robots, also known as anthropomorphic robots, are among the most widely used types of robots, thanks to their flexibility and the ability to be reconfigured to adapt to various applications [109]. An anthropomorphic robot is characterized by a serial mechanical structure, consisting of rigid arms interconnected by joints - typically at least four - which allow for a wide range of movements. The joints used can be either rotary or prismatic, with rotary joints being more common due to their structural similarity to the human arm. Each joint in these robots is driven by a motor, generally electric, and the end effector, located at the end of the kinematic chain, is specifically designed for the processing for which the robot is intended. The control of the robot's movements is entrusted to a control system that uses the end of the end effector as the reference point for processing, making the programming focused on this point [110]. The relatively simple structure of articulated robots, combined with their high number of degrees of freedom, allows for the programming of even complex movements and the transportation of large masses, depending on the specifications of the motors used and the configurations of the arms.

Figure 5. Anthropomorphic robot – FANUC M-800iA/60

These robots find a wide range of applications in industrial automation, particularly in assisting machines or machine tools, where they are capable of executing rapid and precise movements for the transportation of workpieces or already processed parts. In addition, articulated robots are used for the transport of raw materials or for large-scale palletizing operations. Their flexibility and precision also make them suitable for applications such as welding or spray painting within production chains, as well as being employed in assembly operations and handling of parts [111]. This versatility allows articulated robots to play a key role in a wide range of production processes.

2.3 Collaborative Robots

COllaborative roBOTs (COBOTs) are classified based on reference frame location as fixed, mobile and hybrid solution [1,2]. The first class considers the robot placement in a time-invariant position, meanwhile the mobile configuration allows the robot motion. The hybrid architecture has been composed by the mentioned elements and it can move between different tasks, work areas, and enabling the material transportation (kit, tools, light parts, subassemblies) [114]. In addition, they are offered with sensors as well as user interface that recognize and react to unstructured environment. In this context, Automation and AI are impacting on workers and job profiles where repetitive or dangerous tasks are prevalent. COBOTs can be programmed without involving experts of high-skilled resources. SME (Small and Mid-size Enterprises) is the pivotal player due to the investments leverage that is not widely affordable for pioneering technologies [115]. The obtained flexibility permits at the SMEs to accomplish productivity enhancement without compromising the low volumes production [116] to react at to customer demand variability. In the other hand, large multimodal factories can rapidly switch from a range of different applications: from oil and gas to aerospace, building, automotive products [117]. These companies manage the ability to operate with several product lines, employing teams with various skills able to reconfigure the layout to respond to a dynamic order. [118]. Moreover, considering the transformation of digital factory models and Industry 4.0 enabling technologies, the data is gathered at each phase of production from machines/equipment – according to ISO10218 safe interaction in a collaborative workspace [4,8,9]. Data is then aggregated and processed to optimize the entire production process [121]. For instance, the gripping force or the trajectory of a robot arm can be updated if the digital twin estimates an enhancement in production performance in terms of safety, quality, or production indicators [122]. Although the literature presents various COBOT applications in industrial context, further studies are required to investigate the recent advances. In particular, the increase of the COBOT abilities shows the need of a set of guidelines to permit a valuable comparison[123].

2.3.1 Collaborative robots architecture frame

In the last decades, collaborative robots have attracted interest from academic researchers to industrial and service operators in a wide research area [124]. The definitions of collaborative robot were given in the 1990s. The initial concept was a passive mechanism supervised by a human operator [13,14].

Meanwhile, literature provides works that study: three-dimensional workspace sharing, collaborative and cooperative tasks, programming, and the interaction. Additional factor referring the business layout that is important to assume, are described as:

- Coexistence: the working areas need to be defined without overlapping zone. The human operator and the robot can perform the activities separately.

- Synchronization: human and the robot share the work environment with independent tasks.
- Cooperation: human and the robot share the work environment and the task execution is in a step-by-step procedure.
- Collaboration: human and robot share the working area and the task concurrently

To evaluate the practical applications, this analysis focuses on three macro-elements:

- Safety: COBOTS are designed to work safely in same workspace occupied by operator detecting and reacting at the risk of accidents or injuries.
- Flexibility: COBOTS can be reconfigured to execute a set of unknown tasks.
- User-friendliness: COBOTS are equipped with intuitive interfaces to program and operate without requiring extensive technical knowledge.

Collaborative robotics are employed in both manufacturing and service applications. The manufacturing applications primarily focused on:

- Manufacturing processes: the use of collaborative robots in various manufacturing processes, such as assembly lines and welding.
- Material handling: the application of collaborative robots in material handling tasks, including picking, sorting, and transporting objects

In the service applications domain, the chapter discussed of:

- Personal assistance: use of collaborative robots in providing assistance to individuals in tasks such as household chores or caregiving.
- Security and inspections: application of collaborative robots in security-related tasks, such as surveillance, monitoring, and inspections in various settings.
- Medicare: utilization of collaborative robots in healthcare and medical environments, including patient care, surgical assistance, and rehabilitation.

Furthermore, it is important to highlight the importance of the interaction between humans and collaborative robots, focusing the attention to its significance within collaborative robotics. A Specific focus is given to human interactions with collaborative robots. This included four key areas:

- Control interface: different interfaces and control mechanisms for humans to interact and communicate with collaborative robots effectively.
- Intention recognition: techniques, algorithms, and sensor systems used to enable robots to recognize and understand human intentions.
- Programming and learning: methods and techniques for programming and teaching collaborative robots, including machine learning, programming languages, and algorithms.
- Virtual reality perspectives: the potential of virtual reality systems in enhancing human-robot interactions and collaboration, such as immersive training environments and augmented reality interfaces.

Finally, to examining applications and human interactions, the research also prioritize the analysis of core technologies that support and enable collaborative robotics.

2.4 Classification of COBOT applications

An initial classification of COBOT application is established on the device usage context: industrial (assembly and handling tasks) or service (personal assistance, security and Medicare),

2.4.1 Industrial Application of collaborative robots: Assembly

In manufacturing and assembling processes the production depends on the availability of tools, human labour, and machinery. The efficiency determines the lead time and the product quality. During the manufacturing processes, various repetitive activities that cause fatigue in human labour are often involved. Therefore, to eliminate employee risks and fatigue, it is necessary to develop robots that would complement human labour in heavy or repetitive work. Levratti, A. et al. introduce a modern tire workshop assistant robot which can bear weighty wheels and transfer them to any spot of the workshop and can be interacted with either via gestures or tele operatively through a haptic interface [127]. Further, Peternel, L. et al. propose a method to enable robots to adapt their behaviour to human fatigue in human-robot co-manipulation tasks. The online model is used to estimate human motor fatigue, and when a specific level is discerned, the robot applies the acquired ability to gain the challenging phase of the task. The efficacy of the proposed approach is evidenced by trials on a real-world co-manipulation task [128].

In assembly domain, COBOTs are employed support the assembly of complex products. Cherubini, A. et al. present a collaborative human-robot manufacturing cell for homokinetic joint assembly in which the COBOT switches active and passive behaviours to lighten the burden on the operator and to comply with his/her needs. The approach is validated in a series of assembly experiments, and it is fully compatible with safety standards [129]. Many papers discuss how humans-robots can work simultaneously to improve the efficiency and complexity of assembly processes. The work of Tan, J. T. C. et al. studies the design COBOT in a cellular manufacturing. Task modelling, safety development, mental workload, and man-machine interface are all studied to optimize the system design and performance [130]. Krueger, J. et al. also looks at logistic and financial aspects of cooperative assembly, such as efficient component supply [131]. The study of Erden, M. S. et al. presents an end-point impedance measurement at human hand while performing welding interactively with the KUKA robot [132]. A paper discusses hu-man-robot cooperation in precise positioning of a flat object on a target. Algorithms have been developed to represent the cooperation schemes, and these were evaluated using a robot prototype and experiments with human. Furthermore, the main challenge of Wojtara, T. et al. is in regulating the robot-human interaction, as the robot interprets signals from the human in order to understand their intention [133]. Morel, G et al. define a control algorithm combining visual servo control and force feedback within the impedance control approach to perform peg-in-hole insertion experiments with a 7-axis robot manipulator [134]. Magrini, E. et al. present a framework for guaranteeing human safety in robotic cells that enable harmonious coexistence and dependable interplay between hu-mans and robots. Certified laser scanners are also employed to observe human-robot proximity in the cell, while safe communication protocols and logical units are utilized for secure low-level robot control. Furthermore, a smart human-machine interface is included to facilitate in-process collaborative activities, as well as gesture recognition of operator instructions. The framework has been tested in an industrial cell, with a robot and an operator closely examining a workpiece [135]. Another critical application of collaborative robots in manufacturing is the elimination of redundancy in operations. For most manufacturing activities, the repetitive processes often come towards the end of the production activities. During these activities, a series of other repetitive actions are performed. To ensure higher quality and uniformity, polishing, lifting of assembling parts can be assigned to collaborative robots [136].

Machine learning in accordance with collaborative robots ensures consistency in the quality and cycle time to accomplish the industrial tasks. G. Michalos et al highlight how learning control techniques are essential in human-robot collaboration for better handling of materials. They are implementing control techniques through collaborative robots that are human centred with neural networks, fuzzy logic control, and adaptive control forms the basis for ensuring collaborative robots' dependable material handling ability. Like humans, collective human-centred robots need logical interpretation of situations as they present themselves to correctly hand-related risk issues [137]. A robot should take initiative during joint human-robot task execution. Three initiative conditions are tested in a user study: human-initiated, reactive, and proactive. Results show significant advances in proactive conditions [138].

2.4.2 Industrial Application of collaborative robots: Material handling

The application of collaborative robots in material handling provides significant benefits. Material handling processes can be complex, involving multiple stages and various types of equipment. Coordinating these processes and ensuring that they are executed correctly can be challenging. Donner, P. and Buss, M. present a controller that can actively damp undesired oscillations, while allowing desired oscillations to reach a desired energy level. In the paper, real-world experiments show the positive results in interaction with an operator [139]. Dimeas, F. et al. work on a method to detect and stabilize unstable behaviour in physical human-robot interactions using an admittance controller with online adaptation of the admittance control-gains [140]. Deformable materials are critical to handle. Kruse, D. et al. discuss a novel approach to robotic manipulation of highly deformable materials, using sensor feedback and vision to dictate robot motion. The robot is capable of contact sensing to maintain tension and equipped with a head-mounted RGBd sensor to detect folds. The combination of force and vision controllers allows the robot to follow human motion without excessive crimps in the sheet [141].

Gams et al. have extended the dynamic movement primitives (DMPs) framework in order to enable dynamic behavior executing and cooperative tasks that are bimanual and tightly coupled. To achieve this, they proposed a modulation approach and evaluated it for the purpose of interacting with objects and the environment. This permits the combination of independent robotic trajectories, thereby allowing implementation of an iterative learning control algorithm to execute bimanual and tightly coupled cooperative tasks. The algorithm is used to learn a coupling term, which is then applied to the original trajectory in a feed-forward manner, thereby adjusting the trajectory to the desired positions or external forces [142].

2.4.3 Service Application of collaborative robots: Personal Assistance

The application of collaborative robots in personal assistance has advanced over the years because of increased artificial intelligence technology that allows robots to take over in some activities that previously humans concentrated on. Because of the ability of collaborative robots to operate in logical and sequential manner, robots, in many ways, have become personal assistants to human beings in handling various issues. For this scope, Bestick, A. et al estimate personalized human kinematic models from motion capture data, which can be utilized to refine a variety of human-robot collaborative scenarios that prioritize the comfort and ergonomics of a single human collaborator. An experiment involving human-robot collaborative manipulation is conducted to evaluate the approach, and results demonstrate that when the robot plans with a personalized kinematic model, human subjects rotate their torso significantly less during bimanual object handoffs [143]. In healthcare, collaborative robots can assist healthcare professionals in various tasks, such as patient monitoring, medication management, and rehabilitation exercises. They can also help patients with limited mobility to perform daily activities, such as dressing, bathing, and grooming. Collaborative robots can provide assistance to elderly people living independently or in care homes.

Moreover, for persons whose movement is restricted because of health complications, facilities have developed robots that help such individuals in their movement. In the pilot study of Kidal et al. it is investigated human factors associated with assembly cells for workers with cognitive disabilities. Preliminary findings indicate that personalized human-automation load balancing strategies and collaborative robots have the potential to empower workers to complete complex-assembly tasks. Design requirements for assembly cells are contrasted with those for regular workforce to ensure that they are optimized for the needs of workers with cognitive disabilities [144]. As personal assistance to older people, collaborative robots help individuals with day-to-day tasks. The paper edited by Bohme, HJ et al. presents a scheme for human-robot interaction that can be used in unstructured, crowded and cluttered environments, such as a mobile information kiosk in a home store. The methods used include vision-based interaction, sound analysis and speech output, and they are integrated into a prototypical interaction cycle. Experimental results show the key features of the subsystems, which can be applied to a variety of service robots, and future research will focus on improving the tracking system, which is currently limited to people facing the robot [145]. Besides the home-based robotics assistance activities, the application of personal assistance robots has been applied in the telecommunication and construction industries. In telecommunications, collaborative robots have been essential in assisting the subscribers of a particular telecommunication authority. As a personal assistant to the subscriber, the collaborative robot forwards and responds to the calls whenever the subscriber is offline or on another call. Through relaying relevant information such as voice notes, personal assistance robots enable individuals to receive information about all the calls they missed while offline. Finally, robots are essential for human labour as personal assistance in construction. The robots help engineers lift material, create a safer work environment, enhance the quality of outcomes, and make the whole process more cost-effective [146].

2.4.4 Service Application of collaborative robots: Security and Inspection

Security context shows technological advancements in accordance with the application of collaborative robots; for persons to be effectively protected against any form of attack. Inspections robots have been developed to help in detecting illegal materials before they are smuggled into public or private places. In most protected sensitive areas such as international airports, collaborative inspection robots are an essential layer of security measures. The robots used in these are of security are made of x-ray that allow the robot to scan passenger's luggage and raise the alarm to detect any illegal object or person [147]. The inspection activities of collaborative robots have enhanced the ability of military personnel to detect and neutralize the possibility of terrorist activities occurring when terrorist weapons of mass destruction are detected by the robots during border inspection using robotic machine inspection. To further complement security inspection, some security inspection robots have been developed and programmed to aid in defusing detected threats, such as bombs, that might be too risky to be handled by human operators. Murphy, RR offers an instructional guide on the utilization of robots in urban search and rescue missions, as well as an examination of the challenges in combining humans and robots. Their paper further presents a domain theory on searches, which is composed of a workflow model and an information flow model [148].

Besides the security inspection, robots are also crucial as human co-workers for product and process inspection. During manufacturing and assembly processes, inspection robots are used to visually inspect flaws in every stage of production. Most industrial inspection collaborative robots are often designed with either 2D or 3D vision sensors [149]. The installation of collaborative robots with 2D and 3D sensors enable the robots to conduct efficient accuracy-based inspections that ensure all requirement for each production stage are obtained [150]. Because of the higher level of COBOTS to evaluate various aspects during the inspection, they have increasingly been adopted in the practical transport system to assess the safety of using a particular means of transport. For this purpose, Tsagarakis et al present a humanoid robot platform that has been exploited to work in representative unstructured environments [151].

2.4.5 Service Application of collaborative robots: Medicare

In Medicare, the collaborative treatment process between human medics and robot has become popular. Patient handling has been one of the demanding responsibilities of causing musculoskeletal issues among Medicare professionals who rely on their physical strength and existence to discharge their duties [152]. Notably, applying collaborative robots has been essential in addressing such challenges. In most modern facilities, nurses have been trained to collaborate with robots in providing services such as muscle massage and fixing of broken bones. The application of medical COBOTS in fixing broken limbs has ensured greater accuracy percentage in storing mobility of individual after sustaining multiple fractures of the limbs. Therefore, collaborative robots are a significant breakthrough in orthopaedic medical facilities.

Moreover, collaborative robots are extensively used in a surgical operation. For most surgical doctors, working collaboratively with robots during operations ensures higher level of operation precision, flexibility, and control [153]. Furthermore, adopting COBOTS in surgical processes facilitates the provision of 3D vision via the robot vision, thus allowing doctors to see the operation site better and reducing error that is caused by lack of proper visibility during the operation. Therefore, through collaborative robots, surgeons can perform delicate and complex procedures such as organ implantation that may be difficult or impossible if done only through human surgeons' collaboration. The relationship between force and motion are a critical factor in conveying intended movement direction. Mojtahedi, K. aims to understand how humans interact physically to perform motor-tasks as moving a tool [154].

COBOT prosthetics applications are becoming increasingly popular in the field of prosthetics. The technology is used to create custom-fit robotic prosthetic arms and hands, allowing users with amputations or other physical impairments the ability to interact with the environment in an innovative way. Vogel, J. presents a robotic arm/hand system that is controlled in 6D Cartesian space through measured human muscular activity. Numerical validation and live evaluations demonstrate the validity of the system and its potential applications [155]. An incremental learning method is purposed to control a robotic hand prosthetics using myoelectric signals. The approach of Gijsberts, A. is effective and applicable to this problem, by analyzing its performance while predicting single-finger forces. Then this method has been tested on a robotic arm and the subject could reliably grasp, carry and release everyday objects, regardless of the signal changes [156]. Electrical signals from the muscles of the operator con be employed as main means of information transportation. The work of Fleischer, C. and Hommel, G. presents a human-machine interface to control exoskeletons. A biomechanical model and calibration algorithm are presented, and an exoskeleton for knee joint support is designed and constructed to verify the model and investigate the interaction between operator and machine [157]. De Vlugt, E describes the design and application of a haptic device to study the mechanical properties of the human arm during interaction with compliant environments [158]. With the same aim, Burdet, E Humans learn to manipulate objects and tools in physical environments by compensating for any forces arising from the interaction. This is achieved by learning an internal model of the dynamics and by controlling the impedance [159].

2.4.6 Supernumerary Robotics

Soft Robotics Limbs (SRLs) have become increasingly popular tools for augmenting the manipulation and locomotion capabilities of humans [160]. They are designed to provide additional degrees of freedom that need to be controlled independently or simultaneously with respect to biological limbs. A bilateral interface between the robot and the operator is necessary for proper functioning, wherein control signals are acquired from the human without interference with the biological limbs and feedback is provided from the robot to the human. SRLs have been developed for various usages, for instance, legs, arms, hands and fingers. In the work published by Luo, J. et al, the authors face with the challenge of providing a solution that allows one individual operator to accomplish overhead tasks with the assistance of the robotic limb. To address this challenge, the authors propose a balance controller for the SuperLimb wearable robotic solution, utilizing a decomposition methodology to decouple joint torques of the SuperLimb and the interaction forces. Additionally, a force plate is used to measure the Center Of Pressure position as an evaluation method of the standing balance [161]. In 2012, Baldin L. et al. presented a novel approach to using a compliant robot to reduce the load on a human while performing physical activities. The robot is attached to the subject's waist and supports their body in fatiguing postures, allowing them to sustain those posture with less effort. The team conducted mathematical analysis to optimize the robot's posture and joint torques, thereby decreasing the load on the individual. Results from numerical simulations and experiments showed that the proposed method was successful in reducing the workload of the subject [162]. The work of Parietti, F et al. presents a new approach to physically assisting the human with a wearable robot. Supernumerary Robotic Limbs (SRLs) are attached to the waist of the human to support their body in fatiguing postures, such as hunching over, squatting, or reaching the ceiling. The SRL is able to take an arbitrary posture to maximize load bearing efficiency, rather than constrained movements that leg exoskeletons require. A methodology for supporting the human body is described and a mathematical analysis of load bearing efficiency is conducted. Optimal SRL posture and joint torques are obtained to minimize the human load. Numerical and experimental results of a prototype SRL demonstrate the effectiveness of this method [163].

Recent advancements in robotic technology have proposed SRLs as a potential solution to reduce the risk of Work-Related Musculoskeletal Disorders (WMSD). SRLs can be worn by the worker and augment their natural ability, thus providing a new generation of personal protective equipment. For instance, a supernumerary robotic upper limb allows for indirect interaction with hazardous objects, such as chemical products or vibrating tools, thus reducing the risks of injury associated with joint overloading, bad postures, and vibrations. Within this perspective, Ciullo et al. present a supernumerary robotic limbs system to reduce vibration transmitted along the arms and minimize load on the upper limb joints. An off-the-shelf wearable gravity compensation system is integrated with a soft robotic hand and a custom damping wrist, designed based on a mass-spring-damper model. The efficacy of the system is experimentally tested in a simulated industrial work environment, where subjects perform a drilling task on two materials. Analysis of the results according to ISO-5349 show a reduction of 40-60% in vibration transmission with the presented SRL system without compromising time performance [164].

Present research on the potential of a supernumerary leg. The studies conducted by Khazoom, C. et al. demonstrate the potential of a supernumerary leg powered by delocalized magnetorheological clutches (MR) to assist walking with three different gaits. Simulations show that the MR leg's low actuation inertia reduces the impact impulse by a factor 4 compared to geared motors and that delocalizing the clutches reduces by half the inertial forces transmitted to the user during swing.

Other studies focus on hands applications. Surgeons may be able to use a third hand under their direct control to perform certain surgical interventions without the need for a human assistant, thus reducing coordination difficulties. To assess this possibility, Abdi E. et al present a study with naive adults using three virtual hands controlled by their two hands and right foot. The results of this study show that participants were able to successfully control virtual hands after a few trials. Further, the workspace of the hands was found to be inversely correlated with the task velocity. There was no significant difference between the three and two hand controls in terms of success in catching falling objects and average effort during the tasks. Participants reported that they preferred the three-hand control strategy, found it easier, and experienced less physical and mental burden [165]. Meraz, N.S. et al. present a sixth finger system as an extension of the human body and investigate how an extra robotic thumb affects the body schema and self-perception. The sixth finger is controlled with the thumb of the opposite hand and contact information is conveyed via electrostimulation. Reaching task experiments are conducted with and without visual information to evaluate the level of embodiment of the sixth robotic finger and the modification of the self-perception of the controlling finger. Results indicate that the sixth finger is incorporated into the body schema of the user and the body schema of the controlling finger is modified, implying the brain's ability to adapt to different scenarios and body geometries [166].

2.5 Interactions with human beings: practical implications

As COBOTs become more common in various industries for several applications, there is an increasing research activity on the technologies that enable them to work safely and efficiently alongside humans. COBOTS are equipped with a range of technologies, including control systems, intent recognition, programming, and learning systems. Dynamics from the signals have influence through individual and social aspects that incorporate personality traits.

These technologies allow COBOTs to adapt to changing conditions in real time, learn from their experiences, and interact with humans in a way that is safe and efficient. This section provides a detailed analysis of each technology's research activity. The control system is the component of COBOTS responsible for ensuring that the machine operates safely and efficiently in a shared workspace with human. COBOT control systems are designed to drive and monitor the robot's movements and ensure that it does not collide with humans or other objects in the environment. They also enable the robot to adapt to changing conditions, such as changes in lighting or the presence of new obstacles. COBOT control systems typically include sensors, software, and other technologies that allow the robot to detect and respond to changes in the environment in real-time. Observing human action instead of a robot leads to interference of executed actions. However, various aspects affiliated with human movement have been instrumental in triggering the interference effect. Observing movement has measurable consequences towards peripheral motor system [167]. In action observation, there exists a significant increase in a motor-evoked potential originating from hand muscles that are utilized while making such movements. For instance, P. Maurice et al. worked on method for performing ergonomic assessments of collaborative robotic activities and applying an evolutionary algorithm to optimize the robot's design for improved ergonomic performance [168]. Current investigations focused on whether an interference effect linked with observed human action towards executed action contains specifics information of biological motion trajectory. The research carried out by J. Rosen et al. studied the integration of a human arm with a powered exoskeleton and its experimental implementation in an elbow joint, using the neuromuscular signal (EMG) as the primary command signal. Four indices of performance were used to assess the system and results indicated the feasibility of an EMG-based power exoskeleton system as an integrated human-machine system [169]. Human movements are likely to cause interference with incongruent executed arm movement only under biological trajectory. Additionally, the observed non-biological (CV), incongruent human movement lacks interference effect associated with executed movements. When contrasting, an observed ball movement causes interference on incongruent executed arm motion despite being observed biological or non-biological. The method described by K. A. Farry at al. focuses on command two grasping (key and chuck) options and three thumb motions (abduction, extension, and flexion). Outcomes include a 90% correct grasp selection rate and an 87% correct thumb motion selection, both using the myoelectric spectrum [170]. Such effects are outcomes from quantity of information distinguished by the brain based on distinct kinds of motion stimuli [171]. Alternatively, the impact resulting from prior experience with diverse kinds of form as well as motion needs to be taken into consideration. Extensive research is necessary to assist in discriminating amid the existing possibilities [172]. Data driven interaction involves using data to optimize interactions between collaborative robots and human workers mainly in manufacturing and industrial environments [173]. According to Magrini et al., the collaboration between humans and robots depends on suitable exchange of contact forces that are likely to take place at various points along an existing robot structure. The researchers concentrated on the physical collaboration elements whereby humans determine the nature of contact with robots as the robot reacts as function of the altered forces [174]. The implication is that safe coexistence has been made possible and ensured. O. Khatib et al. work on physical collaboration, where robots have to ensure that they accomplish various kinds of subtasks [175]. The first task entails detecting contact with human and distinguished amid intentional contact and undesired collision. Secondly, the identification of points within the robot surface where contact has taken place. Third involves estimating the alteration between Cartesian forces. Finally, controlling the robot for reaction based on the desired behaviour. Force and pressure represent significant considerations affiliated with the designing process and implementation of collaborative robot interactions. According to Tsumugiwa et al., the human and robot cooperative responsibility has two main groups that include the carrying task and positioning task. The carrying task has independence characteristic of a robot undergoes adjustments depending on the mode of estimation stiffness from the arm stiffness [176]. Virtual stiffness is maintained depending on human characteristics whereby the stiffness by human operator's arm or applied force to robots is part of the cooperative task [177]. One of the major assumptions is that human operators often stiffen their arms at the positioning task [178]. Morel et al. proposed that a novel variable impedance control comprising of virtual stiffness. Such virtual forces produced through the proposed controller making a cooperative positioning task to achieve easy and precise outcomes. For confirmation of the usefulness of proposed control, a cooperative peg-in-hole task was executed by a robot [179]. Experimental outcomes illustrate how the proposed control happens to be effective for cooperative carrying as well as positioning task [180]. Vision is a significant element in the process of enabling robots to effectively perceive and comprehend their surroundings and to interact with humans within a safe and effective process. Using vision in cobot interaction is effective in object recognition as well as tracking whereby vision sensors including cameras are commonly identified and tracking objects in the surroundings of a robot. The human-computer interfaces are ideal in facilitating communication that offer assistance in exchanging information, procedure commands, in addition to controls. Within this domain, C. Plagemann et al. present a novel interest point detector for mesh and range data that is particularly well suited for analyzing human shape. The experiments carried out show that our interest points are significantly better in detecting body parts in depth images than state-of-the-art sliding-window based detectors [181]. Working in the robotics sector, professionals often concentrate on the integration of spoken natural language besides natural gestures associated with commanding and controlling the semi-autonomous mobile robots. Both spoken natural language along with natural gesture have become user-friendly platforms of interaction with mobile robot. Considering the human perspective, the mode of interactions become easier since the human is incapable of learning additional interactions despite depending on natural channels for communication. According to Perzanowski et al., the objective of developing a natural language or gesture interface in a semi-autonomous robot was successful. Using natural language or gesture within the interface relies on two distinct assumptions [182]. The first assumption suggests that as natural language remains ambiguous, gestures disambiguate various kinds of information in the speech. The second assumption is that humans utilize natural gestures in an easier manner when issuing directives and locomotive commands in mobile robots. Association of vision and force/pressure sensing provides several positive outcomes for COBOTs, enabling them to safely interact with humans and carry out a range of tasks. Zanchettin, A.M. and Rocco, P. combine these two elements in a constraint-based algorithm for combined trajectory generation and kinematic control for robotic manipulators. The algorithm shifts from an imperative programming paradigm to a declarative motion programming approach [183].

Furthermore, L. Peternel et al. propose an exoskeleton control method for adaptive learning of assistive joint torque profiles in periodic tasks. Within this research, human muscle activity is utilized as feedback to modify the assistive joint torque behaviour in a way that reduces the muscle activity [184]. Force/pressure measurement tends to be critical components playing central roles in making certain there is safe and effective collaboration amid humans and robots [185]. According to Lippiello et al., it is important to consider the interaction control between a robot manipulator and the partially known environment. Autonomy defining a robotic system has strict connection to availability of sensing information within external surroundings besides the different sensing capabilities, vision and force that have critical roles. This is confirmed within a work purposed by A. Cherubini et al., where a multimodal sensor-based control framework for intuitive human-robot collaboration has been developed. The approach is marker-less, utilizes a Kinect and an on-board camera, and is based on a unified task formalism. The framework has been validated in an industrial mock-up scenario of humans and robots collaborating to insert screws [186]. Another research of Lippiello et al., confirmed by a simulation case study, proposes an algorithm for online estimation of the pose of an unknown and possibly time-varying rigid object based on visual data from a camera. Force and joint position measurements are also used to improve estimation accuracy [187].

2.5.1 Intention Recognition

Intention recognition is key technology for COBOTs applications. COBOT intention recognition system typically relies on sensors and software that allow the robot to detect and interpret human movements and gestures. By understanding the intentions of humans, COBOTs can adapt their actions to avoid collisions or other safety hazards. They can also provide more effective assistance to human workers by anticipating their needs and responding in real-time. Intention recognition is an essential technology for COBOTs evolution, making it an important area of research.

An approach to developing relevant knowledge on discrete robot motions from different sets of demonstration is relevant especially during intention recognition. In a study by Mohammad and Billard, there is the development of a motion in the form of a non-linear autonomous dynamical system (DS) as the researchers concentrate on the definition of sufficient conditions to facilitate global asymptotic stability at the existing targets [188]. The study presents proposition of a learning approach known as Stable Estimator of Dynamical Systems (SEDS), which is ideal in learning the different parameters under dynamical systems to ascertain all motions follow demonstrations as they reach and stop at the target [189]. From the study, it is logical to state that DS provides a significant frame-work ideal in allowing fast learning of robot motions through small sets of demonstrations.

Image-based collision detection is currently being studied in industrial robots environment. The study published by F. Stulp et al. investigates the legibility of robot behaviour as a property that emerges from requirements on the efficiency and robustness of joint human-robot task completion. Two experiments involving human subjects demonstrate that robots are able to adjust their behaviour to increase human subjects' ability to predict the robot's intentions, resulting in faster and more reliable task completion [190]. An ideal approach associated with conducting the collision test depending on images retrieved from numerous stationary cameras in a work cell has been also presented in the study conducted by Ebert and Henrich [191]. The work of V. Magnanimo et al. proposes a Dynamic Bayesian Network for recognizing tasks which consist of sequences of manipulated objects and performed actions. The DBN takes RGB-D raw data as input and classifies manipulated objects and performed actions. To evaluate the effectiveness of the proposed approach, a case study of three typical kitchen tasks is conducted [192]. The sensor-controlled transfer motion originating from current configuration to transferring motion from current configuration is a necessary basic skill that allows robots to operate safely within humans under the same workspace. This has been studied in a paper by L. Bascetta et al., which presents advanced algorithms for cognitive vision. Using a dynamic model of human walking, these algorithms are applied to detecting and tracking humans and estimating their intentions [193]. D. J. Agravante et al. purpose a framework combination that involves vision and haptic information aligned with human-robot joint actions is an ideal angle to understand the connection between vision and force/pressure in the intention recognition of COBOT interaction. The framework comprised of hybrid controller that utilizes visual serving in addition to impedance controllers. Presence of humanoid robots has contributed to various advantages as they work alongside humans with the aim of performing different kinds of tasks [194]. Furthermore, humanoids can maintain interaction with human-like ranges of motion while they sense capabilities. The proposed general framework by human-robot joint collaborative responsibilities proves to be effective.

2.5.2 Programming and Learning

Programming and learning are two critical technologies that enable COBOTs to adapt to changing conditions and perform tasks safely and efficiently. COBOT programming typically involves creating a set of instructions or commands that the robot will follow to complete a specific task. Programming can be done manually by a human operator through a programming visual interface. COBOTS can also learn from humans by observing their movements and actions and adapting their behaviour accordingly.

Paradigms affiliated with simultaneous and proportional control from hand prostheses continue to gain momentum within the robotics rehabilitation community, which demonstrates the value of bioelectric bioelectricity in programming. Simultaneous and proportional control is designed to facilitate control of desired force or torque from each DoF of the hand or wrist that has real-time predictions. The restoration process of motor function for an upper following an amputation presents a significant task to the rehabilitation engineering sector. The study conducted by I. Strazzulla et al. applies a simultaneous and proportional control approach to two robotic hands [195]. In an investigation conducted by Calinon et al. the Robot Programming by Demonstrate (PbD) is ideal, since it addresses methods through which robots develop new skills via the supervision of humans. The methodology proposes a probabilistic approach combining

Hidden Markov Models (HMM) and Gaussian Mixture Regression (GMR) for learning and reproducing human motions. This approach is tested on simulated and real robots, demonstrating their ability to handle cyclic and crossing movements as well as multiple constraints at once [196]. The connection between robots and human-like activities enables the machines to interact with people in natural and harmless ways. New and complete strategies have been detected, estimated, and implemented to handle dynamic force interaction taking place at various points in the robot structure. For instance, L. Rozo et al. present a robot motion adaptation method for collaborative tasks that combines extraction of the desired robot behaviour, task-parametrized Gaussian mixture model, and variable impedance control for human-safe interaction. This approach is tested in a scenario where a 7 DOF back drivable manipulator learns to cooperate with a human to transport an object, and the results show that the proposed method is effective [197]. Human-robot interaction (HRI) is an indication that robots can establish communication with a person based on needs and behave in a manageable manner [198]. Furthermore, the authors present a framework that allows a user to teach a robot collaborative skill from demonstrations, which can be applied to tasks involving physical contact with the user. This method enables the robot to learn trajectory following skills as well as impedance behaviours [199]. The process of determining the levels of engagement in human-robot interaction is crucial. Engagement measures depend on the dynamics linked with social signals traded through the partners, precisely speech, and gaze. This has been studied by S. Ivaldi et al., who assessed the influence of extroversion and negative attitude towards robots on speech and gaze during a cooperative task [200]. In the model presented by A. Colome et al., Dynamic Movement Primitives (DMP) and visual/force feedback are utilized within the Reinforcement Learning (RL) algorithm to enable the robot to learn safety-critical tasks such as wrapping a scarf around the neck. Experimental results demonstrate that the robot is consistently capable of learning tasks that could not be learned otherwise, thus improving its capability with this approach [201]. Furthermore, according to the research presented by S. Lallee et al., a cooperative human-robot interaction system has been developed to recognize objects, recognize actions as sequences of perceptual primitives, and transfer this learning between different robotic platforms. This system also provides the capability to link actions into shared plans, forming the basis of human-robot cooperation [202]. Thus, in the future, the sharing of spaces between humans and collaborative robots will become more common. As a result of a process of integrating ever more advanced technologies, people and COBOTs will be able to collaborate more effectively and securely [203] in the same working environment. As confirmed by M. Lawitzky et al., C combining, planning and learning algorithms can lead to superior results in goal-directed physical robotic assistance tasks [204]. The potential to cooperate, establish, and utilize shared action measures is a distinguish cognitive capacity designed to separate humans against non-human primates. Language has become an inherently cooperative activity whereby a listener and speaker cooperate to ensure the arrival at a shared objective of communication [205]. Current investigations are in the greater context of cognitive developmental robotics that possess physical embodiments designed to play the central role in structuring representations in a system. The robotic system can attain global information regarding the surrounding environment that is utilized for task planning and obstacle avoidance. Having a complementary nature has influenced a natural belief of vision and force being exploited in the integration and synergic mode of designing sufficient planning and controlling strategies for the existing robotic system. L. Peternel et al. demonstrate that robots can be taught to dynamic manipulation tasks in cooperation with a human partner using a multi-modal interface. They employ Locally Weighted Regression for trajectory generalization and adaptive oscillators for adaptation of the robot to the partner's motion. The authors conduct an experiment teaching a robot how to use a two-person crosscut saw demonstrating this approach [206].

2.5.3 Virtual Reality (VR) based COBOT

The combination of virtual reality (VR), digital twins, and virtual commissioning of robotics and COBOTs is emerging as a promising solution for automation. This solution allows for the real-time simulation of robotic systems in a virtual environment and enables engineers and designers to monitor and optimize performance in a cost-effective and safe manner. In addition, by using VR, digital twins, and virtual commissioning, users can gain a better understanding of the robotic system, its components, and its environment. For instance, the work of Oyekan, J.O. et al. presents the use of a Virtual Reality digital twin of a physical layout as a mechanism to understand human reactions to both predictable and unpredictable robot motions. A set of established metrics as well as a newly developed Kinetic Energy Ratio metric is used to analyse human reactions and validate the effectiveness of the Virtual Reality environment [207]. Duguleana, M. et al. present an analysis of Virtual Reality (VR) as an alternative to real-world applications for testing material handling scenarios that involve collaboration between robots and humans. They measure variables such as the percentage of tasks completed successfully, the average time to complete tasks, the relative distance and motion estimate, presence and contact errors, and compare the results between different manipulation scenarios [208]. People with two-arm disabilities face difficulties in completing tasks that require them to grasp multiple objects that are closely spaced. Current arm-free Human-Robot Interfaces (HRIs) such as language-based and gaze-based HRIs are not effective in controlling robotic arms to complete such tasks. Zhang, C et al. propose a novel Human-Robot Interaction (HRI) system that leverages Mixed Reality (MR) feedback and head control for arm-free operation. The proposed HRI system is designed to enable users with disabilities to control a robotic gripper with high accuracy and flexibility. Experiments conducted on objects of various sizes and shapes demonstrate its capability to complete tasks with high adaptability and point cloud error tolerance [209]. With the advancement of Artificial Intelligence technology in making smart devices, understanding how humans develop trust in virtual agents is emerging as a critical research field. In order to face with this issue, Gupta et al. present a novel methodology to investigate user trust in auditory assistance in a Virtual Reality (VR) based search task. The study collected physiological sensor data such as EEG, GSR, and HRV, subjective data through questionnaires such as STS, SMEQ, and NASA-TLX, and a behavioural measure of trust in response to valid/ invalid verbal advice from the agent.

Results show that cognitive load and agent accuracy play an important role in trust formation in the customized VR environment [210].

2.1 Cobot market analysis: potentialities and limits

In this section, 195 COBOTs that are existing in the current market have been investigated. The classification is based on i) the degrees of freedom; ii) the robot typology, as anthropomorphic, Cartesian, SCARA, and Torso; iii) the payload; iv) the reach volume; v) the accuracy. The aim of this assessment is to provide a synthetic overview of the features and performance of COBOTs available on the market.

2.1.1 COBOTs assessment: Degree of Freedom

The robotic arms are characterized by the numbers of DoF from one to fourteen. A higher number of DoF implies that the robot has more pose options. COBOTS can be classified into four categories: Anthropomorphic, Cartesian, SCARA and Torso, as in Table 1.

Class	No.
Anthropomorphic	176
Cartesian	1
SCARA	14
Torso	4

Table 1. COBOT models by mechanism class

Anthropomorphic COBOTs consist of a mechanical serial structure composed of rig-id arms linked with joints, at least four, that allow their movement. The joints can be cylindrical or prismatic. Cartesian COBOTs consist of a motion based on an orthogonal Cartesian ternary system. To move in space, they use orthogonal sliding joints through metal arms. Since the movement works on linear axes, the movements are easily programmable at the cost of less flexibility. SCARA COBOTs, acronym for Selective Compliance Assembly Robot Arm, are defined with two arms that can move in the horizontal plane, with at the end of them a prismatic coupling that allows vertical movement. Torso COBOTs have a human-like aspect and behaviour capable of twisting, bending, and rotating in multiple directions, giving them a high degree of freedom. The structure can be based on serial, parallel or differential kinematic, each with pros and cons aspects. Serial torso COBOTs are commonly easier to control. In contrast, parallel and differential kinematics offer a greater number of DoF driven by higher number of smaller actuators; how-ever, the kinematics are more complex in control and design.

The most popular class of COBOT is Anthropomorphic, followed by SCARA, Torso and Cartesian. The anthropomorphic class represents the 90% of the total COBOTs offered by the market. Finally, Torso COBOTS (2%), despite being designed with multiple degrees of freedom to provide greater flexibility and adaptability in a wide range of applications, the complexity of its cinematic and its large footprint limit their acceptance.

2.1.2 COBOTs assessment: Reach and Payload

The payload capacity refers to the mass and inertia that the robot's wrist can manage. The robotic arm's reach is a measurement of the distance that the mechanism can execute defining the tridimensional workspace. The COBOTs studied in this review are grouped into five categories, as shown in Table 2.

COBOTs cluster	Payload (kg)	Reach (mm)
Group 1	$P \leq 5.0$	$R < 500$
Group 2	$5.0 < P \leq 10.0$	$500 < R \leq 1{,}000$
Group 3	$10.0 < P \leq 15.0$	$1000 < R \leq 1{,}500$
Group 4	$15.0 < P \leq 20.0$	$1500 < R \leq 2{,}000$
Group 5	$P > 20.0$	$R > 2{,}000$

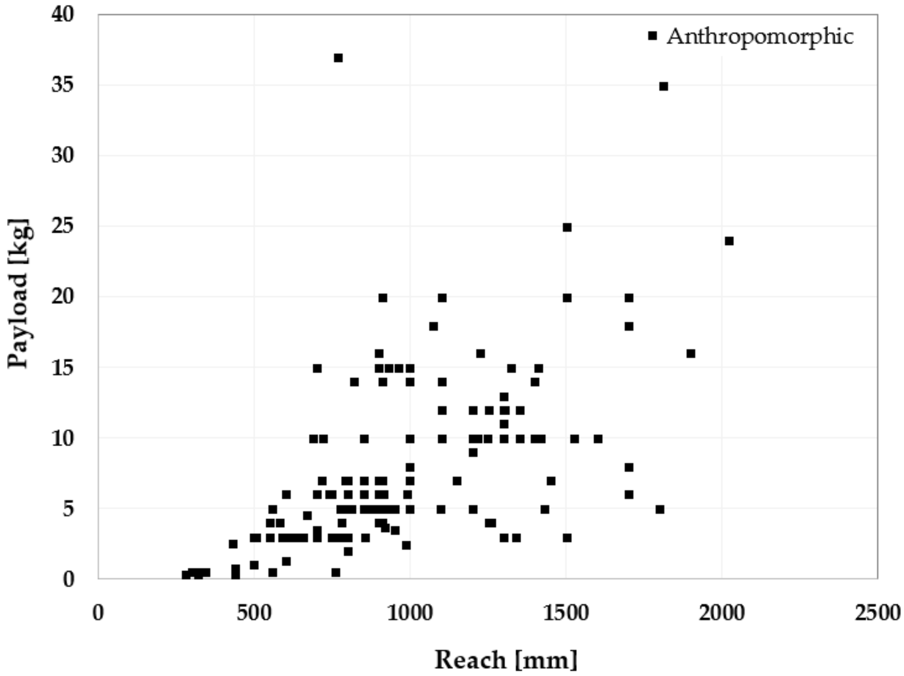
Table 2. COBOTs cluster based on payload and reach features.

Group 1 includes small size COBOTs, with a payload lower than 5 kg and a limited reach of 500 mm. Medium size COBOTs includes payload between 5 and 20 kg. Large size COBOTs involve devices with highest payload, greater than 20 kg, and the highest reach Group 5. The Anthropomorphic class represents more than the 90.0% of total, the most popular size is represented by Group 2, Group 3 and Group 4 that counts the 88.6% of the total anthropomorphic models, as illustrated in table 3. Small and Large Anthropo-morphic models of Group 1 and Group 5 are 16 and 4, respectively. The technology of COBOTs derives from traditional robotics equipment, thus it is possible to find Anthropomorphic COBOTs with a long-distance reach and great payload, up to 170 kg. In this case, the producer equipped the traditional equipment with a tactile skin and proximity sensors that allow it to avoid collisions and retract, depending on the contact force. The Mentioned COBOT model is an exception of size, features and application, thus this model has been excluded by graphing and statistics. The Cartesian COBOTs counts 1 model; cartesian robots consists of a motion based on an orthogonal Cartesian tern. These machines are widely installed in production lines, typically with the aim of performing activities of feeding pallet or chain conveyors. SCARA counts 14 models purposed by the market, representing the 7.2% of total; its typical application is pick and place with high speed and high accuracy performances, comparable and even higher than anthropomorphic. Torso COBOTs, despite of its number degrees of freedom, the complexity of its cinematic and its large footprint limit the diffusion and development.

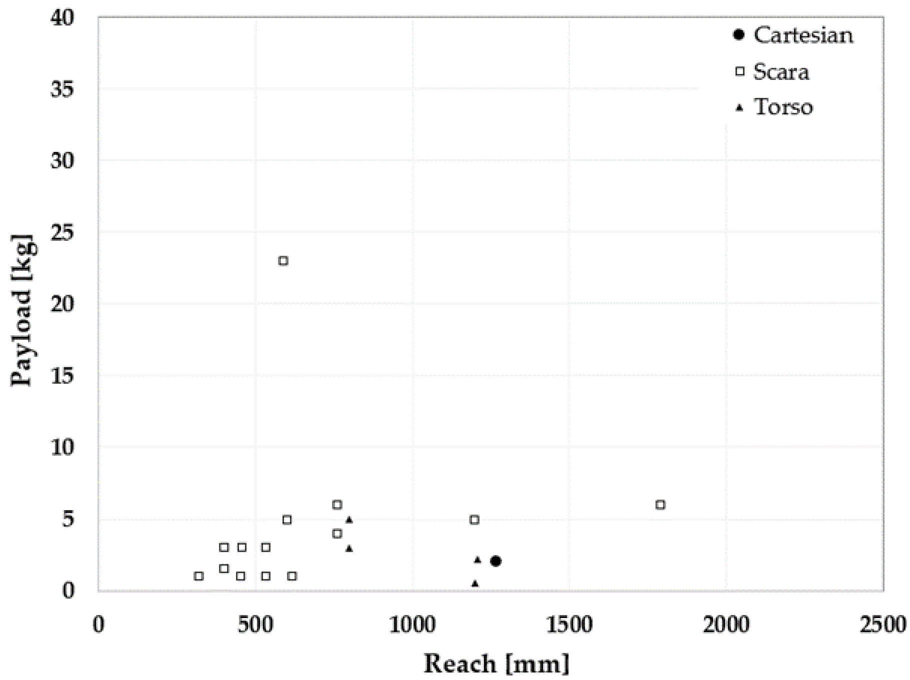
Class	Group1	Group2	Group3	Group4	Group5	Total
Anthropomorphic	16	91	50	15	4	176
Cartesian			1			1
SCARA	5	6	1	1	1	14
Torso		2	2			4
Total	**21**	**99**	**54**	**16**	**5**	**195**

Table 3. Number of available COBOTs grouped by mechanism class and payload-reach clusters.

Figure 6 shows the payload and the reach relation as proportional trend for anthropomorphic and SCARA classes. The correlation coefficient is in 29.4% - 38.5% range for anthropomorphic and SCARA typology, respectively.



(a)

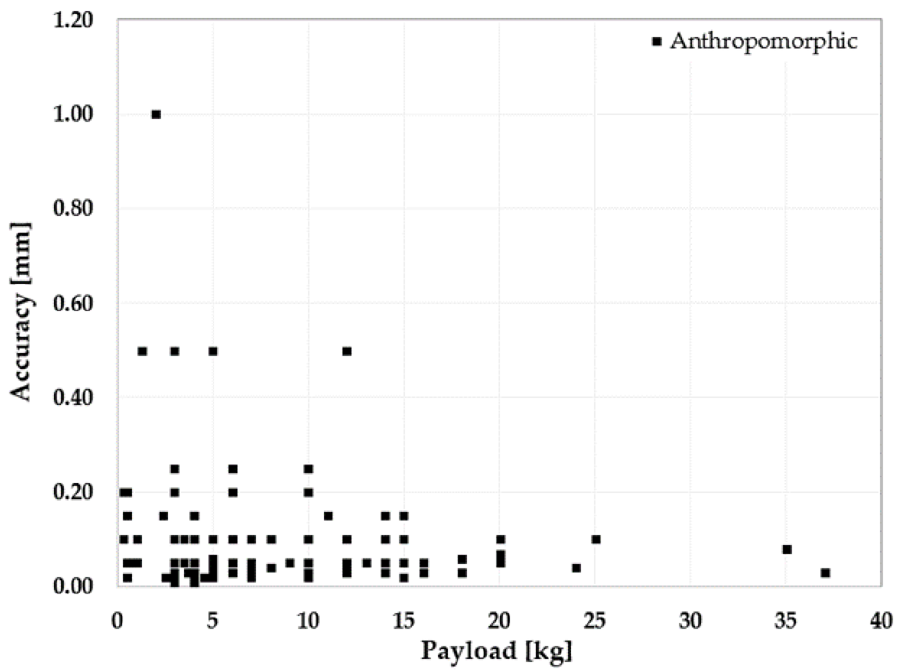


(b)

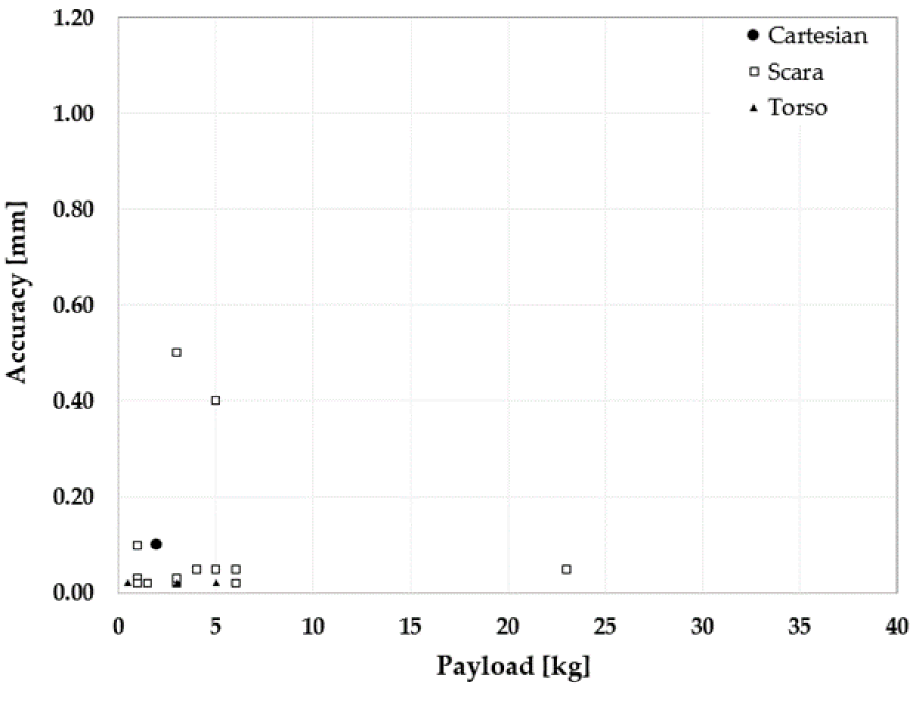
Figure 6. COBOT scatter plot of payload and reach: Anthropomorphic (a); Cartesian, SCARA and Torso (b)

2.1.3 COBOTs assessment: Accuracy

Accuracy is an indicator that represents the deviation between the planned and the observed pose. COBOTs providers have declared accuracy is expressed in comparison with payload capacity in **Figure 7**. In current market, more than 90% of the anthropomorphic COBOTs show performance in 0.01mm and 0.20 mm range with no interrelate impact of robot payload ability from 0.3 kg to 20.0 kg, figure 4a. Moreover, it is not highlighted a significant trend between the maximum payload and the deterioration of accuracy performance. Figure 4b shows that the payload ranges of Cartesian, Torso, and SCARA COBOTs concertante in the range 0.5-5.0 kg, and the level of accuracy is lower than 0.10 mm.



(a)



(b)

Figure 7. COBOTs scatter plot of accuracy and payload: Anthropomorphic (a); Cartesian, SCARA and Torso (b).

Figure 8 shows a percentile representation of accuracy for the two main classes: Anthropomorphic is described by Q1 – 25th percentile as 0.03mm, Q3 – 75th percentile as 0.10mm and median as 0.05mm. SCARA COBOTs level of accuracy is Q1 – 25th percentile as 0.02mm, Q3 – 75th percentile as 0.06 and median as 0.04mm.

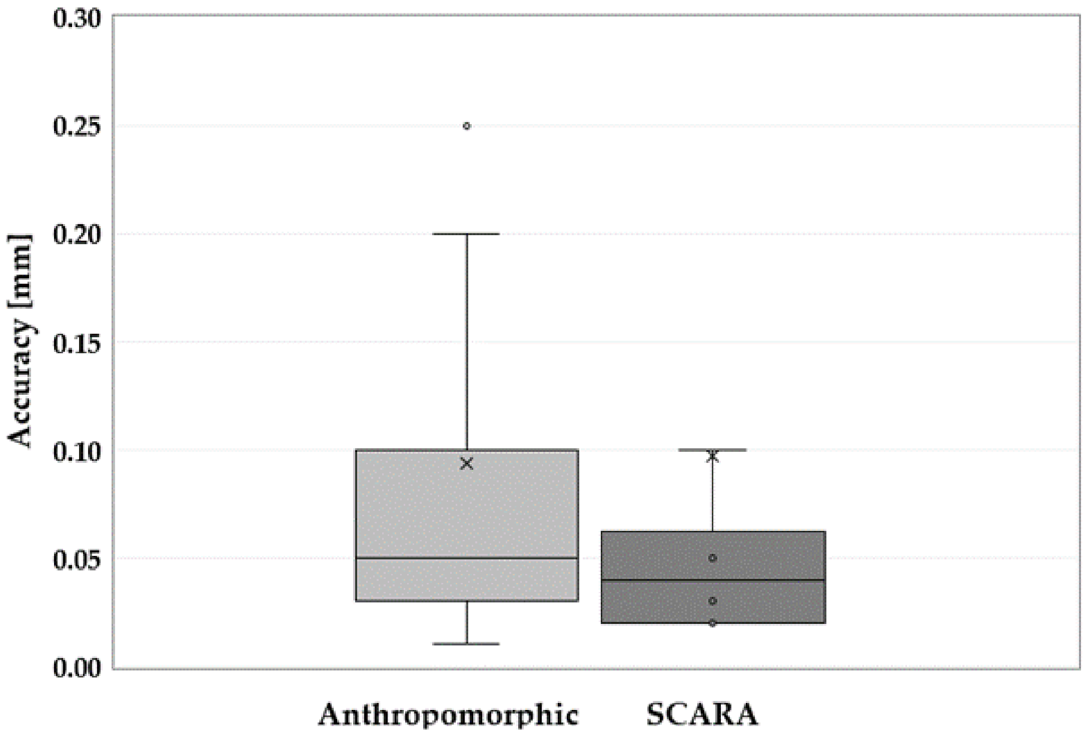
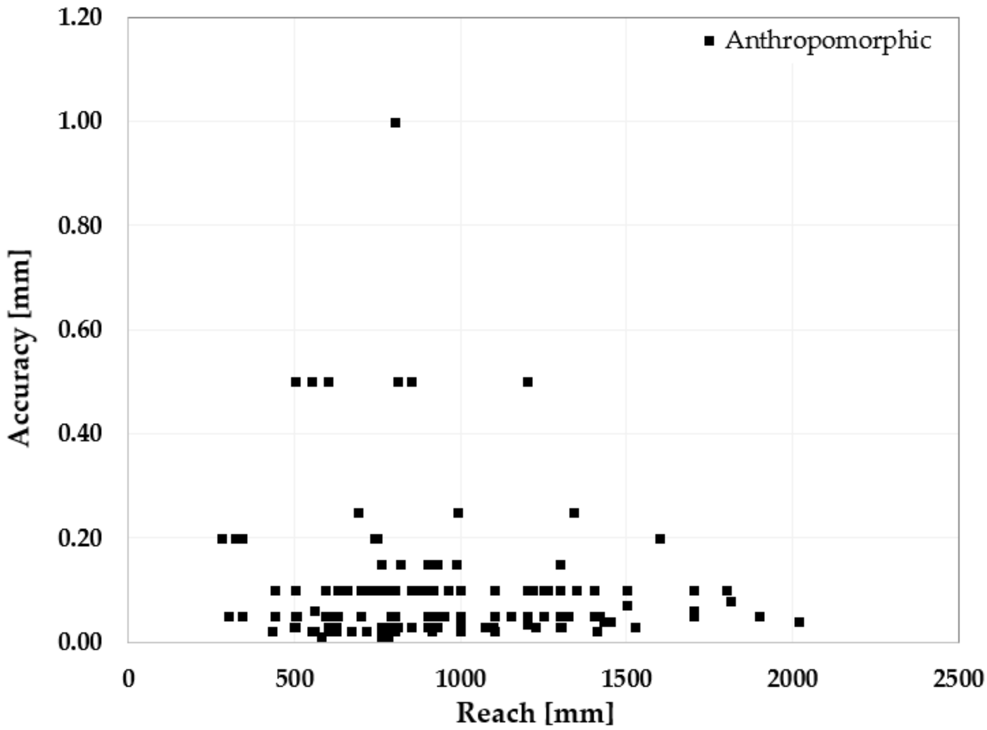
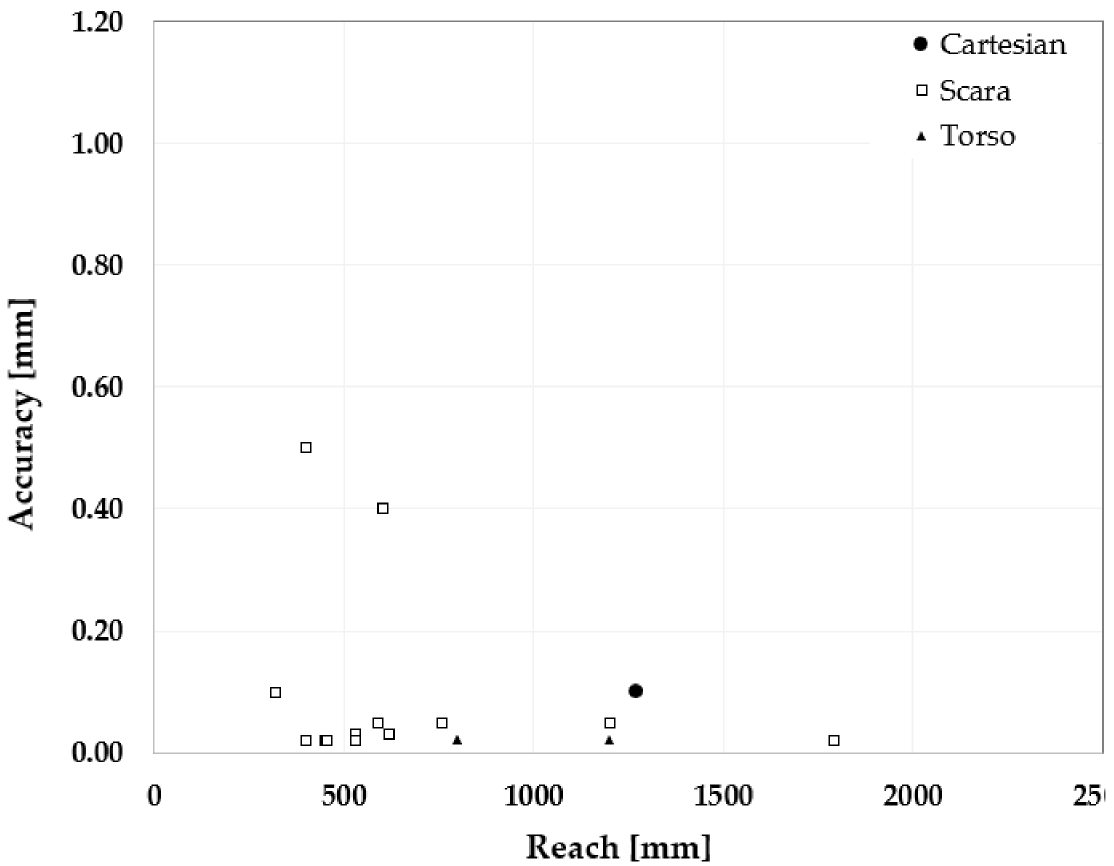


Figure 8. COBOTs box plot of accuracy for Anthropomorphic and SCARA.

Figure 9 a,b confirms the correlation analysis shows that the accuracy is not affected by the COBOT reach, for Anthropomorphic configuration in figure 6a and in Cartesian, SCARA and Torso architecture in figure 6b. The level of accuracy is lower than 0.25mm and it is concerned by models or providers.



(a)



(b)

Figure 9. COBOTs scatter plot of accuracy and reach: Anthropomorphic (a); Cartesian, SCARA and Torso (b)

2.1.4 COBOTs assessment: Energy consumption vs Tool Center Point (TCP)

The TCP velocity is a valuable characteristic of the COBOT and refers to the end-effector motion performance during its operations. The TCP velocity has a direct im-pact on the cycle time of the workstation and to the operator safety. On the other hand, the power consumption is an index that is central in the equipment installation and device daily supervision. The energy consumption increases consistently with the payload. **Figure 10** shows a correlation between Energy consumption [kW] and the maximum TCP velocity [m/s], listed in Annex 2. The investigated cobot payload range is within 0.5 kg – 20.0 kg with a TCP velocity from 0.3 m/s – 6.0 m/s. The expected power consumption exceeds 0.50 kW for cobots that provide a payload greater than 10 kg. It is significative the evidence that the TCP increment from 1.0 m/s to 3.0 m/s does not statistically influence an increment of energy consumption. The main driver for power use is the payload offered by the anthropomorphic cobot, in particular for payload from 1.0 kg to 6.0 kg considering the total gripper combined with the manipulated workpiece mass and inertia.

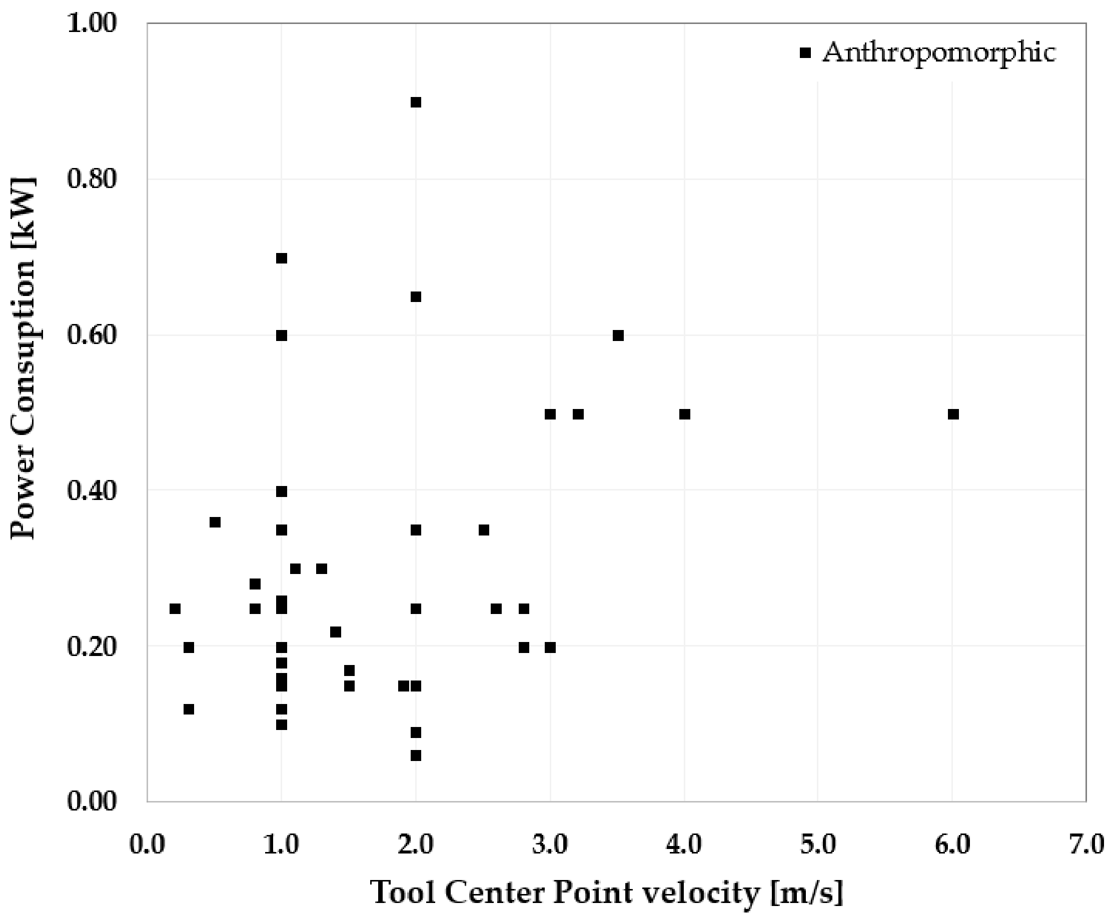


Figure 10. COBOTs scatter plot of Power consumption and Tool Center Point velocity of Anthropomorphic architecture

2.1.5 Discussion

Developing a COBOT selection procedure is a challenging task that covers a broad range of domains. In particular, the application leads the device concept and design. Furthermore, interaction and COBOTs providers may offer advantages with ad-hoc solutions than a robust procedure is not able to guarantee. This paragraph provides an overview of the current state of the art of COBOTs applications, learning abilities and the market existing equipment. The applications of COBOTs are growing in terms of installations remarkably in SME context. A number of research works are focusing their efforts on the development of methods for reducing emotional workload and productivity optimization. These methods are mainly employed to produce complex components. The research in material handling is working on the challenging task of handle unstable materials. In this field, the developed methods for adjusting and compensating trajectories in real time are very promising. COBOTs offer new opportunities in a variety of contexts in healthcare, improving accuracy and precision in tasks such as surgery or rehabilitation. By combining AI and machine learning algorithms with robotics, COBOTs can be trained to assist physical therapists in providing superior and faster restoration. COBOT-assisted physical therapy could also provide personalized and dynamic treatment, allowing for more effective rehabilitation. The use of AI and machine learning systems is rapidly accelerating the ability of COBOTs to interact with humans and the training time-consumption. Various research has been carried out to control COBOTs using natural language and gesture. Efforts are currently focusing on training COBOTs to understand and respond to natural language, interpret human gestures, and visualize objects to more accurate task completion. Additionally, AI-enabled systems are being developed to allow COBOTs to constantly update their knowledge and refine their decision-making. Force, pressure, and vision sensors are critical components in enabling robots and humans' interaction.

The market analyses results show that the most promising typology for COBOTs applications is the anthropomorphic one, which can provide greater flexibility and adaptability than traditional robotics. Anthropomorphic COBOTs show improved adaptability to time-variant conditions and un-structured environment. Future developments should consider the usability conditions to increase the compliant applications. The proposed classification and comparison underline how the SME and researchers are moving toward innovative solution.

Chapter 3

The Expansion of Industrial Robotics in the Global Context

This chapter examines the global expansion of industrial robot usage, highlighting a significant increase in the adoption of such technologies over the past decade. Through a detailed analysis of annual installations and the growing use of robotics across various industrial sectors, the text underscores the increasingly important role of automation in modern production processes. This trend is expected to continue, driven by technological evolution, market demands, and international competition.

3.1 Industrial robotics deployment - World

3.1.1 Annual implementation of industrial robotics systems - World

Over the past decade, there has been a considerable rise in the use of industrial robots as indicated by data of annual world installations reported in Table 4.

Year	Units	Year-on-year
2011	166,000	0%
2012	159,000	-4%
2013	178,000	12%
2014	221,000	24%
2015	254,000	15%
2016	304,000	20%
2017	400,000	32%
2018	423,000	6%
2019	391,000	-8%
2020	394,000	1%
2021	517,000	31%

Table 4. Annual installation of industrial robots (world). IFR World Robotics 2022

Robotics has been steadily integrated into the global production landscape, with a slight stabilization between 2018 and 2020, followed by another significant increase in 2021. In 2011, there were 166,000 industrial robots installed globally. Although there was a slight 4% decrease the following year, the period between 2013 and 2017 saw a robust upward trend. In 2017, annual installations reached a peak of 400,000 units, marking a significant increase of 32% compared to the previous year. However, signs of slowing emerged in 2019 with an 8% decline, influenced by various macroeconomic and geopolitical factors. The modest 1% growth in 2020 was conditioned by global uncertainties related to the COVID-19 pandemic. The increasing demand for automation of production processes is one of the main growth factors of industrial robotics.

Technological advancements, such as artificial intelligence, machine learning, and sensors, have allowed robots to become more sophisticated and versatile, capable of adapting to changing environments and tasks.

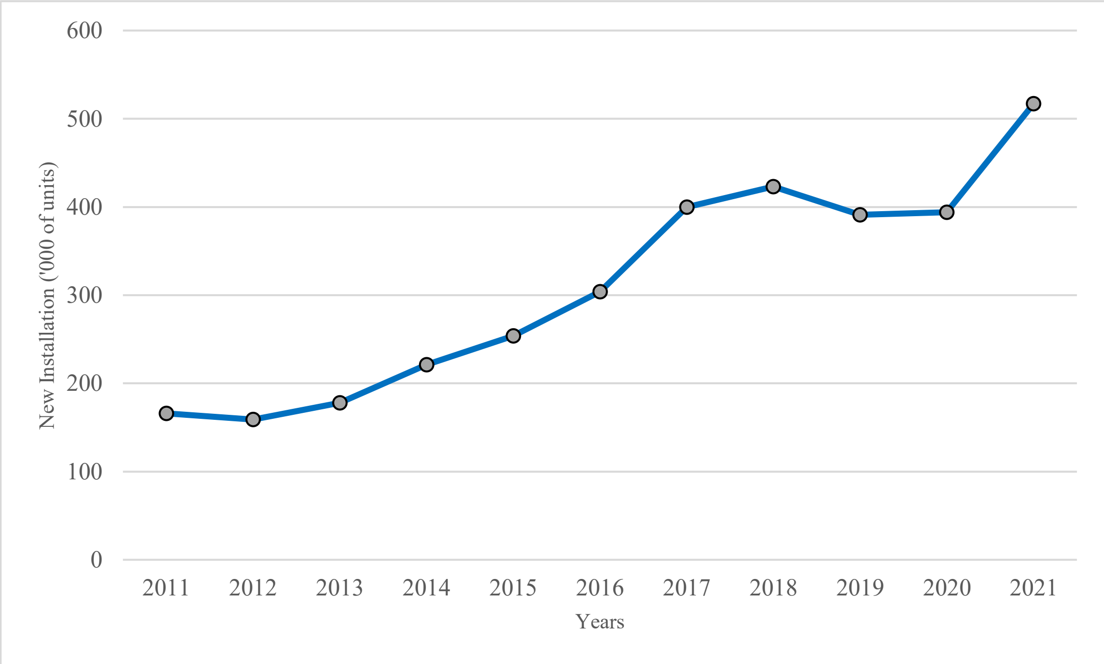


Figure 11. Annual installation of industrial robots - World.
IFR World Robotics 2022

This has led to the emergence of new applications and sectors, such as logistics, healthcare, and agriculture, where robots can perform tasks that were previously difficult or impossible for humans. The growth of industrial robotics is a trend that will continue in the coming years, driven by technological advancements, market demands, and global competition. The manufacturing sector is undergoing a significant shift towards a new production paradigm that embodies the Fourth Industrial Revolution, characterized by system integration and the implementation of highly innovative technologies such as artificial intelligence. The ever-increasing number of installed robots, which has recorded a significant annual growth rate in recent years, highlights the growing dependence of the manufacturing sector on robotics. While there are challenges and risks associated with the adoption of robotics, there are also opportunities and benefits that can be realized through responsible and sustainable practices.

3.1.2 Working stock of industrial robot – World

Simultaneously, the number of active industrial robots reveals a phenomenon of considerable interest. The constant growth compared to the starting point of 2011 suggests that not only are new robotics units being installed, but also those already in use maintain their functionality, thus contributing to the overall increase in the fleet of machines.

Year	Units	Year-on-year
2011	1,153,000	0%
2012	1,235,000	7%
2013	1,332,000	8%
2014	1,472,000	11%
2015	1,632,000	11%
2016	1,838,000	13%
2017	2,125,000	16%
2018	2,441,000	15%
2019	2,740,000	12%
2020	3,035,000	11%
2021	3,477,000	15%

Table 5 Operational stock of industrial robot – World. IFR World Robotics 2022

The examination of the Table 5 highlights a constant and significant growth in the number of operational industrial robots on a global scale. Over the course of a decade, it is noticeable how this value has practically tripled, from 1,153,000 units in 2011 to 3,477,000 units in 2021.

The graph in **Figure 12**, with its constantly upward trend, further confirms this trend. It shows an almost linear trend, with few fluctuations, testifying to stability in the adoption of robotics. In the context of the years 2017 and 2018, there was a rapid acceleration of technological innovation and a process of globalization of the manufacturing industry. This trend that reached its peak in 2017 with an increase of 16%. Even in the presence of potential economic crises or slowdowns, growth has remained robust.

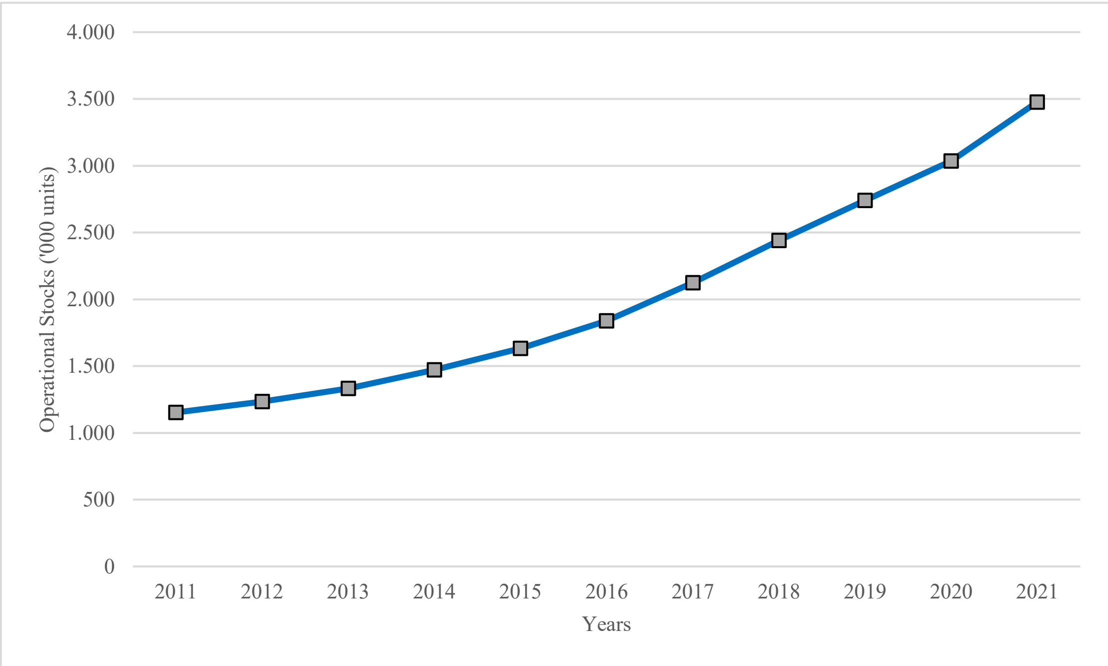


Figure 12. Operational stock of industrial robot – World.
IFR World Robotics 2022

For example, in 2021, growth reached 15%, suggesting that businesses consider robotics as a key element in addressing new challenges in the context of production and operations. This led to a proliferation of new technologies and an increase in research and development activities. In particular, the manufacturing sector underwent a significant transformation during this period. The introduction of automation and robotics increased the efficiency and productivity of factories. This evolution has led not only to a reduction in costs but also to the creation of new job opportunities, especially in the fields of engineering and programming.

3.1.3 Annual implementation of industrial robotics systems by Customer Industry

The analysis of annual installations of industrial robots divided by customer sector reveals dynamics of interesting relevance within the global industrial landscape. Through the examination of data collected in the most recent three years, Table 6, there is a clear evolution in the context of robotics adoption.

Industry	**2019** [units]	**2020** [units]	**2021** [units]	**(2019-2021)**
Automotive	102,000	84,000	119,000	17%
Electrical/Electronics	89,000	110,000	137,000	54%
Metal and machinery	52,000	44,000	64,000	23%
Plastic and chemical products	18,000	19,000	24,000	33%
Food	11,000	12,000	15,000	36%
All others	30,000	37,000	52,000	73%
Unspecified	87,000	87,000	107,000	23%

Table 6 Annual installation of industrial robots by customer industry. IFR World Robotics 2022

Sectors such as the automotive industry, traditionally a benchmark for the application of industrial robotics, experienced a contraction in 2020, with 84,000 units installed, compared to 102,000 in 2019, before registering a significant recovery in 2021, reaching a total of 119,000 units, indicating an overall increase of 17% compared to 2019. In this context, robots are employed in operations such as assembly, welding, and painting within production lines, which are fully automated, including assembly lines and transfer systems. The widespread adoption of robotics in this area is justified by the fact that the tasks to be performed can be precisely defined and require minimal feedback interventions to monitor the accuracy of the process. In parallel, the electronics sector, which involves electronic components and devices, showed a significant increase, transitioning from 89.000 units in 2019 to a considerable total of 137,000 in 2021, representing a notable increase of 54%. This phenomenon reflects the increased demand for electronic products and technological evolution within this sphere. Furthermore, the metals and machinery sector recorded a growth of 23%, transitioning from 52,000 to 64,000 units between 2019 and 2021. Even the chemical and plastics sector experienced a slight growth of 33% during this same period, while the food industry,

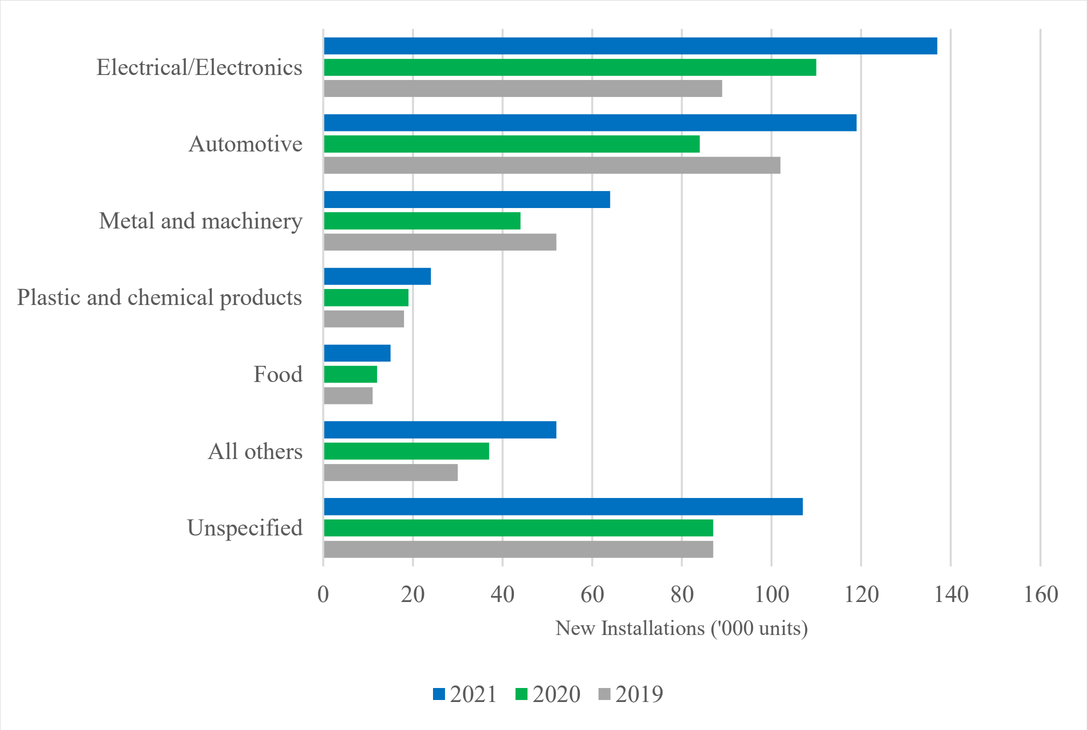


Figure 13. Annual installation of industrial robots by customer industry.
IFR World Robotics 2022

Finally, the increase observed in the "Other" category, which recorded a significant growth of 73%, transitioning from 30.000 to 52.000 units, suggests that robots are being adopted in increasingly unconventional sectors, highlighting a diversification in the use of such devices. Overall, there is a clear and increasingly pervasive diffusion of the adoption of industrial robots, and while maintaining a consolidated leadership in traditional sectors, there is a growing orientation towards robotization also in emerging industries.

3.1.4 Annual implementation of industrial robotics systems by Application

Below are reported the data of annual installation of industrial robots based on application. The analysis of **Figure 14** reveals significant trends characterizing the applications of robotics in the period between 2019 and 2021, allowing us to explore the dynamics at play in various industrial sectors.

Application	**2019** [units]	**2020** [units]	**2021** [units]	**(2019-2021)**
Handling	177,000	169,000	230,000	30%
Welding	74,000	70,000	96,000	30%
Assembling	40,000	50,000	62,000	55%
Cleanroom	26,000	32,000	32,000	23%
Dispensing	12,000	8,000	11,000	-8%
Processing	7,000	5,000	7,000	0%
All others	55,000	60,000	80,000	45%

Table 7 Annual installation of industrial robots by application. IFR World Robotics 2022. IFR World Robotics 2022

Examining the materials handling sector, it is noted that it constitutes a key element in industrial automation. During the analysed period, with an increase of 30%, the number of industrial robots used has gone from 177,000 units in 2019 to 230,000 units in 2021. This denotes a clear inclination to invest in robotics technologies for the transport and handling of goods and components, in response to the growing emphasis placed on maximizing efficiency and optimizing workflow within modern production chains. Similarly, the welding sector, of fundamental importance in production operations, has followed a similar trajectory, also showing a 30% increase. Starting from a base of 74,000 units in 2019, there was a slight contraction in 2020, followed by an increase that brought the total to 96,000 units in 2021. The increasing adoption of robotized welding solutions reflects the growing need for precision, repeatability, and quality, especially in the automotive and aerospace sectors. The assembly sector has experienced significant growth, with an overall 12% increase in the installation of industrial robots from 2018 to 2019. This surge in demand is indicative of the growing complexity of products and quality expectations, which require solutions capable of ensuring uniformity in component assembly.

In the cleanroom assembly segment, there has been a 23% increase, thus highlighting the growing importance of sectors requiring sterile environments, such as pharmaceutical production and semiconductor production. In this context, robotics provides solutions aimed at reducing contamination and improving process consistency. Interestingly, the distribution sector has experienced an 8% reduction in installations. This decline could be interpreted as the exploration by some sectors of alternative methods or as an indication of a market that has temporarily reached a saturation point in this specific segment.

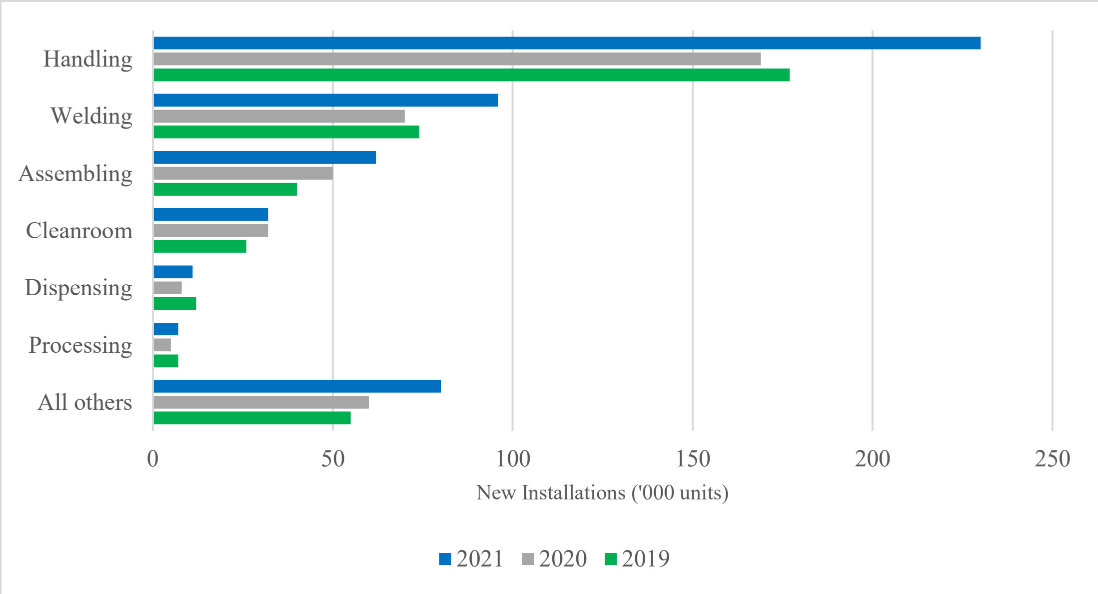


Figure 14. Annual installation of industrial robots by application.
IFR World Robotics 2022

The processing sector has shown stagnant growth, suggesting that the adoption of robotics solutions has reached a maturity phase, with few changes in adoption year after year. To conclude, the "All Other" category has marked a significant increase of 45%, highlighting the emergence of new applications and the remarkable versatility of robots in contexts other than those traditionally known.

3.1.5 Annual implementation of industrial robotics systems by Country

In this paragraph, are reported data on annual installations of industrial robots by country in 2021. The **Figure 15** allow us to analyse which countries or geographic areas are most prone to using this technology.

Asia tops the list, with China demonstrating massive use of this technology, having installed 268,200 units. This not only reflects China's wide investment in integrating robots into the manufacturing sector, but also highlights its role as a leader in global production. Japan and the Republic of Korea also show significant commitment with 47,200 and 31,100 installations respectively, confirming Asia's important investment in the field of robotics. Contributions from Chinese Taipei with 9,600 units and Singapore with 3,500 are also noteworthy.

Country	Units
China	268,200
Japan	47,200
USA	35,000
Rep. Of Korea	31,100
Germany	23,800
Italy	14,100
Chinese Taipei	9,600

France	5,900
Mexico	5,400
India	4,900
Canada	4,300
Thailand	3,900
Singapore	3,500
Spain	3,400
Poland	3,300

Table 8 Annual installation of industrial robots by country (2021). IFR World Robotics 2022.

Focusing on North America, the United States, with 35,000 units installed in 2021, reflects their global position as a technological and productive leader. For instance in the automotive and electronics sectors, where use robots intensively for assembly lines, or emerging sectors such as renewable energies and biotechnologies employ robotics for complex operations and the handling of hazardous or sensitive materials. Canada, with 4,300 units installed, shows a growing commitment towards automation, particularly in manufacturing sectors such as automotive, aerospace, food and consumer goods. Both countries are at the forefront of advanced robotics and artificial intelligence development, with numerous startups and universities conducting cutting-edge research. This commitment to research and development translates into a continuous flow of innovations that benefit not only their economies but also the global evolution of the robotics sector.

In Europe, the numbers are significant although they do not reach Asia's figures. Germany tops European installations with 23,800 units, reflecting its consolidated automotive and manufacturing industry. Italy follows with 14,100 units, and other countries such as France (5,900), Spain (3,400), and Poland (3,300) show solid adoption, albeit more contained than industry leaders.

In emerging economies, the adoption of industrial robots is becoming a key indicator of their rapid development and modernization. India, with its 4,900 robots installed in 2021, is a clear example of how these economies are trying to bridge the technological gap with industrialized nations. This investment is often driven by the need to increase productivity and quality in production, to face international competition and to respond to the needs of an increasingly technological and automated global market. Countries such as Mexico and Thailand, with 5,400 and 3,900 units respectively, are also leveraging robotics to improve their production efficiency and attract foreign investment, particularly in manufacturing and automotive industries.

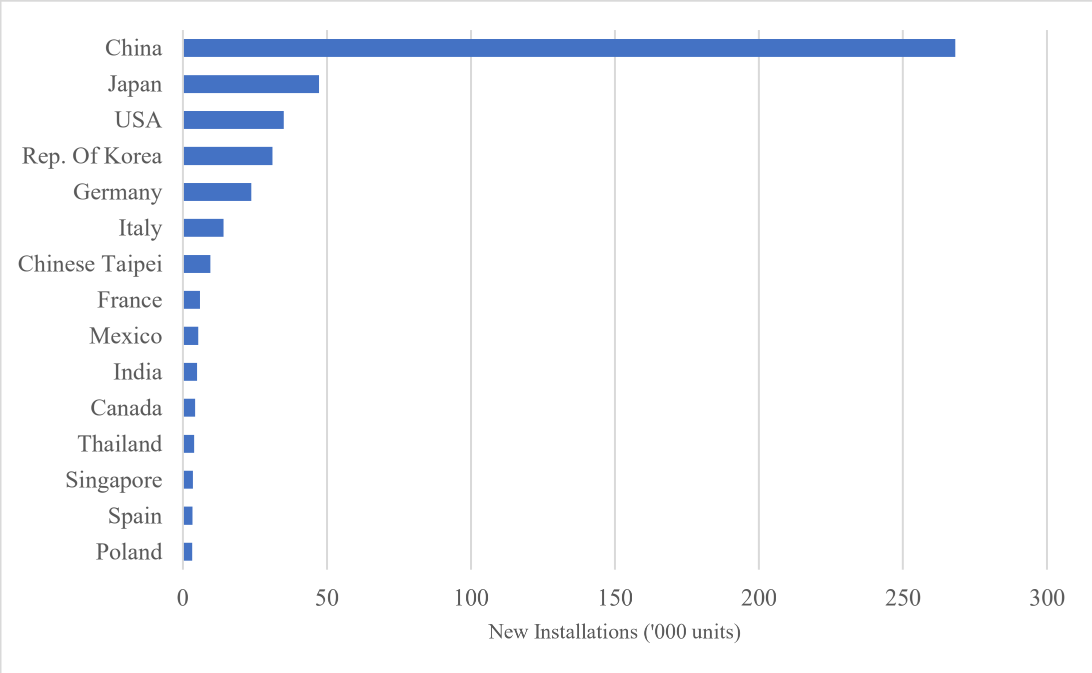


Figure 15. Annual installation of industrial robots by country. IFR World Robotics 2022.

The installation of robots in these economies is not only an industrial phenomenon but also a sign of a broader transformation that includes infrastructure upgrading, increasing technological skills of the workforce, and adopting more advanced production practices.

3.1.6 Annual implementation of industrial robotics systems by Country (2011-2021)

The detailed examination of annual installations of industrial robots from 2011 to 2021 reveals significant dynamics signalling a notable shift in global production power and an accelerated adoption of robotics in specific regions. These elements emerge clearly through the analysis of the data presented in the Table 9. Annual installation of industrial robots China vs World (2011-2021)Table 9 and **Figure 16**.

Year	**China** [units]	**Rest of World** [units]
2011	268,000	195,000
2012	178,000	132,000
2013	148,000	149,000
2014	155,000	170,000
2015	156,000	148,000
2016	97,000	137,000
2017	69,000	128,000
2018	57,000	106,000
2019	37,000	93,000
2020	23,000	92,000
2021	23,000	108,000

Table 9. Annual installation of industrial robots China vs World (2011-2021). IFR World Robotics 2022

At the beginning of the observation period in 2011, industrial robot installations in China and the rest of the world were essentially comparable, with China recording 23,000 units compared to 108,000 for the rest of the world. However, starting in 2013, there was significant growth in the adoption of industrial robotics by China, which surpassed the rest of the world by a considerable margin. This phenomenon is attributed to the rapid industrialization underway in the Asian country and its strategic commitment to integrating advanced technologies into its production sectors.

The discrepancy between Chinese installations and those of the rest of the world further widened from 2016, when China totalled 97,000 installations compared to 137,000 for the rest of the world. This gap widened even more in 2021, when China recorded an extraordinary number of 268,000 installations, far surpassing the 195,000 units of the rest of the world.

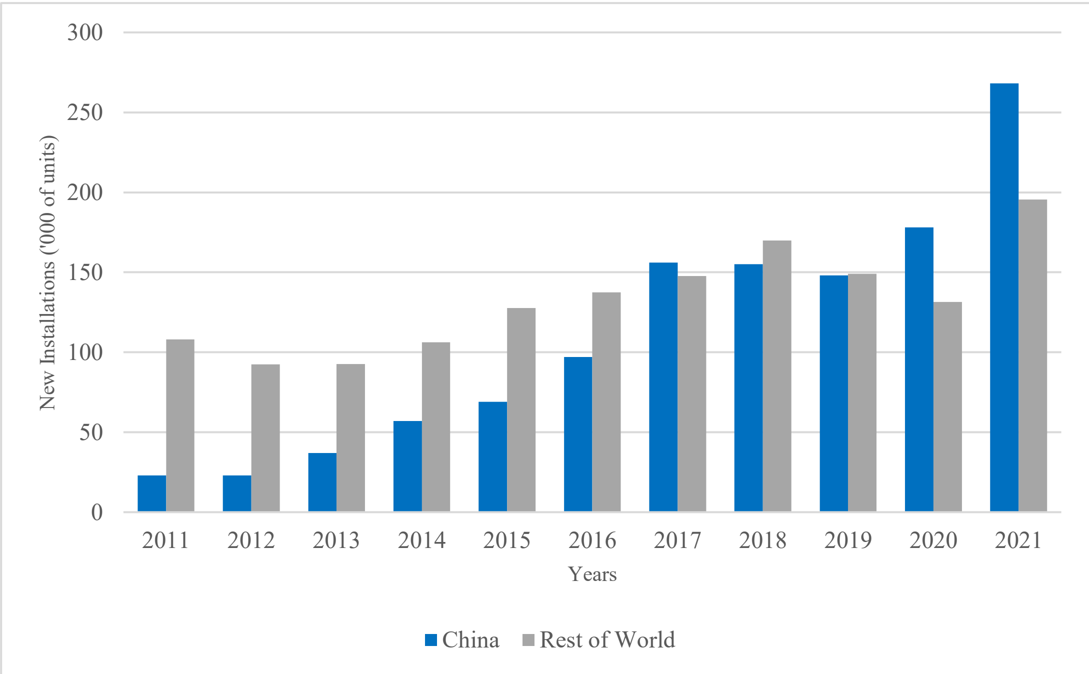


Figure 16. Annual installations of industrial robots China vs World (2011-2021).
IFR World Robotics 2022

On the other hand, the rest of the world showed overall steady growth, with some fluctuations, highlighting, for example, a peak of 170,000 units in 2018 and a slight contraction in both 2019 and 2020, followed by a recovery in 2021. These oscillations reflect global economic dynamics, including the impacts of macroeconomic events and the variable responses of different economies to the challenges of global markets.

3.1.7 Industrial robotics systems installed per 10.000 employees

Table 10 and **Figure 17** below provide an overview of the density of industrial robots per 10,000 employees in the major global economies. This density indicator plays a significant role in evaluating a country's degree of automation within the manufacturing context, highlighting the rapid transformation of industry towards automated systems.

Country	**Density** [units/10,000]
Rep. Of Korea	932
Singapore	605
Japan	390
Germany	371
Sweden	289
Hong Kong	275
United States	255
Chinese Taipei	248
China	246
Denmark	246
Italy	224
Belgium	221
Netherlands	209
Austria	205
Spain	203
France	194
Slovenia	183
Switzerland	181
Canada	176
Slovakia	175
Czech Republic	162

Table 10 Density: Robots installed per 10.000 employees. IFR World Robotics 2022

The Republic of Korea emerges as the undisputed leader with a density of 932 robots per 10,000 employees. This primacy is not surprising, given South Korea's historically dominant role in the adoption of robotics, especially in the highly advanced automotive industry, and thanks to government policies oriented towards technological improvement.

Singapore ranks second with a density indicator of 605, which testifies to its transition from a global financial centre to a high-tech production centre. Singapore's position gains further relevance considering its limited geographic size and traditional dependence on services. Japan and Germany, with densities of 390 and 371 respectively, represent traditional powers in the field of advanced manufacturing. Their position in the ranking reflects their constant commitment to automation and innovation, with sectors such as automotive and electronics leading the adoption of advanced robotics. Sweden and Hong Kong, with densities of 289 and 275 respectively, demonstrate how even smaller economies are quickly embracing automation in order to preserve their competitiveness at a global level.

In the United States, China, and the remaining European countries, levels of industrial robot density are significantly lower when compared to those found in the Republic of Korea and Singapore.

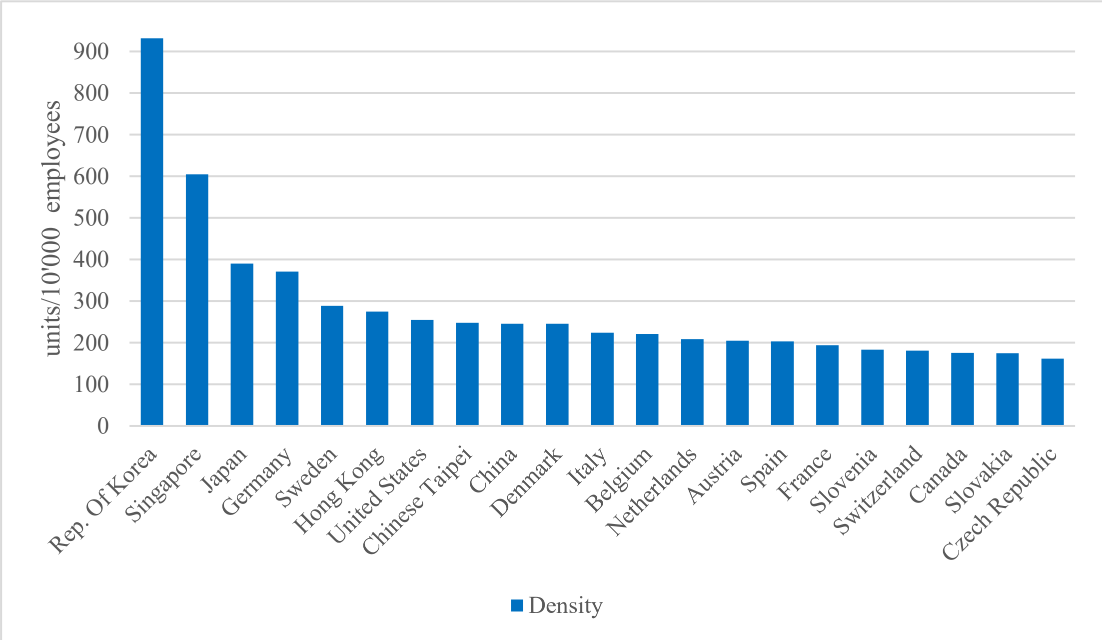


Figure 17. Robots installed per 10.000 employees.
IFR World Robotics 2022

In fact, despite the United States being one of the world's largest economies, its robot density, at 255, underscores the importance of considering the diversity of the US industrial sector, ranging from highly automated sectors such as the automotive industry to less mechanized ones. China, which has experienced exponential growth in the adoption of robotics in recent years, as evidenced by the data, with a slightly lower density (around 250), testifies to the continued significant amount of work performed by humans. Similarly, countries such as Italy, Belgium, the Netherlands, and Austria have densities ranging from 200 to 230, confirming the steady adoption of robotics, albeit with a strong presence of non-automated industries.

3.2 Industrial robotics deployment - Italy

3.2.1 Annual implementation of industrial robotics systems – Italy

The Italian industry in the field of robotics and automation has experienced significant evolution beginning in the 1970s. In this context, it is important to highlight that most companies in Italy are characterized by small or medium size and low levels of vertical integration. However, these companies demonstrate excellent flexibility and a ability to adapt to the specific requirements of their clients, as well as proficiency in providing highly customized products.

The absence of high vertical integration in these companies is effectively compensated through an extensive network of interrelations within the productive districts, where the sector is organized, and through inter-company cooperation in research and support areas. These aspects significantly contribute to maintaining high standards of quality in production.

The data presented in Table 11 provides an overview and trends of automation in the Italian manufacturing industry. The **Figure 18** represents the trend of annual installations of industrial robots from 2011 to 2021 in the country. In 2011, the number of installations in Italy is 4,056 units, but it underwent a contraction of 14% the following year, dropping to 4,402 units in 2012. This decrease is explained by economic uncertainties of the period with a consequent reduction in investments in technology. However, from 2013 onwards, there was a return to the increase in installations, with some variations along the way. In 2013, the number of installations rose to 4,701 units, recording a 7% increase. In 2014, there is a significant increase of 32%, with a total of 6,215 units. This positive trend continues in the following years, with a growth of 7% in 2015, but it underwent a slight contraction of 3% in 2016.

Year	Units	Year-on-year
2011	5,091	
2012	4,402	-14%
2013	4,701	7%
2014	6,215	32%
2015	6,657	7%
2016	6,465	-3%
2017	7,760	20%
2018	9,847	27%
2019	11,089	13%
2020	8,525	-23%
2021	14,100	65%

Table 11. Annual installations of industrial robots – Italy. IFR World Robotics 2022.

In 2018, the upward trajectory persisted, as the number witnessed a substantial rise of 27%, culminating in a total of 9,847 units. However, the growth rate again tracks a decline in 2019, with an increase of 13% and a total of 11,089 installations. In 2020, the COVID-19 pandemic presented unexpected challenges, leading to a decrease of 23%

in installations, which drop to 8,525 units. This reduction is clearly linked to the global impact, which mainly caused disruptions in supply chains and a temporary closure of factories.

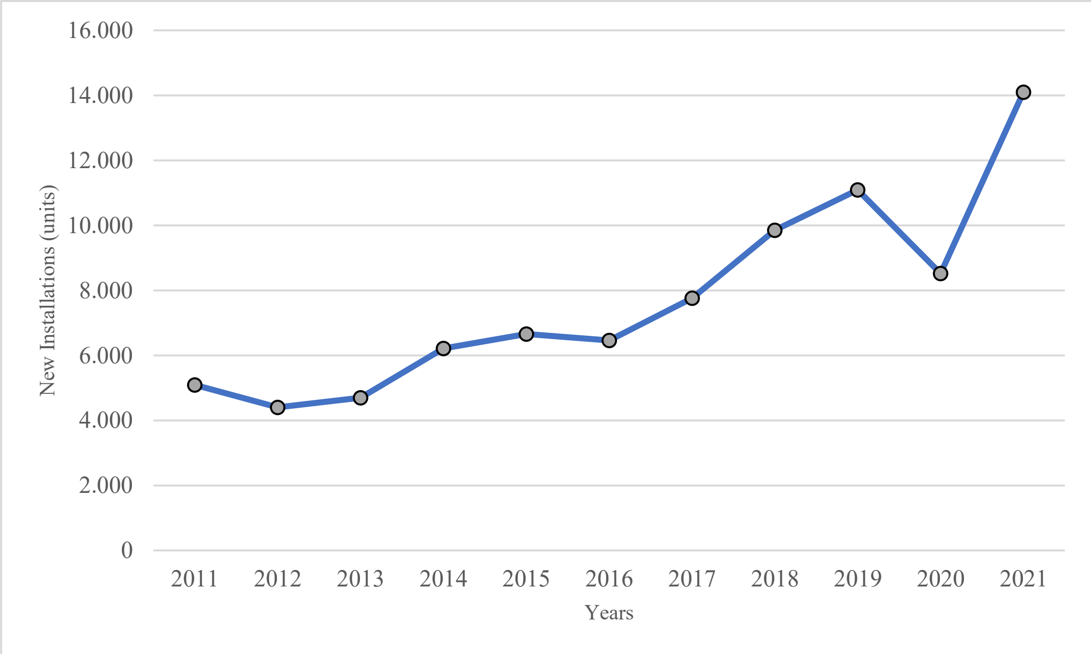


Figure 18. Annual installations of industrial robots – Italy
IFR World Robotics 2022

2021 is characterized by a remarkable recovery, with a significant increase of 65%, bringing the total of installations to 14,100 units. This is the result of a rebound effect, with companies resuming and accelerating investments in automation to reduce dependence on physical human labour.

3.2.2 Annual implementation of industrial robotics systems – Italy

The data presented in **Figure 19** reflects the annual installations of industrial robots in various applications throughout Italy from the years 2019 to 2021. The applications covered include Handling, Welding, Assembling, Dispensing, Processing, and other unspecified categories.

Application	**2019** [units]	**2020** [units]	**2021** [units]	**(2019-2021)**
Handling	50,274	53,128	61,515	22%
Welding	9,884	9,681	10,566	7%
Assembling	5,444	5,939	6,860	26%
Dispensing	1,981	1,951	2,035	3%
Processing	2,060	2,192	2,331	13%
All others	802	978	1,235	54%
Unspecified	3,975	4,283	4,788	20%

Table 12. Annual installations of industrial robots by application – Italy. IFR World Robotics 2022

In detail, the Handling application has recorded a marked increase: starting from 50,274 units installed in 2019, it reached 53,128 in 2020, and 61,515 in 2021. This indicates not only the highest demand for automation but also the highest annual growth rate, a sign of a rapidly expanding sector. Installations in the Welding application have shown slight fluctuations, decreasing slightly in 2020 to 9,681 units compared to 9,884 in 2019, before rising to 10,566 in 2021. This variation is the result of a combination of factors, including contingent market conditions.

The Assembling application, essential for mass production, has also show progressive growth: 5,444 robots in 2019, 5,939 in 2020, and 6,860 in 2021. This increase confirms the increasing importance and applicability of automation in assembly lines.

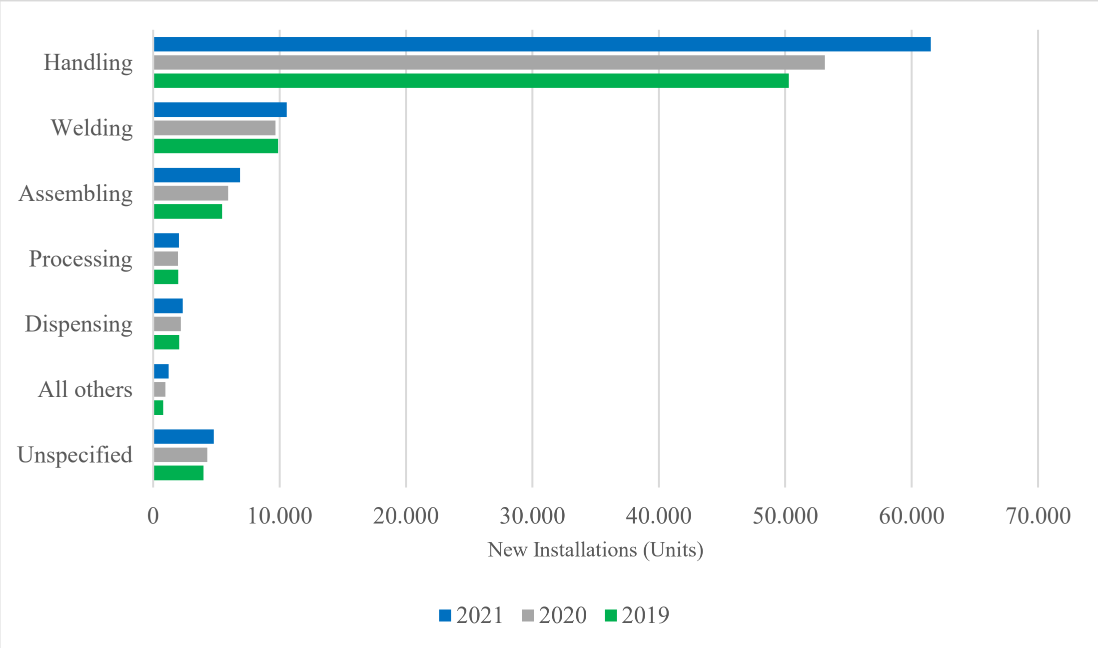


Figure 19. Annual installations of industrial robots by application – Italy
IFR World Robotics 2022

Regarding Dispensing, which includes dosing and application of materials, the numbers have grown modestly but steadily, from 1,981 to 2,035, passing through 1,951 in the triennium under consideration. Although these numbers are more contained than other categories, the positive trend is an indicator of constant interest. Processing, which includes processes such as cutting and processing materials, has shown a consistent growth trend, from 2,060 to 2,331 through 2,192. This sector, vital for the transformation of raw materials, is confirmed to be expanding.

By grouping the "Other" and "Unspecified" categories, an even more significant increase is observed, from a total of 4,777 installations in 2019 to 6,023 in 2021. This jump demonstrates a growing interest in innovative and versatile robotics applications, some of which could represent emerging areas of automation or sectors that have been less explored until now.

3.2.3 Annual implementation of industrial robotics systems – Italy

Table 13 represent the annual installations of industrial robots by customer industry in Italy over a three-year period from 2019 to 2021. Each row shows a different industry sector with the number of installations for each year and the percentage change over the three-year period.

Industry	2019 [units]	2020 [units]	2021 [units]	(2019-2021)
Automotive	12,958	13,206	13,899	7%
Electrical/Electronics	1,846	2,096	2,436	32%
Food	8,538	9,114	9,961	17%
Metal and machinery	19,517	20,046	22,248	14%
Plastic and chemical products	8,879	8,870	9,285	5%
All others	4,936	5,636	6,683	35%
Unspecified	17,746	19,184	24,818	40%

Table 13. Annual installations of industrial robots by customer industry – Italy. IFR World Robotics 2022.

Figure 20 shows an overall trend of increase, with some industries experiencing significant growth and others more moderate.

In the Automotive industry, a steady growth is observed: starting from 12,958 installations in 2019, it reaches 13,899 in 2021, corresponding to a 7% increase. This phenomenon suggests the presence of a mature market that has already implemented robotics solutions in previous years, as well as a progressive adaptation to automation technologies. The Electrical/Electronic sector records a significant increase of 32%, with a jump from 1,846 installations in 2019 to 2,436 in 2021. This data is a clear indication of a sector in rapid evolution and strong expansion towards advanced automation systems. For the Food industry, the increase is 17%, going from 8,538 installations in 2019 to 9,961 in 2021. In this case too, the data reflects a growing interest in automation to ensure high standards in food production.

The Metals and Machinery sector shows an increase of 14%, growing from 19,517 installations in 2019 to 22,248 in 2021. This traditional sector maintains a sustained growth rate, integrating new robotics technologies into production processes. The plastic and chemical Products industry signs a more modest growth of 5%, with a slight stall between 2019 and 2020, but then an increase that brings it to 9,285 installations in 2021. The caution in this sector may be due to various factors, particularly the complexity of robotics integration in chemical processes.

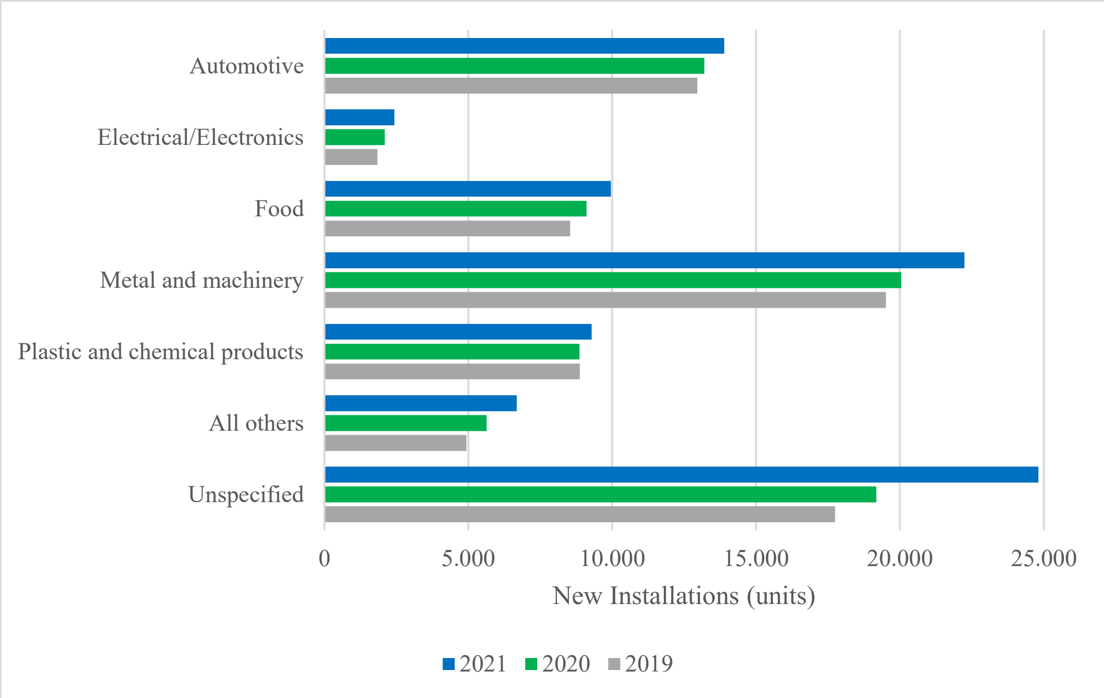


Figure 20, Annual installations of industrial robots by customer industry – Italy
IFR World Robotics 2022.

Finally, the Other Industries and Unspecified categories show the highest growth trends: the former grow by 35%, going from 4,936 installations in 2019 to 6,683 in 2021, while the latter even by 40%, with a jump from 17,746 installations in 2019 to 24,818 in 2021. These numbers indicate a growing cross-cutting adoption of robotics in emerging or diversified sectors, as well as an increase in applications in undefined or new market niches.

3.3 Cobots

3.3.1 Annual implementation of Collaborative Robotics systems - World

Figure 21 displays the sales values comparing traditional robots and collaborative robots in the period from 2017 to 2021. During this time frame, a scenario emerged where traditional robots maintained a predominance in terms of overall volume of installations. Nevertheless, a gradual erosion of this dominance was observed in favour of a more rapid increase in the units of collaborative robots.

Year	**Traditional** [units]	**Collaborative** [units]
2017	389,000	11,000
2018	405,000	19,000
2019	370,000	21,000
2020	368,000	26,000
2021	478,000	39,000

Table 14. Collaborative vs Traditional industrial robots installations. IFR World Robotics 2022.

In detail, in the 2017-2018 period, there is a relatively modest increase in installations of traditional robots, amounting to a growth of 4.1%. In stark contrast, the collaborative robot segment experienced a significantly more pronounced expansion, with a growth rate of 72.7%. This phenomenon represents an indicator of rising interest in collaborative robots, although starting from a base of initially limited new installations.

Between 2018 and 2019, as previously illustrated, there is a contraction in the sales of traditional robots. In opposition to this trend, collaborative robots continued on their growth path, with an increase of 10.5%, further confirmed in the following year when collaborative robots continued to demonstrate their innovativeness, registering an increase of 23.8%.

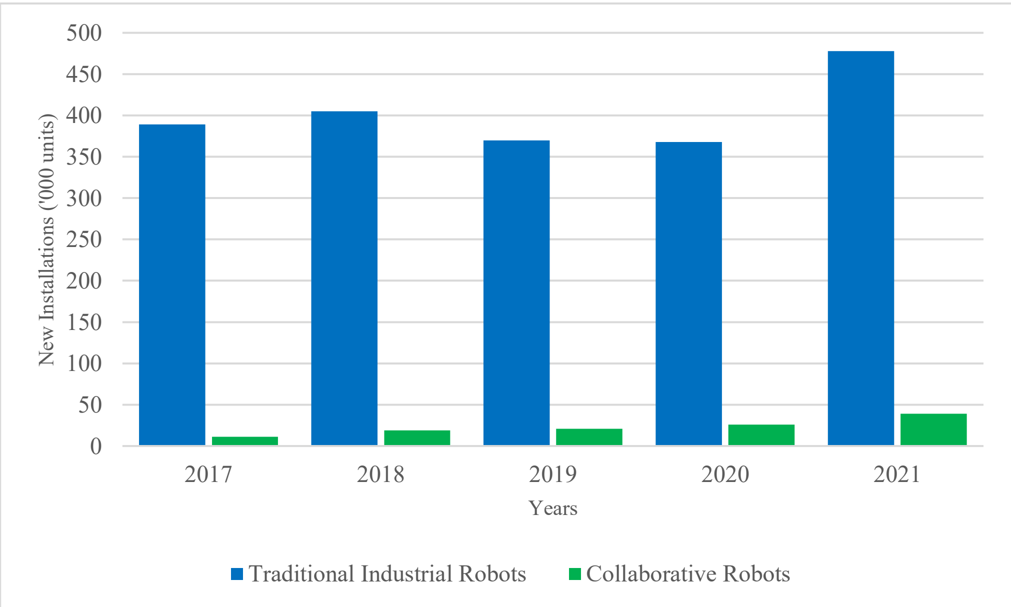


Figure 21. Collaborative vs Traditional industrial robots installations – World IFR World Robotics 2022.

The following year, 2021, characterized by a general post-pandemic recovery, saw both categories benefit from a significant increase in new installations: traditional robots with a growth of 29.9% and collaborative robots with an increase of 50%. Overall, it is observed that in the considered period, collaborative robots maintained a consistently higher annual percentage growth rate compared to their traditional counterparts, suggesting a rapidly evolving market and indicating a broader potential for change in the future of robotics technology.

Chapter 4

Robotics deployment for economic growth of the Province of Brescia

This chapter presents an analysis of the integration and impact of industrial robotics in the province of Brescia. It explores the corporate context of Brescia, focusing on the prominence of Limited Liability Companies (LLCs) and Corporations, and their roles in fostering a competitive and technologically advanced business environment. The chapter emphasizes the agility of SMEs in adapting to technological changes and market fluctuations, as well as the role of larger corporations in driving innovation and contributing to the skilled labour market. The analysis specifically targets companies operating in the mechanical discrete manufacturing sector of Brescia, examining the distribution of these companies and trends in employment. It highlights how robotics influences these dynamics, focusing on the role of robotics in enhancing productivity, quality, and operational efficiency within this specific industry. The study delves into the challenges these businesses face when integrating robotics technologies, including the need for specialized personnel and training, emphasizing the unique aspects and needs of the mechanical manufacturing sector. Furthermore, the chapter addresses the future vision of industrial robotics in Brescia, outlining potential plans for robotics installation and the hiring of specialized graduates in automation engineering. This forward-looking perspective underscores the growing significance of robotics in shaping the province's economic landscape and the need for continued adaptation and innovation in the face of technological advancements.

4.1 The scenario of research: the Province of Brescia

The province of Brescia currently occupies a position of significant economic prosperity within the Lombard and national landscape. This state of economic well-being has primarily been the result of substantial industrial development that occurred during the last decades of the past century. This growth was led by an extremely dynamic steel and metalworking sector, which saw the presence of large leading companies engaged in the production of a wide range of products, including household items, plumbing fixtures, stockings, clothing, valves, automotive components, and general mechanics. These companies also established supply networks with numerous local small and medium-sized enterprises, promoting their expansion.

However, in recent years, the province of Brescia has started experiencing signs of uncertainty due to the downsizing of heavy steel industry, decreased demand for metal products in the market, and the decline of the textile and clothing sector. These factors have hindered the process of economic diversification and the growth of advanced service sectors, prompting many businesses to seek traditional or high-tech services outside the province, towards Milan, Verona, and sometimes abroad, such as Switzerland, Germany, and France. Today, following the decline of the textile sector in the province, which has seen a drastic reduction in the number of employed compared to the 1990s due to outsourcing and the closure of numerous factories, Brescia's productive fabric is primarily based on the metalworking sector. This sector is characterized by a solid organization and collaborative relationships among companies, which are key elements of its competitiveness. In particular, sectors such as metal processing, mechanics, automotive, and agri-food host leading companies specialized in high-quality productions that position themselves in the medium-high market segment. These companies represent the main clientele of an extensive subcontracting system, mainly consisting of micro and small enterprises, which constitute the foundation of the local industry. The main companies in the province demonstrate a significant level of managerial and technical expertise, investing in innovations both at the product and process levels. In some areas of the province, new sectors are emerging, such as agritech, energy recovery, and nanotechnologies, although they do not yet constitute true production chains.

4.1.1 Corporate structures in Province of Brescia's economy

In the province of Brescia, the presence of 26,684 Limited Liability Companies (LLCs) employing 169,698 workers represents a prominent aspect of the entrepreneurial landscape, followed by a contingent of 881 Corporations (Corp) with 92,267 employees. This composition highlights the fundamental importance of small and medium-sized enterprises (SMEs) in the local economic fabric. LLCs stand out for their organizational flexibility and adaptability to changing market conditions. This type of corporate structure is often the preferred choice for startups and growing businesses due to its relatively easy formation process and lower administrative and bureaucratic burdens. This flexibility is particularly valuable in the current economic context, characterized by rapid technological changes and market fluctuations. The ease with which a corporation can adjust its structure and strategy allows it to respond promptly to emerging opportunities and potential risks, thereby ensuring greater resilience in uncertain economic scenarios.

Legal form	**Companies** [units]	**Employees** [units]
Private Limited Company (Ltd)	26,684	169,698
Corporation (Inc, Corp)	881	92,267
Cooperative (Co-op)	583	22,503
Other	221	1,364

Table 15. Legal form structure of the Province (AIDA - Bureau van Dijk).

On the other hand, the presence of a substantial number of Corporations underscores the diversity of Brescia's entrepreneurial ecosystem. Corporations are associated with larger-scale operations and the ability to actively operate in markets beyond the local context. These large corporate entities act as catalysts for innovation and growth, and their presence is indicative of a mature and developed economic environment. The presence of 881 Corporations in the territory of the Province of Brescia highlights a solid and robust base of larger enterprises, operating in capital-intensive sectors with a need for specialized skills. Corporations often serve as drivers of innovation and technological progress in the province, investing substantial sums in research and development. These investments not only promote scientific advancement but also position Brescia as a national and international centre of excellence in fields such as mechanical engineering, biotechnology, and information technology.

Corporations tend to be at the forefront of adopting and implementing new technologies and innovative methodologies, significantly contribute to the creation of skilled jobs and the formation of an acting as true catalysts for change. This pioneering role has a multiplier effect on the entire local economy, encouraging SMEs to follow the path of innovation and modernization. Furthermore, these large companies often serve as strategic partners for public institutions in infrastructure development and training projects, further consolidating their importance in the economic and social fabric of the province. In addition, Corporations highly specialized labour market. Thanks to their ability to attract talent and invest in training, they represent a critical factor in building a competitive and dynamic work ecosystem, which in turn attracts further foreign and national investments. The significant presence of Corporations in Brescia's corporate structure not only indicates a strong and diversified local economy but also serves as a fundamental pillar in supporting and promoting innovation, growth, and competitiveness on a broader scale. Therefore, the business structure in the province of Brescia represents a balance between the flexibility and agility of SMEs and the stability and resources of large corporations. This combination provides the province with resilience and competitiveness that distinguishes it in the Italian and European economic landscape.

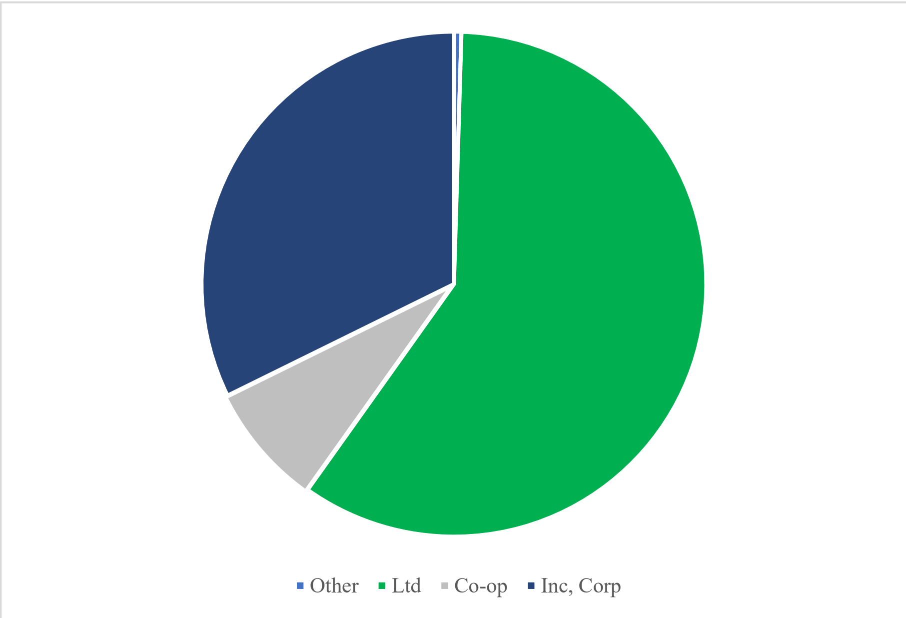


Figure 22. Employees distribution per company profile (2022).
AIDA - Bureau van Dijk

4.1.2 Operating companies and number of employees

The following text examines the various sectors that make a significant contribution to the local economy, highlighting both the number of companies operating in each sector and the number of workers employed. The manufacturing sector, which is the main pillar of Brescia's industrial economy, is represented by a substantial group of 4,890 enterprises, employing a workforce of 109,979 people. The prominence of this sector underscores the region's historical attachment to industrial production and its status as a manufacturing leader in Italy. Commercial activities, including wholesale and retail trade, as well as repair of motor vehicles and motorcycles, are crucial to Brescia's economy. With 4,448 companies and a workforce of 29,924 people, it shows a lively market for goods and services and a strong demand in the consumer sector. Rental, travel agencies, and business support services, is a segment that requires particular attention within the economic fabric of Brescia. Despite representing a smaller proportion of the total number of companies, 968, this sector is an important employer within the province, with a workforce of 28,328 people. From an economic standpoint, the substantial employment figure relative to the number of companies in this sector suggests that the services offered are labour-intensive, requiring a significant investment in human resources. The robust employment numbers reflect a high level of activity in business support services, which are necessary in a region with a dense concentration of manufacturing and commercial enterprises.

	ATECO	**Companies** [units]	**Employees** [units]
C	Manufacturing Activities	4,890	109,979
L	Real Estate Activities	4,502	2,133
G	Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	4,448	29,924
F	Construction	3,705	24,274
M	Professional, Scientific, and Technical Activities	2,354	8,278
I	Accommodation and Food Service Activities	1,392	16,423
N	Rental, Travel Agencies, and Business Support Services	968	28,328
J	Information and Communication Services	948	5,022
K	Financial and Insurance Activities	698	3,681
H	Transportation and Storage	601	8,789
R	Arts, Entertainment, and Recreation	482	2,433
Q	Health and Social Assistance	425	7,469
A	Agriculture, Forestry, and Fishing	366	2,533
S	Other Service Activities	285	2,553
D	Electricity, Gas, Steam, and Air Conditioning Supply	211	4,299
P	Education	188	1,733
E	Water Supply; Sewerage, Waste Management, and Remediation Activities	156	5,290
B	Mining and Quarrying	66	738
U	Extraterritorial Organizations and Bodies	1	0

Table 16.Operating Companies (AIDA - Bureau van Dijk).

Furthermore, the importance of this sector highlights the interconnected nature of Brescia's economy, where the facilitation of business operations, the enhancement of travel logistics, and the provision of essential rental services are inextricably linked to the industrial and commercial health of the region. Therefore, this sector does not operate in isolation, but contributes to the economic ecosystem by supporting other industries.

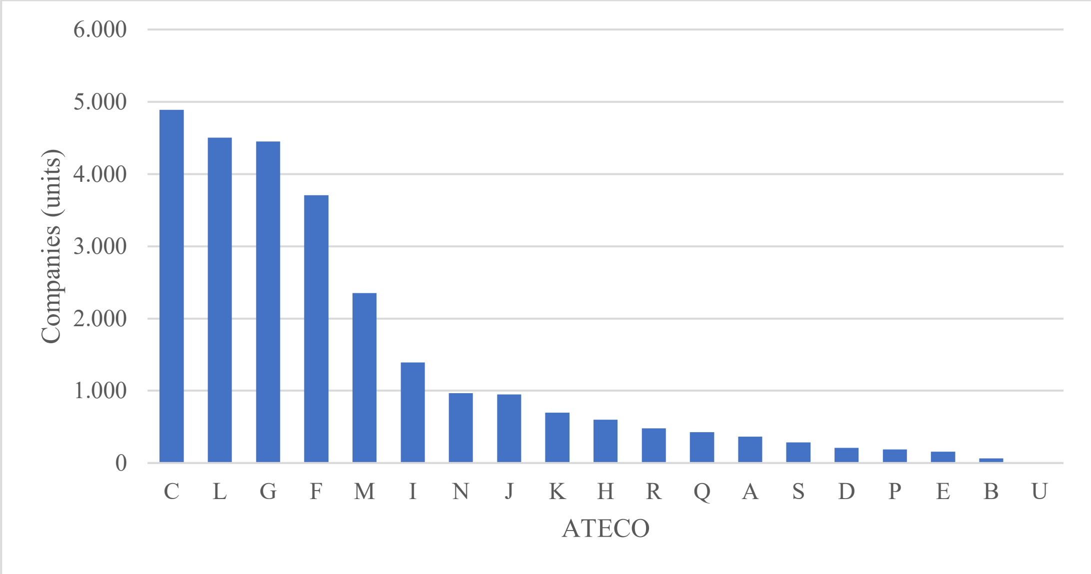


Figure 23. Operating Companies (2022).
AIDA - Bureau van Dijk

The real estate sector and the construction industry constitute a significant part of the regional economy, employing just over 26,000 workers. These numbers reflect a dynamic sector actively involved in defining the province's infrastructure and housing development, implying economic growth and urban expansion. Looking at the accommodation and food service industry, with 1,392 companies employing 16,423 people, we can see a well-established industry, with a growing cultural appeal and demonstrating its potential as a hospitality hub.

Moving on to professional, scientific, and technical activities, there are 2,354 companies that employ 8,278 workers. The nature of this sector is inherently diverse, encompassing a range of activities from legal and accounting services to architectural and engineering operations, technical testing, and analysis. The presence of these activities is indicative of an economy that values and invests in high-level competencies and knowledge-intensive services. It also reflects the region's alignment with global economic trends that increasingly favor industries reliant on intellectual capital over traditional manufacturing and labour-intensive industries. Moreover, the information and communication services sector, although smaller with 948 companies and 5,022 employees, suggests an emerging digital economy, which is essential for supporting the landscape towards digitalization.

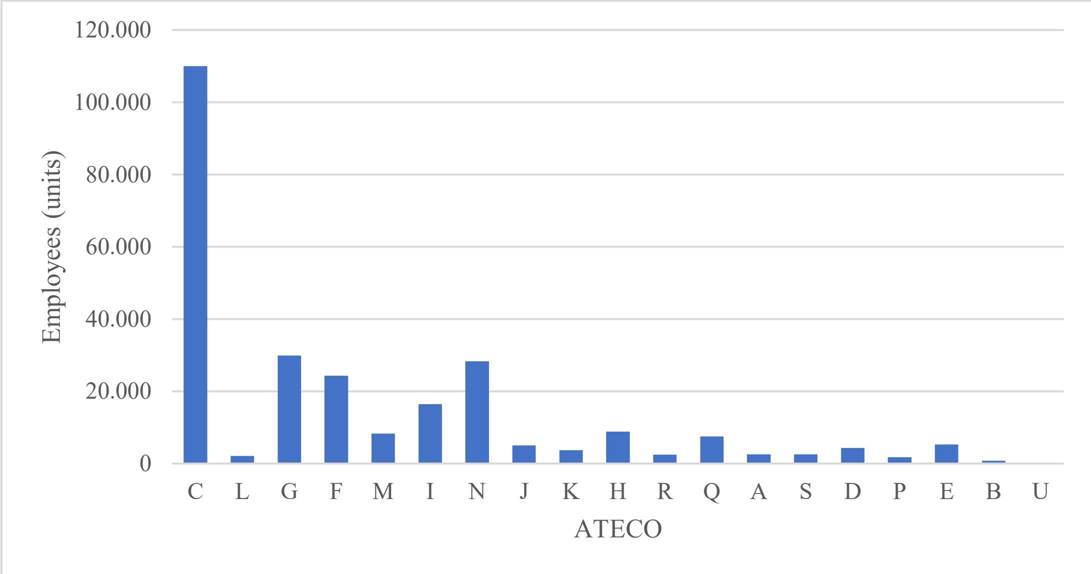


Figure 24. Number of employees (2022).
AIDA - Bureau van Dijk

The health and education sectors, with 425 and 188 companies respectively, employing 7,469 and 1,733 individuals in turn, represent the province's commitment to social infrastructure. These sectors contribute to the development of human capital and, by extension, support long-term growth and stability. Finally, in the context of utilities, the energy supply and water and waste management sectors, with 211 and 156 companies respectively employing 4,299 and 5,290 people, may seem modest in comparison. However, they are the linchpins of the province's infrastructural integrity, providing essential services that underpin all other economic activities.

4.1.3 Analysis of employee distribution trends

The analysis and comparison of the number of employees within an economic study context hold significant importance for several reasons. The quantification of employees in each industrial sector provides an immediate overview of the economic structure under examination, enabling the identification of leading and less developed sectors. Such an analysis allows for the delineation of an overview of the occupational composition within the study area. Furthermore, comparing data over time can reveal trends of growth or decline within various industrial sectors.

The observation of the last decade regarding the evolution of the number of employees in the different economic sectors of Brescia, as classified by the ATECO system, offers highly relevant analytical insights. Below, in **Figure 25**, are presented employment data representing 85% of the total employed population of the province, divided into their respective sectors. Using the year 2013 as the base, the manufacturing sector has registered a consistently growing index, increasing from the unitary reference of 2013 to 1,50 in 2022, reflecting a 50% increase during the decade. This increase is not simply the result of a strong industrial legacy that perpetuates over time. Instead, it is the result of a combination of factors that include resilience, agility, and innovation, demonstrating how the sector has been able to adapt and thrive in a rapidly evolving economic and technological context. This sustained growth in the number of employees is the expression of a series of dynamics internal and external to the sector. Internally, the continuous modernization of production processes, the adoption of advanced technologies, and the promotion of research and development activities have been decisive. Externally, a favourable regulatory framework, accompanied by public policies that have stimulated investment in physical and human capital, has created an ecosystem favourable to growth and expansion.

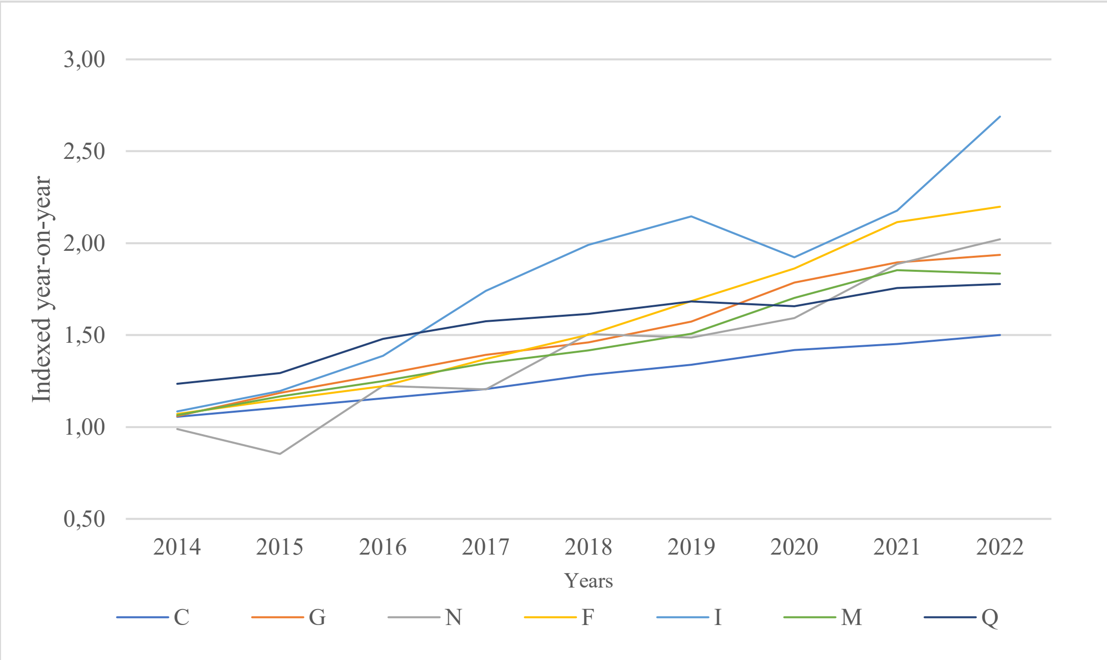


Figure 25. Trend in the number of employees
AIDA - Bureau van Dijk

The resilience and vitality of the manufacturing sector also have implications that transcend sectoral boundaries. The employment growth in this area has generated an incremental demand for intermediate goods and services, thus stimulating other sectors of the economy. This phenomenon, known as the multiplier effect, has had a positive impact on various sectors, from logistics and distribution services to specialized professional services such as engineering and design.

The upward trend in the number of employees in the manufacturing sector during the last decade is not only an indicator of the sector's robustness but also serves as a barometer of the overall economic health of the province of Brescia. It shows a reality where economic challenges have been transformed into opportunities, driving not only the growth of the sector itself but also contributing to the dynamism of the entire provincial economic ecosystem.

	ATECO	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
C	Manufacturing Activities	1.00	1.06	1.10	1.16	1.21	1.28	1.34	1.42	1.45	1.50
G	Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	1.00	1.06	1.19	1.29	1.39	1.46	1.57	1.79	1.90	1.94
N	Rental, Travel Agencies, and Business Support Services	1.00	0.99	0.85	1.22	1.20	1.50	1.49	1.59	1.89	2.02
F	Construction	1.00	1.07	1.15	1.22	1.37	1.50	1.68	1.86	2.11	2.20
I	Accommodation and Food Service Activities	1.00	1.08	1.20	1.39	1.74	1.99	2.15	1.92	2.18	2.69
M	Professional, Scientific, and Technical Activities	1.00	1.06	1.17	1.25	1.35	1.42	1.51	1.70	1.85	1.83
Q	Health and Social Assistance	1.00	1.23	1.29	1.48	1.57	1.61	1.68	1.66	1.76	1.78

Table 17.Trend in the number of employees (AIDA - Bureau van Dijk).

It is not just the manufacturing sector that has shown a positive evolution. Even wholesale and retail trade has seen a sustained increase in the number of employees, going from the unitary base of 2013 to a substantial doubling in 2022. In the services sector, such as rental, travel agencies, and business support services, volatility has been observed. After a decline in 2015, the index grew rapidly, particularly from 2019 to 2022, increasing from 1.59 to 2.02, indicating a strong recovery and expansion in related services. Similarly, in the construction sector, the index has more than doubled, signalling solid and sustained growth over time, reflecting consistently high demand in the construction industry. The accommodation and food service industry has experienced an irregular trend, undergoing a significant contraction in 2020, with a decrease in the index from 2.15 to 1.92, presumably due to the COVID-19 pandemic that has impacted tourism and restaurants. However, a significant recovery has emerged in the following years, reaching a peak of 2.69 in 2022, suggesting a vigorous post-pandemic recovery.

4.1.4 Value of production

Below are analysed the data related to the value of production generated by each individual sector of activity, as presented in **Figure 26**. At the top of the pyramid is the manufacturing sector, with a production value of 48,573 million of euro. This indicator testifies to the importance of the manufacturing industry for the economy of Brescia, highlighting its industrial tradition. The sector of electricity, gas, steam, and air conditioning supply follows with a production value of 22,407 million of euro, reflecting the strong demand for energy from the province's infrastructure. Wholesale and retail trade, along with the repair of motor vehicles and motorcycles, are valued at 24,967 million of euro, highlighting the importance of these commercial activities that constitute a pillar for the local economy, stimulating consumption and employment.

Construction represents another key sector, with a production value of 6,995 million of euro, confirming a dynamic construction activity and infrastructure investments. Less extensive but no less important are the sectors of water supply, waste management, and remediation services, which together contribute 2,560 million of euro, highlighting attention to the quality of environmental services and sustainability.

Transport and storage contribute 2,326 million of euro, a figure that reflects the strategic relevance of logistics in an industrialized and export-oriented province like Brescia.

	ATECO	[‘000 €]
A	Agriculture, Forestry, and Fishing	761,197
B	Mining and Quarrying	319,366
C	Manufacturing Activities	48,573,858
D	Electricity, Gas, Steam, and Air Conditioning Supply	22,407,185
E	Water Supply; Sewerage, Waste Management, and Remediation Activities	2,560,092
F	Construction	6,995,932
G	Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	24,967,156
H	Transportation and Storage	2,326,333
I	Accommodation and Food Service Activities	1,365,303
J	Information and Communication Services	878,532
K	Financial and Insurance Activities	927,839
L	Real Estate Activities	1,237,294
M	Professional, Scientific, and Technical Activities	1,599,937
N	Rental, Travel Agencies, and Business Support Services	1,745,479
P	Education	156,377
Q	Health and Social Assistance	642,608
R	Arts, Entertainment, and Recreation	305,482
S	Other Service Activities	234,742

Table 18.Value of Production (AIDA - Bureau van Dijk).

Agriculture, forestry, and fishing, although in a more modest position than other sectors, are not to be underestimated, with a value of 761 million of euro, denoting the importance of these primary sectors for the economy and the territory.

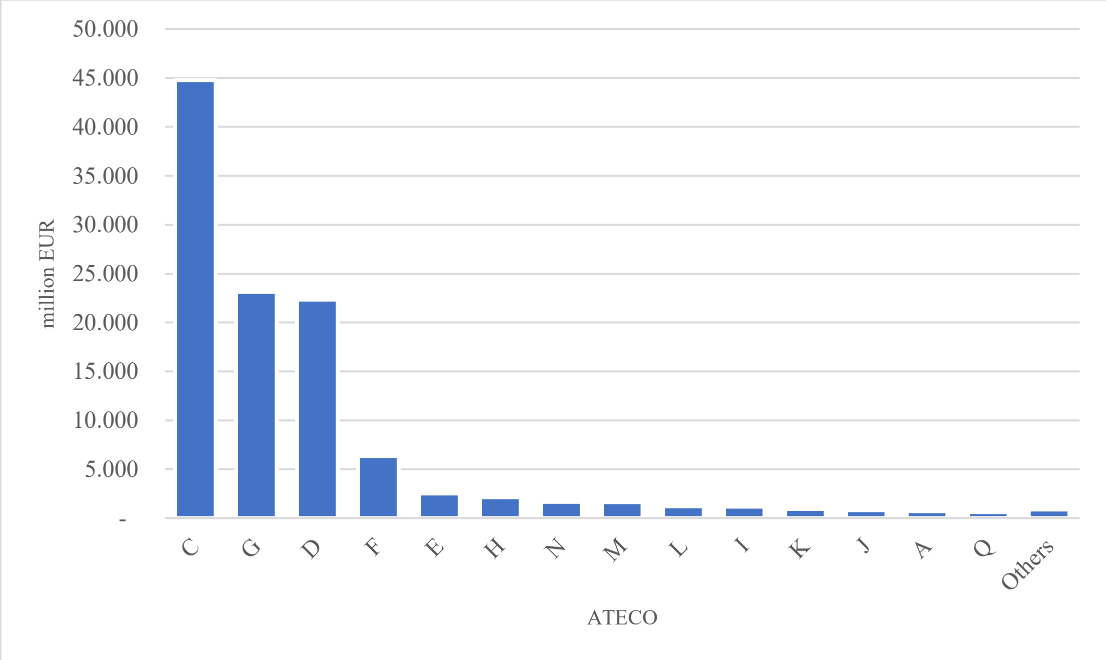


Figure 26. Value of Production (2022).
AIDA - Bureau van Dijk

Other sectors that complete the provincial economic picture include accommodation and food service activities with 1,365 million of euro, information and communication services with 878 million of euro, financial and insurance activities with 927 million of euro, and real estate activities with 1,237 million of euro. These sectors, together with professional, scientific, and technical activities with 1,599 million of euro, rental and business support services with 1,745 million of euro, education 156 million of euro, health and social assistance with 642 million of euro, and arts, entertainment, and recreation activities 305 million of euro, reflect the diversity of the economy of Brescia.

	ATECO	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
C	Manufacturing Activities	1.00	1.04	1.07	1.10	1.23	1.36	1.37	1.25	1.71	2.03
G	Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	1.00	1.08	1.18	1.30	1.52	1.67	1.70	1.67	2.14	2.48
F	Construction	1.00	1.05	1.10	1.20	1.37	1.53	1.71	1.74	2.38	2.98
E	Water Supply; Sewerage, Waste Management, and Remediation Activities	1.00	0.98	0.97	1.01	1.18	1.30	1.33	1.34	1.75	1.94
H	Transportation and Storage	1.00	1.11	1.21	1.32	1.54	1.70	1.78	1.85	2.36	2.70
M	Professional, Scientific, and Technical Activities	1.00	1.04	1.18	1.32	1.46	1.47	1.46	1.46	1.66	1.70

Table 19. Value of production trend (AIDA - Bureau van Dijk).

The Manufacturing sector has shown consistent growth in the period from 2013 to 2022. Starting from a base index of 1.00 in 2013, there was a gradual increase, reaching 1.23 in 2017, followed by a further rise to 1.36 in 2018. The growth rate experienced a slight dip in 2019, decreasing to 1.37, before further declining to 1.25 in 2020, due to the impacts of the pandemic. However, the sector exhibited a strong recovery in the two subsequent years, with an index rising to 1.71 in 2021 and peaking at 2.03 in 2022.

Similarly, the Wholesale and Retail Trade sector has recorded consistent growth. Starting from a base value of 1.00 in 2013, it increased to 1.52 in 2017 and then to 1.67 in 2018. The index maintained a level of 1.70 in 2019, experienced a slight decrease to 1.67 in 2020, and then resumed growth in the following years, with a jump to 2.15 in 2021 and a further increase to 2.48 in 2022. The Construction sector exhibited a consistent upward trend throughout the examined period. Starting from a base index of 1.00 in 2013, it saw a gradual increase, reaching 1.38 in 2017 and 1.53 in 2018. Subsequently, there was sustained growth, leading to 1.71 in 2019, followed by a slight increase to 1.74 in 2020. The growth was notably stronger in the last two years, with the index reaching 2.39 in 2021 and 2.98 in 2022.

The Waste Management and Remediation Activities sector (Sector E) followed a slightly different pattern. After a slight decline from 1.00 in 2013 to 0.97 in 2015, the sector began to grow, reaching 1.18 in 2017 and 1.30 in 2018. The growth continued, with the index reaching 1.34 in 2020 and seeing further increases to 1.75 in 2021 and 1.94 in 2022. One of the key drivers of growth in this sector has been the increasing awareness of environmental issues and the need for sustainable solutions. Governments and businesses have invested in technologies and practices that reduce waste and pollution, leading to an increased demand for companies offering waste management and remediation services.

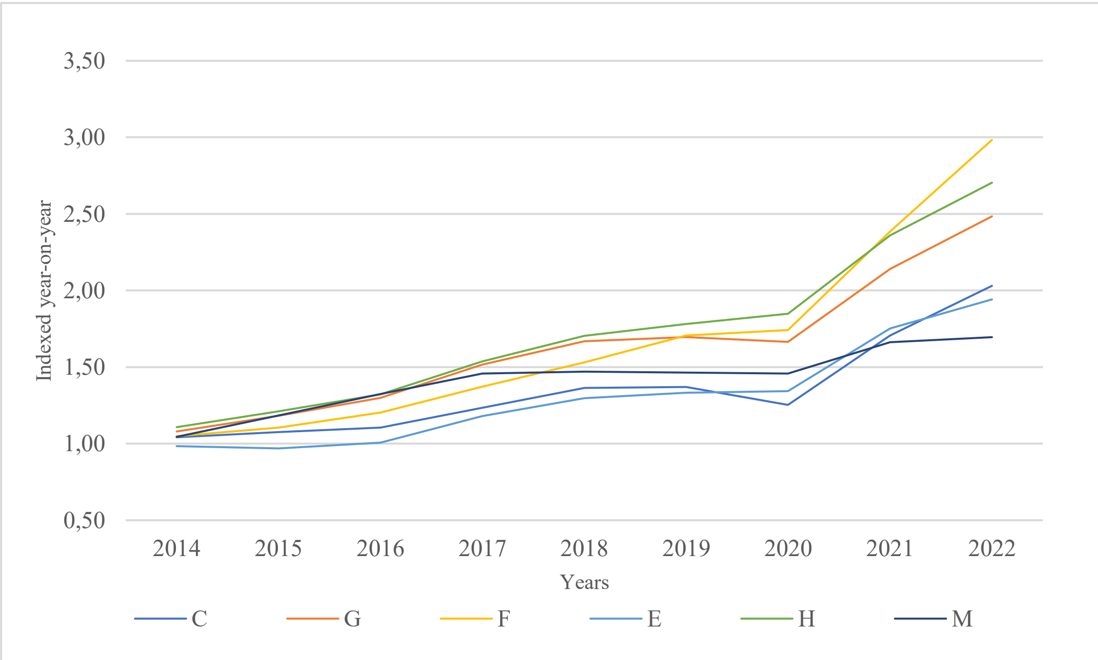


Figure 27. Value of production trend.
AIDA - Bureau van Dijk

The Transportation and Warehousing sector showed consistent growth. Starting from a base index of 1.00 in 2013, it experienced an increase to 1.55 in 2017 and 1.71 in

2018. There was continuous growth, reaching 1.86 in 2020, followed by a significant jump to 2.37 in 2021 and a further increase to 2.70 in 2022.

In conclusion, the Professional, Scientific, and Technical Activities sector (Sector M) exhibited a relatively stable trend. After an increase from 1.00 in 2013 to 1.46 in 2017, the index remained almost unchanged at 1.47 in both 2018 and 2019. In 2020, there was a slight decrease to 1.46, followed by a subsequent increase to 1.67 in 2021 and 1.70 in 2022.

4.1.5 Economic Value Added

The concept of value added constitutes a fundamental indicator in the economic analysis of a specific industrial sector or a particular enterprise, playing a relevant role in understanding income generation within an economic area. This parameter represents the difference between the total value of products or services generated by a company, or an economic sector and the costs incurred for acquiring the necessary production factors, such as materials, labour, and services. In other words, value added can be defined as the net contribution provided by a company or a sector to the economy, obtained by subtracting the costs associated with production factors from the total value of sales or revenues generated.

	ATECO	**[‘000 €]**
A	Agriculture, Forestry, and Fishing	154,422
B	Mining and Quarrying	114,151
C	Manufacturing Activities	10,828,836
D	Electricity, Gas, Steam, and Air Conditioning Supply	976,882
E	Water Supply; Sewerage, Waste Management, and Remediation Activities	759,094
F	Construction	1,866,431
G	Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	2,532,729
H	Transportation and Storage	706,948
I	Accommodation and Food Service Activities	502,529
J	Information and Communication Services	375,100
K	Financial and Insurance Activities	696,524
L	Real Estate Activities	402,585
M	Professional, Scientific, and Technical Activities	474,456
N	Rental, Travel Agencies, and Business Support Services	980,517
P	Education	69,411
Q	Health and Social Assistance	265,019
R	Arts, Entertainment, and Recreation	90,294
S	Other Service Activities	99,607

Table 20. Economic Value Added (AIDA - Bureau van Dijk).

In the specific context of the Province of Brescia, manufacturing activities emerge as a critically relevant component within the economic landscape. With a total value of 10,828 million euro, as presented in **Figure 28**, the manufacturing sector confirms its position as a fundamental pillar of the provincial economy. The production of goods through the use of machinery, equipment, and a workforce represents an essential driver for economic development, as evidenced by its significant contribution to the overall economic value. This contribution not only reflects the productive efficiency of businesses but also indicates substantial demand at both the national and international levels for manufactured products. Manufacturing itself is divided into various subcategories, including the automotive, electronics, textile, food, and mechanical industries, each of which plays a distinct role in the economic panorama. Furthermore, it should be emphasized that the manufacturing sector is closely interconnected with other components of the economy, such as transportation and warehousing, the supply of electricity and gas, and professional, scientific, and technical activities, thus significantly contributing to their development.

Subsequently, the retail trade sector emerges with a value added of 2,532 million euro, ranking second in terms of value creation. This sector plays a crucial role in the distribution of goods to end consumers, serving as an essential link between producers and consumers themselves. The value added in retail trade stems from its ability to enhance the value of goods acquired from producers through selection and offering processes, thereby increasing their overall value. These activities not only contribute to the monetary value of products but also improve their accessibility and desirability among consumers. The diversity of formats and business models within the retail trade sector is a significant aspect to consider, as it encompasses a wide range of entities, from large supermarket chains to small independent stores, each of which adopts its own value delivery model. With technological advancement, e-commerce has further expanded the reach and effectiveness of this sector. The construction sector, with a value added of 1,866 million of euro, encompasses a wide range of activities, including residential and commercial construction, public infrastructure such as roads, bridges, and water systems, as well as large civil engineering projects. This diversification confers a central role on the sector in various aspects of the economy and society. Value added in this sector emerges through the process of transforming raw materials into functional and habitable structures. This process not only generates value through the physical construction of buildings and infrastructure but also substantially contributes to the growth of the surrounding territory, as each phase of construction entails a series of economic transactions that further stimulate the economy. Every euro invested in construction generates additional economic activity in related sectors, such as manufacturing (for building materials and equipment), wholesale and retail trade (for material sales), and professional services (such as engineering and design).

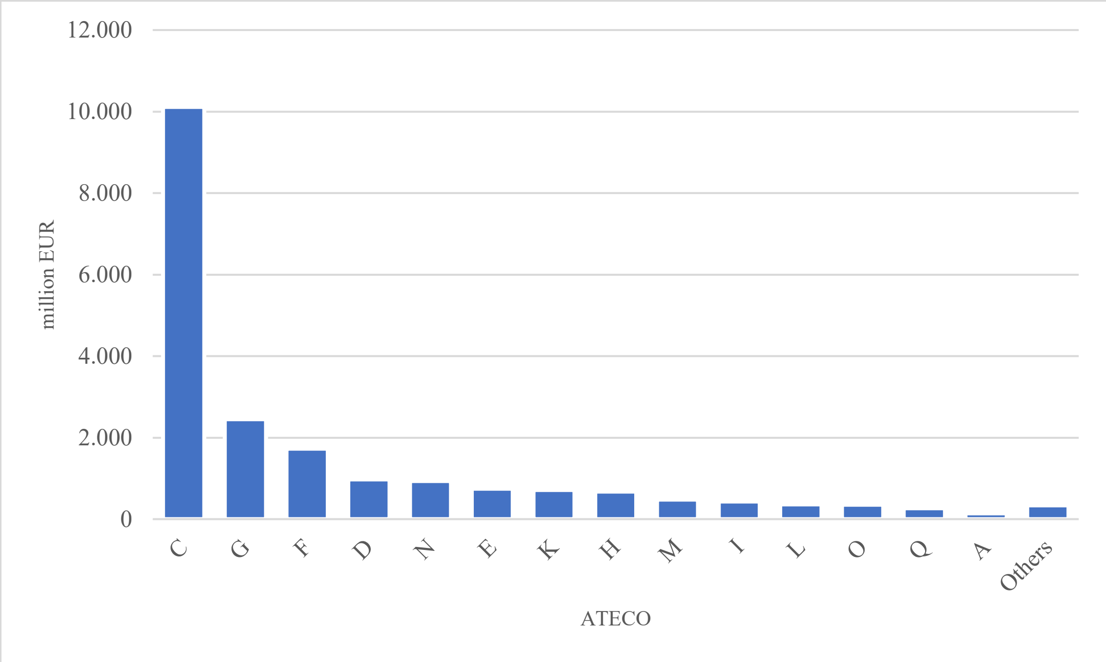


Figure 28. Economic Value Added (2022).
AIDA - Bureau van Dijk

The category of business support services represents a relevant element in the economic ecosystem, with a value added 980 million of euro. This sector includes a wide range of essential services for the functioning of business operations. Value added in this context derives from the provision of services aimed at enhancing the productivity and efficiency of client businesses, including business consulting, administrative outsourcing, marketing and advertising services, research and development, and IT support. Following this, environmental services, such as water supply and waste management, contribute with a value of 759 million of euro, while the financial and insurance sector highlights the importance of capital and risk management, with a value of 696 million of euro. Logistics, including transportation and warehousing, is essential for the movement of goods and generates an overall value of 706 million of euro. Professional, scientific, and technical activities contribute with 474 million of euro, emphasizing the key role played in innovation and development. The tourism and hospitality sector, with 502 million of euro, along with real estate activities, with 402 million of euro, represent dynamic sectors that promote investment and consumption. Healthcare and social assistance demonstrate their significant social value with 265 of euro million, while agriculture, forestry, and fishing, with 154 million of euro, maintain their traditional role in the economy.

This analysis that follows aims to examine the evolution of the added values of the main industrial sectors of the Province of Brescia in the period between 2013 and 2022.

	ATECO	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
C	Manufacturing Activities	1.00	1.08	1.16	1.25	1.36	1.49	1.53	1.42	1.82	2.09
G	Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	1.00	1.06	1.15	1.34	1.52	1.60	1.69	1.76	2.40	2.67
F	Construction	1.00	0.96	1.02	1.12	1.26	1.42	1.56	1.60	2.16	2.57
D	Electricity, Gas, Steam, and Air Conditioning Supply	1.00	1.00	0.97	1.72	1.57	1.54	1.72	1.49	1.79	1.77
N	Rental, Travel Agencies, and Business Support Services	1.00	1.12	1.31	1.49	1.83	2.09	2.16	2.11	2.73	3.17
K	Financial and Insurance Activities	1.00	1.20	1.01	0.85	0.86	0.91	1.01	1.18	1.22	1.26

Table 21- Economic Value-Added trend 2013 – 2022 (AIDA - Bureau van Dijk).

Beginning with Sector of Business Support Services, characterized by a significantly ascending evolution over the decade. The growth index, starting from a unitary base in 2013, showed an increase up to 1.12 in 2014, and then reached 1.31 in 2015. The progression remained steady, with values of 1.49 in 2016, 1.83 in 2017, and 2.09 in 2018. In 2019, a peak of 2.16 was observed, followed by a slight contraction to 2.11 in 2020, presumably influenced by the global pandemic context. However, the sector showed a robust recovery, with an index of 2.73 in 2021 and 3.17 in 2022. The Wholesale and Retail Trade sector recorded a more moderate growth trend. With an index of 1.06 in 2014 and 1.15 in 2015, it continued its ascent reaching 1.34 in 2016. The positive trend further consolidated, with values of 1.52 in 2017, 1.60 in 2018, and 1.69 in 2019, culminating at 1.76 in 2020. A significant increase occurred in 2021 and 2022, with indices of 2.40 and 2.67, respectively.

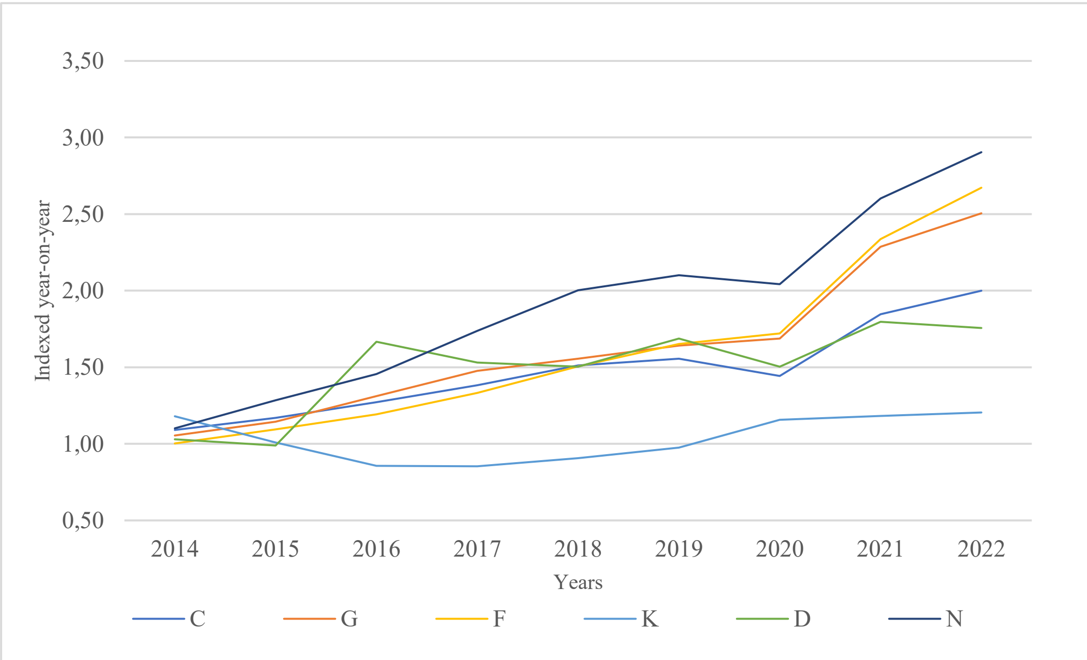


Figure 29. Economic Value Added trend 2013 – 2022.
AIDA - Bureau van Dijk

The Construction Sector showed a more variable growth dynamic. Starting from a reference point of 1 in 2013, it experienced a decline to 0.96 in 2014, then gradually recovered, stabilizing at 1.26 in 2017. The growth rate continued to increase, reaching 1.60 in 2020 and 2.57 in 2022. Regarding the Financial and Insurance Activities Sector, there was a substantial increase to 1.20 in 2014, followed by a decrease to 1.01 in 2015 and further to 0.84 in 2016. After a period of relative stability with values of 0.86 in 2017 and 0.91 in 2018, the sector showed improvement, reaching 1.01 in 2019, 1.18 in 2020, 1.22 in 2021, and finally 1.26 in 2022.

Finally, the Manufacturing Sector displayed sustained growth, with the index rising to 1.36 in 2017. Despite a slight decline in 2019, the sector experienced a more marked drop in 2020, then recorded a recovery in the following two years, culminating in a maximum value of 2.09 in 2022.

4.1.6 Labour Cost

The investigation into the cost of labour across the different productive realities of the province of Brescia has outlined a sectoral economic hierarchy, as has already emerged in the previous paragraphs. In detail, as represented in **Figure 30**, the Manufacturing Activities sector stands out with a *labour* expenditure amounting to 5,414 million of euro. This data not only confirms the sector's quantitative predominance, as previously discussed, but also highlights the intensity of the human capital employed and the high qualification of the required competencies.

	ATECO	**[‘000 €]**
A	Agriculture, Forestry, and Fishing	63,237
B	Mining and Quarrying	42,212
C	Manufacturing Activities	5,414,771
D	Electricity, Gas, Steam, and Air Conditioning Supply	335,404
E	Water Supply; Sewerage, Waste Management, and Remediation Activities	250,569
F	Construction	952,509
G	Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	1,153,043
H	Transportation and Storage	378,515
I	Accommodation and Food Service Activities	284,014
J	Information and Communication Services	212,803
K	Financial and Insurance Activities	46,052
L	Real Estate Activities	61,820
M	Professional, Scientific, and Technical Activities	301,058
N	Rental, Travel Agencies, and Business Support Services	753,346
P	Education	49,807
Q	Health and Social Assistance	195,538
R	Arts, Entertainment, and Recreation	60,948
S	Other Service Activities	61,655

Table 22- Labour Cost (AIDA - Bureau van Dijk)

The significant magnitude of labour costs in this sector sheds light on an advanced industry, characterized by marked diversification and a demand for specialized workers, resulting in substantial investments in terms of wages and training. The value also highlights the concentration of high-value-added industrial activities, intrinsically linked to sophisticated and cutting-edge production processes that presuppose high labour productivity. The wholesale and retail trade establishes itself as a cornerstone in the economic landscape of Brescia, with a labour cost of approximately 1,153 million of euro. This amount is the culmination of multiple dynamics: first and foremost, the high employment needed to cover the wide range of operations distinctive to the sector, from logistics to customer support, from sales to administration, implying a considerable commitment in terms of human resources. The figure also reflects the trend towards personnel qualification, essential for managing complex interactions with suppliers and customers and for developing specific competencies related to stock management, in-depth product knowledge, and negotiation and sales skills. The demand for qualified customer service and a personalized shopping experience lead companies to invest more in personnel, consequently raising labour costs.

Regarding the construction sector, an expense of 952 million of euro in terms of labour costs testifies to the complexity and specialization of modern construction, requiring advanced knowledge in areas such as engineering, architecture, and craftsmanship, as well as mastery of construction techniques, workplace safety, and adherence to environmental standards. This value also reflects the need to comply with continuously evolving technical regulations that impose high levels of energy efficiency and sustainability and to integrate construction into the existing urban fabric. Subsequently, Business Support Services stand out with a labour cost of 753 million euro, while Transportation and Warehousing and the provision of Electricity, Gas, Steam, and Air Conditioning show costs of 378 and 335 million euro, respectively. Professional, Scientific, and Technical Activities are at 301 million euro. The hospitality and food service sector, a hub of tourism, records a commitment of 284 million euro, while services related to Water Management, Sewerage, Waste Management, and Remediation Activities absorb 250 million euro. Activities in the field of Information and Communication and those of Health and Social Assistance, with 212 and 195 million euro respectively, reinforce their infrastructural role in the Province of Brescia’s society.

	ATECO	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
C	Manufacturing Activities	1.00	1.07	1.12	1.19	1.28	1.39	1.46	1.39	1.63	1.68
G	Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	1.00	1.06	1.15	1.29	1.42	1.56	1.65	1.67	1.96	2.04
F	Construction	1.00	1.06	1.13	1.24	1.40	1.58	1.81	1.84	2.30	2.43
N	Rental, Travel Agencies, and Business Support Services	1.00	1.11	1.31	1.48	1.83	2.14	2.16	2.10	2.72	2.96
D	Electricity, Gas, Steam, and Air Conditioning Supply	1.00	1.06	1.01	1.55	1.37	1.44	1.52	1.53	1.56	1.71
H	Transportation and Storage	1.00	1.08	1.21	1.32	1.50	1.72	1.91	2.04	2.37	2.44

Table 23 - Labour Cost trend 2013 – 2022 (AIDA - Bureau van Dijk)

Finally, sectors such as Agriculture, Forestry, and Fishing, Real Estate Activities, Services, Entertainment, Recreation, Education, Financial and Insurance Activities, and Mining and Quarrying are placed in a range of labour costs varying from 63 to 42 million of euro, thus delineating the entire spectrum of the province's economic activity.

The graphical representation in **Figure 30** outlines the trend of labour costs within the province of Brescia over a decade, extending from 2013 to 2022. Initially, the year 2013 serves as the reference year, in which the index value for each sector was normalized to 1. This uniform starting parameter allows for a comparative analysis of the annual percentage increase. In the realm of business support services, there is a continuous increase, marking an index of 1.11 in 2014, then recording a rise to 1.31 in 2015. The progression has not slowed, culminating in a peak of 2.96 in 2022. Similarly, the transportation and storage sector has shown an increasing trend from 1 to 1.08 in 2014, continuing in a steady climb to reach a value of 1.44 in 2022. The construction sector shows a rise in the index value to 1.06 in 2014, with subsequent and steady growth reaching 1.43 in 2022. In contrast, the wholesale and retail trade exhibit a more modest increase compared to other sectors, rising slightly to 1.05 in 2014 and arriving at 1.04 in 2022.

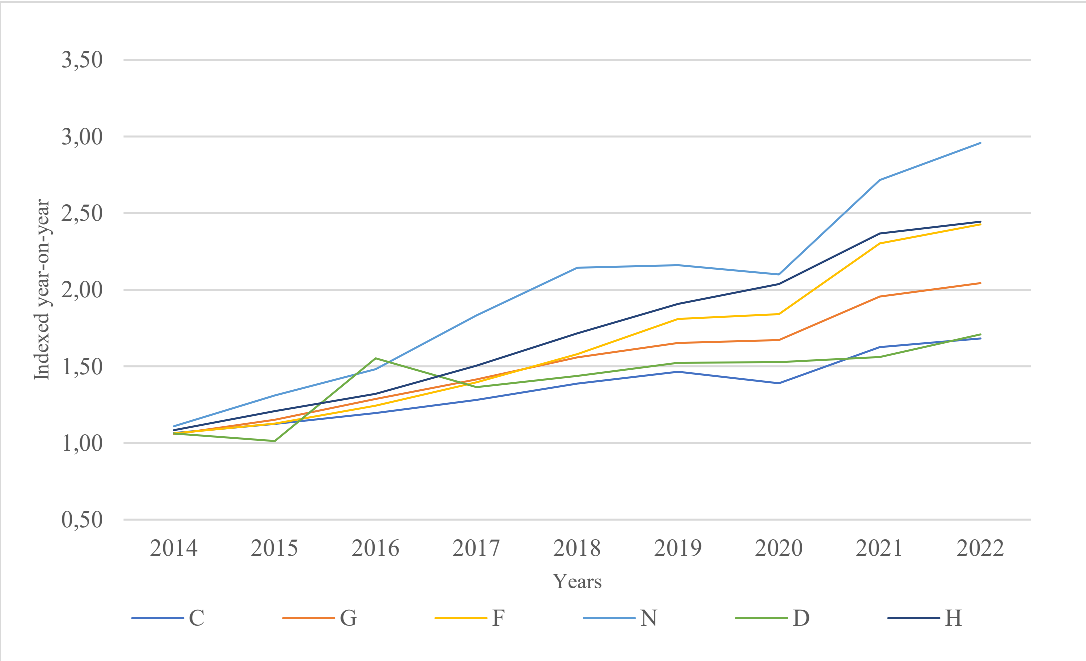


Figure 30. Labour Cost trend 2013-2022.
AIDA - Bureau van Dijk

Concurrently, the industry of the supply of electricity, gas, steam, and air conditioning presents a fluctuating trend, with a slight contraction to 1.01 in 2014, followed by a significant increase to 1.55 in 2015, and finally reaching an index of 1.71 in 2022. In conclusion, the manufacturing sector demonstrates a gradual growth starting from 2013, advancing to 1.06 in 2014, and arriving at 1.68 in 2022. The overall analysis confirms an ascending trend in the cost of labour across the various economic sectors of the province during the period under review.

4.1.7 Manufacturing Activities

In this paragraph, an analysis of the ATECO Sector C "Manufacturing Activities" is conducted to examine its composition and identify the principal activities in terms of the number of enterprises, number of employees, and the value of production generated. To simplify the analysis, the activities constituting the sector have been subdivided into eleven distinct clusters. The clusters in Table 24, along with their respective activities, are outlined as follows.

Food and Beverage encompasses the Food Industries, which include the production and processing of various food products, and the Beverage Industry, which focuses on the manufacturing of alcoholic and non-alcoholic drinks. Textile cluster groups three main activities: Textile Industries, the Manufacture of Clothing, and the Manufacture of Leather and Fur Articles. Additionally, it includes the Manufacture of Leather and Similar Articles. These activities represent the textile sector's comprehensive approach to producing a wide range of textile goods, from basic fabrics to specialized leather and fur products. Wood and Paper Product covers the Wood and Wood Product Industries, including the Manufacture of Straw and Plaiting Materials, which indicates a focus on both traditional wood products and more niche areas like straw goods. It also involves Paper Manufacturing and Paper Products, emphasizing the production of paper and related products. Furniture Manufacturing is another important activity within this cluster, representing the industry's integration of wood processing and furniture design and production. Services and Support includes Printing and Reproduction of Recorded Media, pointing to the supportive role this sector plays in providing essential services to other industries, particularly in media and publishing. Heavy Industries and Materials cluster comprises the Manufacture of Coke and Petroleum-Derived Products, Manufacture of Other Non-Metallic Mineral Products, and Metallurgy. These activities are the industries producing basic materials necessary for various manufacturing processes and end products. Plastic, Rubber, and Chemical Products includes highlights the chemical industry's role in producing raw materials and components used across various sectors, including consumer goods, healthcare, and technology. Pharmaceuticals and Health Products focuses on the Basic Pharmaceutical Products and Pharmaceutical Preparations Manufacturing. It reflects the pharmaceutical industry’s operating in health and wellness. Metal and Machinery represents the Manufacture of Metal Products (excluding machinery and equipment) and the Manufacture of Machinery and Equipment N.E.C. (not elsewhere classified). These activities characterize the metal industry's role in providing necessary components and machinery for various manufacturing and industrial applications. High Technology and Equipment includes the Manufacture of Computers and Optical and Electronic Products, underscoring the high-tech industry in advancing technological innovation and production in electronics and electrical devices.

L2	ATECO	Cluster	Cluster cod.
11	Beverage Industry		C1

10	Food Industries	Food and Beverage	
14	Manufacture of Clothing; Manufacture of Leather and Fur Articles	Textile	C2
15	Manufacture of Leather and Similar Articles		
13	Textile Industries		
31	Furniture Manufacturing	Wood and Paper Product	C3
17	Paper Manufacturing and Paper Products		
16	Wood and Wood Product Industries; Manufacture of Straw and Plaiting Materials		
18	Printing and Reproduction of Recorded Media	Services and Support	C4
19	Manufacture of Coke and Petroleum-Derived Products	Heavy Industries and Materials	C5
23	Manufacture of Other Non-Metallic Mineral Products		
24	Metallurgy		
20	Chemical Products Manufacturing	Plastic, rubber and chemical products	C6
22	Manufacture of Rubber and Plastic Products		
21	Basic Pharmaceutical Products and Pharmaceutical Preparations Manufacturing	Pharmaceuticals and Health Products	C7
28	Manufacture of Machinery and Equipment N.E.C.	Metal and Machinery	C8
25	Manufacture of Metal Products (Excluding Machinery and Equipment)		
26	Manufacture of Computers and Optical and Electronic Products; Electromedical Equipment, Measuring Devices and Watches	High Technology and Equipment	C9
27	Manufacture of Electrical Equipment and Non-Electric Domestic Appliances		
29	Manufacture of Motor Vehicles, Trailers and Semi-Trailers	Automotive	C10
30	Manufacture of Other Transport Equipment		
32	Other Manufacturing Industries	Others	C11
33	Repair, Maintenance and Installation of Machinery and Equipment		

Table 24.Manufacturing Activities: details and clustering (AIDA - Bureau van Dijk).

The Automotive cluster comprises the Manufacture of Motor Vehicles, Trailers, and Semi-Trailers, along with the Manufacture of Other Transport Equipment; finally, Others group includes Other Manufacturing Industries and Repair, Maintenance, and Installation of Machinery and Equipment, encompassing a wide range of miscellaneous manufacturing activities and essential services that support the maintenance and functionality of machinery and equipment.

4.1.8 The manufacturing: Operating companies and number of employees

The Table 25 and **Figure 31** facilitate the observation of the distribution of companies across various sectors within the manufacturing domain. Particularly salient is the sector encompassing Metal and Machinery, counting 2541 companies, constituting 52% of the total entities delineated in the table.

Cluster cod.	**Cluster**	**Companies** [units]	**Employees** [units]
C1	Food and Beverage	275	6,110
C2	Textile	298	4,913
C3	Wood and Paper Product	204	3,615
C4	Services and Support	78	701
C5	Heavy Industries and Materials	356	18,105
C6	Plastic, rubber and chemical products	286	8,035
C7	Pharmaceuticals and Health Products	6	276
C8	Metal and Machinery	2,541	52,234
C9	High Technology and Equipment	296	6,361
C10	Automotive	141	6,099
C11	Others	409	3,530

Table 25.Manufacturing Activities: Companies No. and Employees. (AIDA - Bureau van Dijk).

Conversely, the Heavy Industries and Materials sector, with its complement of 356 companies, embodies 7.3% of the enumerated enterprises, maintaining substantive significance. In contrast, the Textile, High Technology and Equipment, as well as Plastic, Rubber, and Chemical Products sectors, present analogous counts of companies, ranging from 286 to 298, each approximating 6% of the aggregate. The domain of Food and Beverage Products is populated by 275 companies, equating to 5.6% of the total. Meanwhile, the Wood and Paper Products sector encompasses 204 companies, delineating 4.2% of the total, while the Automotive sector hosts 141 companies, representing 2.9% of the overall cohort. Additionally, the Services and Support sector comprises 78 companies, constituting 1.6% of the total, whereas the Pharmaceuticals and Health Products sector encompasses merely 6 companies, symbolizing a minute 0.1% of the total. Lastly, the category denoted as "Others," encapsulating unspecified sectors, is populated by 409 companies, approximating 8.4% of the aggregate.

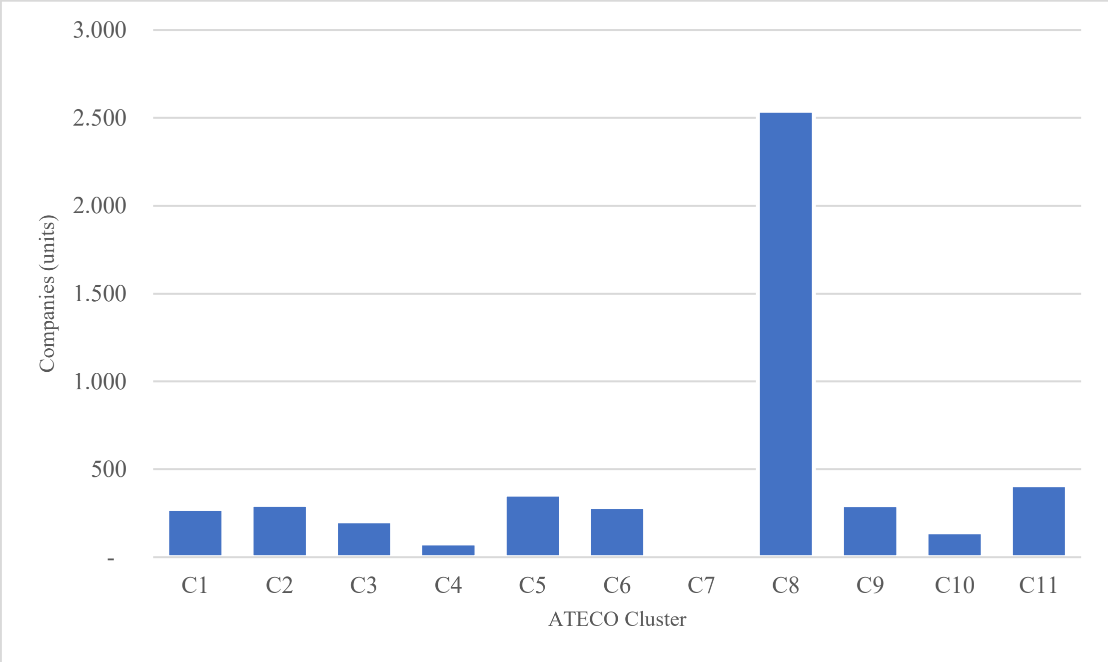


Figure 31. Manufacturing Activities: Operating Companies (2022).
AIDA - Bureau van Dijk

Moving to the analysis of the employed personnel by activity, **Figure 32** illustrates that the Metal and Machinery sector stands out clearly with 52,234 employees, accounting for 47.5% of the total workers considered. This predominance reflects the large scale of enterprises and employment volume, indicating a strong industrial concentration. Similarly, the Heavy Industries and Materials sector demonstrates significant labour activity, with 18,105 workers representing 16.5% of the total employees. The sector of Plastic, Rubber, and Chemical Products employs 8,035 individuals, the 7.3% of the total. The High Technology and Equipment sector, with 6,361 employees, is pivotal for technological progress and innovation in manufacturing, yet it requires considerable complexity and specialization. Even the Food and Beverage sector accounts for 5.6% of the total employees, with larger companies requiring many workers for the production and distribution of food products. In the same way, the Automotive sector employs around 5.5% of the total, or 6,099 employees. Other sectors such as Textiles, Wood and Paper Products, Services and Support, Pharmaceuticals and Health Products, and Others show smaller employment numbers, representing a minority portion of total employment. This could reflect smaller company sizes or less labor-intensive nature of the activity.

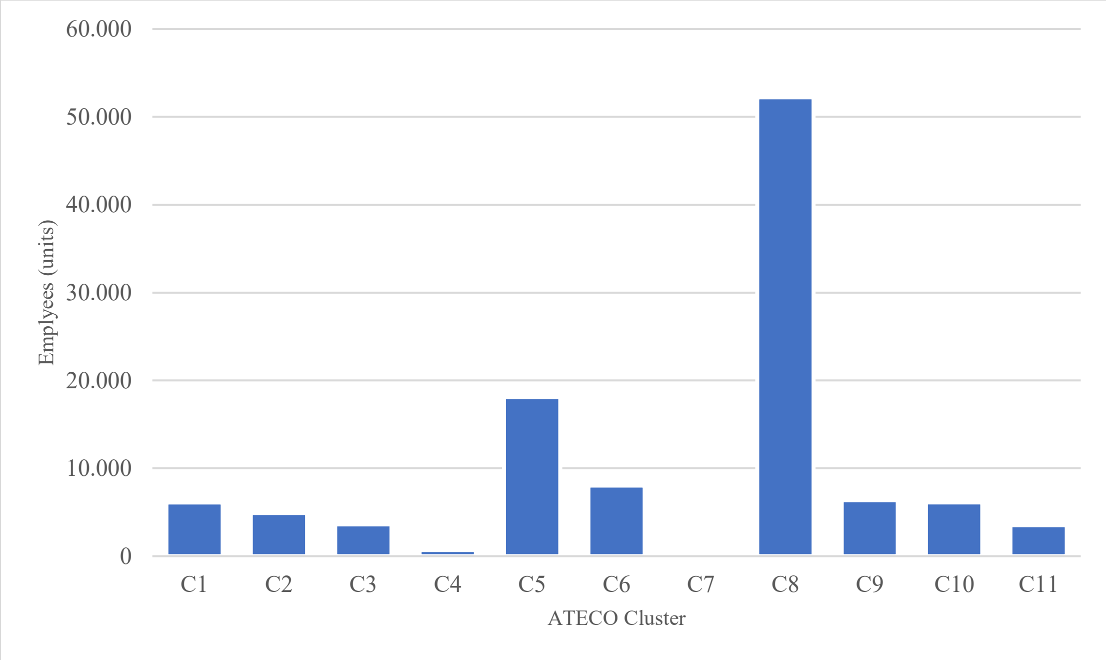


Figure 32. Manufacturing Activities: Employees (2022).
AIDA - Bureau van Dijk

The analysis of data presented in Table 26 reveals a breakdown of production in the manufacturing sector into various aggregation clusters. Two predominant categories emerge, Metal and Machinery and Heavy Industries and Materials, which constitute the majority of the overall production value. The Metal and Machinery segment accounts for 34.4% of the total, equivalent to approximately 16,695,463 euros, indicating an active presence of operations related to metal processing and machinery production, necessary in several other manufacturing industries and the construction sector. Following closely, Heavy Industries and Materials contribute with a production value of 16,097,266 euros, representing 33.1% of the total.

Cluster cod.	Cluster	['000 €]
C1	Food and Beverage	4,126,852
C2	Textile	1,296,161
C3	Wood and Paper Product	1,400,987
C4	Services and Support	173,262
C5	Heavy Industries and Materials	16.097,266
C6	Plastic, rubber and chemical products	3,013,471
C7	Pharmaceuticals and Health Products	57,401
C8	Metal and Machinery	16,695,463
C9	High Technology and Equipment	2,406,518
C10	Automotive	2,565,236
C11	Others	741,243

Table 26.Manufacturing Activities: Value of Production. (AIDA - Bureau van Dijk).

Further subcategories such as Food and Beverage constitute 8.5% of the total, followed by Plastic, Rubber, and Chemical Products at 6.2%. Segments like Automotive and High Technology and Equipment also show a low presence, at 5.3% and 5.0% of the total production, respectively. Minor categories such as Wood and Paper Product, Textile, and Others together share less than 7% of the total. Activities in Services and Support and Pharmaceuticals and Health Products contribute only marginally to the total production of the manufacturing sector.

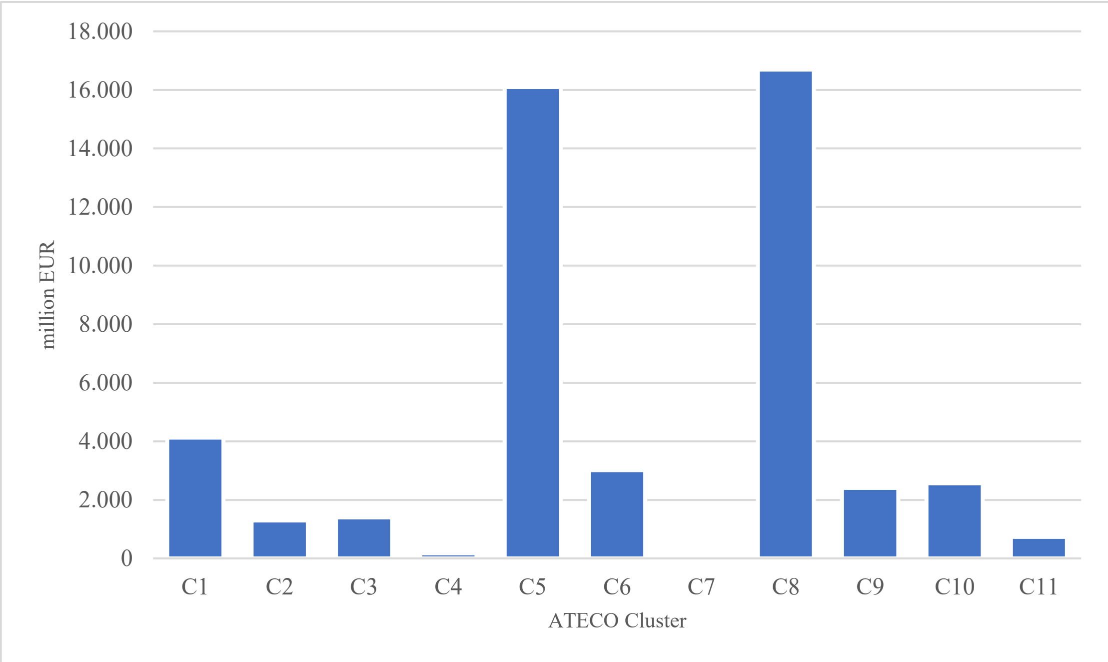


Figure 33. Manufacturing Activities: Value of Production (2022).
AIDA - Bureau van Dijk

From the analysis of the collected data, the predominant role of the Metal and Machinery sector within the manufacturing industry of the Province of Brescia is clearly evident. This sector is established as a keystone, distinguished by its breadth both in terms of entrepreneurial aggregation and economic contribution. Specifically, the Metal and Machinery sector accounts for 52% of the total enterprises operating in the manufacturing sector. This statistic underscores that more than half of the manufacturing enterprises in the province are categorized within this specific sector. From an employment perspective, the sector employs 47.5% of the total workforce in manufacturing, reinforcing its significance as a major employer. In terms of turnover the sector contributes 34.4% to the total value of manufacturing production. This figure reflects the sector's profound influence on the industrial economy of the area. In conclusion, the Metal and Machinery sector is affirmed as a fundamental pillar of the manufacturing industry in the Province of Brescia, demonstrating its impact and its representative role.

4.2 Methodology of the survey

4.2.1 Methodology of the survey

Survey research is a methodological approach used to investigate relationships between various variables in empirical studies focusing on prevalent attitudes or actions. This method involves drawing a representative sample from a broader population and developing a standardized questionnaire. This questionnaire is then administered to selected participants to collect analysable data. Unlike census surveys, which involve the entire population of interest, survey research is characterized by its focus on a smaller sample of individuals. This sample is examined using a meticulously designed questionnaire, aimed at ensuring consistency in the formulation and sequence of questions for all respondents. The primary goal of this methodology is to ensure that responses are comparable across different participants, a fundamental requirement for conducting coherent data analysis and drawing valid interpretive conclusions. Surveys can be conducted in various ways, each with specific advantages and limitations: personal method, telephone interviews, postal surveys, and electronic surveys.

The personal method of data collection, commonly utilized in qualitative research, presents several advantages and disadvantages that must be considered. One of the primary advantages of personal interviews is their ability to handle complex questions effectively. This method enables an in-depth exploration of topics, as interviewers can provide clarifications and follow-up questions in real-time, tailoring the discussion based on respondents' answers. Furthermore, the use of visual aids during personal interviews enhances comprehension and engagement, which can be particularly beneficial when conveying intricate or detailed information. Another significant advantage is the typically higher response rates associated with personal interviews. The face-to-face interaction helps to establish a rapport and trust between the interviewer and the respondent, often leading to more thoughtful and complete answers. However, this method is not without its drawbacks. Conducting personal interviews is generally more expensive than other data collection methods. The costs associated with travel and the time required to conduct interviews can accumulate, especially in studies involving a large number of participants or geographically dispersed locations. Additionally, personal interviews are time-inefficient not only due to the duration of each interview but also because of the travel and preparation time involved. Lastly, there is a potential for bias, which can stem from the interviewer's influence on the respondent. This risk necessitates thorough training for interviewers to ensure they maintain neutrality and avoid leading questions that could skew the data.

Telephone interviews serve as a method of data collection, especially where geographical or budget constraints limit the feasibility of face-to-face encounters. This method offers a blend of advantages and disadvantages that researchers must weigh based on the context of their study. The advantages of telephone interviews are varied. Firstly, they allow for the clarification of questions and answers in real-time, which can be important for ensuring that respondents fully understand the questions and provide accurate answers. This direct interaction also helps in probing deeper when necessary, to elicit more detailed responses. Additionally, telephone interviews can reach a wider geographic radius than personal interviews, making them suitable for regional and national studies without the significant costs associated with travel. They are generally less expensive and less time-consuming compared to face-to-face interviews, offering a more cost-effective solution while still maintaining a personal touch. Furthermore, the response rates for telephone interviews often surpass those of less interactive methods like postal or electronic surveys, owing to the immediate nature of the interaction. However, telephone interviews also have disadvantages. A significant limitation is the absence of visual aids, which can hinder the communication of complex information that might be more easily understood through charts, graphs, or other visual presentations. This lack of visual context can lead to misunderstandings or superficial responses if the topic requires detailed visual information for full comprehension. Another drawback is the challenge in developing a rapport with respondents, as the absence of face-to-face interaction can make it difficult to build the same level of trust and openness. This barrier might result in shorter, less detailed responses, which can affect the depth and quality of the data collected.

Postal surveys are a traditional method of data collection. One of the principal advantages is their ability to encompass a broad geographic scope. This method facilitates data collection from a wide and diverse demographic spread over vast areas without the necessity for electronic communication facilities. Furthermore, postal surveys can incorporate visual aids, albeit in a limited fashion. These aids can enhance respondent understanding and engagement, especially useful in complex questionnaires that may benefit from graphical representations. This method is also relatively cost-effective, especially when considering the avoidance of travel and personal interview expenses. Despite these benefits, postal surveys carry significant limitations. A notable disadvantage is their generally low response rate. The lack of direct interaction and personal engagement often results in higher rates of non-response, as recipients might disregard or overlook mailed questionnaires. Additionally, the time taken for data compilation is considerably lengthy, as researchers must wait for the posted responses to return. This delay can be problematic, particularly in studies where time-sensitive data is crucial. Moreover, the quality of data collected through postal surveys can be compromised due to the absence of an interviewer to clarify questions or probe deeper into responses. This can lead to misinterpretations of questions or superficial answers, which might affect the overall validity and reliability of the research findings.

Electronic surveys have emerged as a prevalent method of data collection in various research fields due to their digital nature and adaptability. The benefits and limitations of this method must be considered for researchers planning to utilize these tools for data gathering. A significant advantage of electronic surveys is their capability to target a vast audience swiftly and efficiently, transcending geographical barriers. This broad reach is particularly beneficial for studies requiring input from diverse and widespread populations. Electronic surveys also facilitate the inclusion of various types of visual aids, such as images, videos, and interactive content, which can enhance understanding and engagement among participants. Moreover, these surveys are known for their rapid response capabilities, as data can be collected in a much shorter timeframe compared to traditional methods. The compilation of data is similarly expedited, as responses are automatically formatted into databases, facilitating immediate analysis and interpretation. However, electronic surveys also present several disadvantages. One major issue is the high incidence of non-response, which can skew the data and potentially lead to biased outcomes. This may occur as recipients may overlook or choose to ignore online survey requests. Additionally, electronic surveys often fail to reach all segments of the population, particularly those without reliable internet access or those who are less technologically savvy, such as older adults. This limitation can result in a sample that is not fully representative of the target population, further challenging the generalizability of the findings [211].

Within this study a mixed-mode approach has been employed, integrating telephone and electronic methods. This blend of methodologies leverages the strengths of each to compensate for their respective limitations, providing a robust framework for gathering information. The mixed-mode approach, combining telephone and electronic surveys, addresses several key aspects of data collection that single-mode approaches may not fully achieve. One of the most significant advantages is the potential for increased response rates. While electronic surveys are advantageous for quickly reaching a large number of respondents, they often suffer from low response rates due to their impersonal nature. Telephone surveys, conversely, offer a more personal interaction that can encourage participation. By integrating both methods, it can be effectively engaging participants more deeply, thus potentially boosting overall response rates. Another advantage of this mixed approach is the enhancement of data quality. Telephone surveys allow for direct communication questions and probe deeper into responses, ensuring that data are more accurate. Electronic surveys, on the other hand, are excellent for standardizing responses and can efficiently collect data. The logistical efficiency of mixed-mode surveys also contributes to their advantages. Data can be gathered rapidly through electronic surveys, and follow-up can be conducted via telephone to delve deeper into specific areas of interest.

In preparation for this survey, each company was contacted in advance to introduce the nature of the investigation. Furthermore, the contact details of the production manager and an employee who had been with the company for at least ten years were requested. This requirement was intended to ensure that respondents were well-acquainted with the company's recent history. Following these preliminary steps, the electronic survey was administered. This meticulous approach yielded a considerable response rate and a high quality of responses, demonstrating the effectiveness of the preparatory measures in enhancing the survey's reliability.

This research, conducted within the economic context of the Province of Brescia, focuses on exploring the mechanical discrete manufacturing industry corresponding to the Metal and Machinery sector, a distinctive sector that involves the processing of specific components, chosen because particularly relevant for the analysis due to its intensive adoption and spread of industrial automation, especially articulated robotics. It is important to note that the survey excludes process mechanical industries, such as steel mills, to focus on those operating in the processing of specific parts. Moreover, the decision to focus on the mechanical industry is also driven by its significant weight within the provincial economy, has studied in the previous paragraphs.

The selection leads to the identification of a homogeneous population of about 2,541 companies of Metal and Machinery cluster (C8) as defined in the previous paragraph. Regarding the stratification of the participating companies, they are divided into size categories according to company cluster definition criteria described in the following paragraph, resulting in a classification that includes Large Enterprises, Medium Enterprises, and Small Enterprises. Micro-enterprises have been excluded from the investigation due to their limited participation and often incomplete feedback.

Company Cluster	Contacted	Answers	Accepted
Large	58	55	48
Medium	270	252	92
Small	380	348	102

Table 27. Companies participating to the survey.

The data presented in Table 27 reflects the response dynamics of the survey distributed among companies of varying sizes. Specifically, the survey targeted 58 large companies, resulting in 55 responses, of which 48 were accepted, indicating a high level of engagement and a robust acceptance rate among the large entities. In the medium-sized category, 270 companies were contacted, and 252 responded, but only 92 of these responses were deemed acceptable. Finally, the small companies, which formed the largest group, saw 380 firms contacted. Of these, 348 provided responses, with 102 being accepted.

4.2.2 Company clusters definition

In the field of statistical analysis, grouping data into homogeneous clusters based on distinctive attributes is paramount. This approach requires adopting a systematic and rigorous methodology for classifying study objects. In this context, the classification of companies follows the European Commission Recommendation 2003/361/EC, proposing a subdivision into four size categories: Large, Medium, Small, and Micro Enterprises, based on workforce parameters and financial indicators.

To determine workforce size, has been applied a simplified methodology compared to EU directives, using annual work units (AWU) as the measurement unit. These reflect the number of full-time employees, with the proportional inclusion of part-time staff. In counting employees, all active professional figures within the company are considered, excluding non-operational owners. The data come from public accounting records, referencing the closing date of the 2021 financial year. From a financial perspective, annual turnover and total balance sheet are considered, following the guidelines of the European Commission 2003/361/EC. The classification of SMEs, including companies with fewer than 250 employees and an annual turnover or a total balance sheet below certain thresholds, is detailed in the relevant table.

Company Cluster	No. Emplyees		
		Revenues (Mln) Euro	Total Balance (Mln) - Euro
Large	> 250	> 50	> 43
Medium	< 250	< 50	< 43
Small	< 50	< 10	< 10
Micro	< 10	< 2	< 2

Table 28. Company clusters definition

In this classification scheme, microenterprises are defined as entities with a maximum of 9 employees and specific financial limits, representing a fundamental pillar for local economies. Medium-sized enterprises are characterized by an intermediate workforce and financial parameters, distinguishing themselves for their managerial and organizational scale. Lastly, large enterprises exceed the established limits in terms of staff, turnover, and total balance sheet, placing themselves in a distinct category.

4.2.3 Survey structure

. The survey is structured into four main thematic areas: Context, Impact, Competences and Future Vision.

Context: aims to investigate the spread of robotics, focusing on which types of companies employ it most, specific applications, and the motivations behind the adoption of robotic solutions.

Q.1.1 Is there any robot running?

Q.1.2 Which type and how many robots are running in the plant?

Q.1.3 For which application robots are running in the plant?

Q.1.4 Which are the primary driving factors that lead you to install robots?

Impact: explores the effects recorded in companies that have invested in robotics, analysing both operational aspects (such as productivity and quality) and those related to human resources, identifying both problems and benefits arising from the implementation of robotic systems.

Q.2.1 Which are the impacts led by the robot’s deployment?

Q.2.2 What is not satisfying the expectations?

Competences: delves into the diffusion of knowledge and skills related to robotics within companies, distinguishing between activities carried out internally and those outsourced, and analysing the perception of companies regarding the training of operators in the context of robotics management and the evolution of the production system.

Q.3.1 Do existing skills meet the requirements for managing robotic equipment? If not, how do you make up this lack?

Q.3.2 Which tasks are supported by external suppliers?

Q.3.3 Reflecting on the decision-making process, which services would have been helpful?

Q.3.4 Which professional figure does the company consider appropriate for the installation and management of robots?

Future Vision: asks participants to express their perception of the future, focusing on development and investment intentions, the effectiveness of policy stimulus tools, and the relationship between universities and businesses.

Q.4.1 Is the company planning to install new robots?

Q.4.2 Is the company planning to hire graduates with a Master's degree in automation engineering within the next three years?

Each section of the survey is accompanied by a set of specific questions, which make up the questionnaire represented in **Figure 34**.

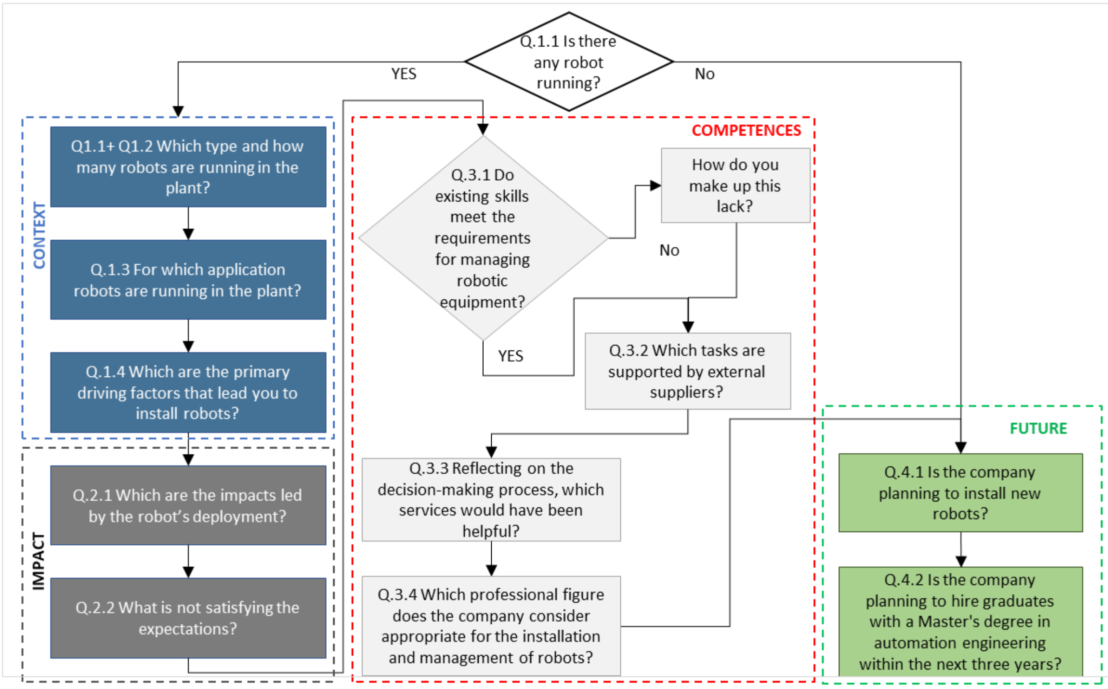


Figure 34. Research survey diagram.

4.3 Context

4.3.1 Q1.1+ Q1.2 Which type and how many robots are running in the plant?

The initial question of the survey aims to investigate the number and types of robots present in the sample of interviewed companies. Four main categories of robots are examined. The first is the anthropomorphic robot, equipped with mechanical arms with multiple joints, which offers high flexibility and precision in movements, making it particularly suitable for a wide range of industrial applications.

	Large	**Medium**	**Small**
With Robot	100%	77%	28%
Anthropomorphic	100%	92%	77%
Cartesian	52%	34%	36%
Scara	38%	14%	19%

Table 29. Type of robot running in the plant.

Next is the Cartesian robot, which operates along three orthogonal axes, ensuring precise and repeatable movements, ideal for palletizing, material handling, cutting or dispensing applications. The SCARA, characterized by a rigid arm in vertical movements and flexible in horizontal ones, suitable for high-speed assembly operations, is then considered. Finally, the adoption of COBOTS (collaborative robots), an emerging type in the industrial robotics landscape, is explored. Analysing the collected data, relevant observations emerge on the evolution of robotization in companies. One data point stands out in particular: all large companies have implemented robotic solutions, emphasizing their tendency towards advanced automation. In stark contrast, only 28% of small businesses have adopted this technology, highlighting a significant disparity in the adoption of automation based on company size. This phenomenon suggests that large companies, equipped with greater economic, technical, and human resources, are more inclined and capable of adopting innovative technological solutions to increase productivity and reduce operating costs.

Among the types of robots considered, the anthropomorphic robot proves to be the most widespread, with adoption rates of 100% in large companies, 92% in medium-sized companies, and 77% in small ones. This prevalence was widely anticipated and confirms the adaptability of this type of robot to a wide variety of activities and applications. On the contrary, Cartesian and Scara robots show less diffusion. The former is present in 52% of large companies, 34% of medium-sized ones, and 36% of small ones, while the latter is present in 38% of large, 14% of medium-sized, and 19% of small businesses. These percentages reflect a relatively limited use attributable to specific applications and intrinsic limitations of their mechanical structure.

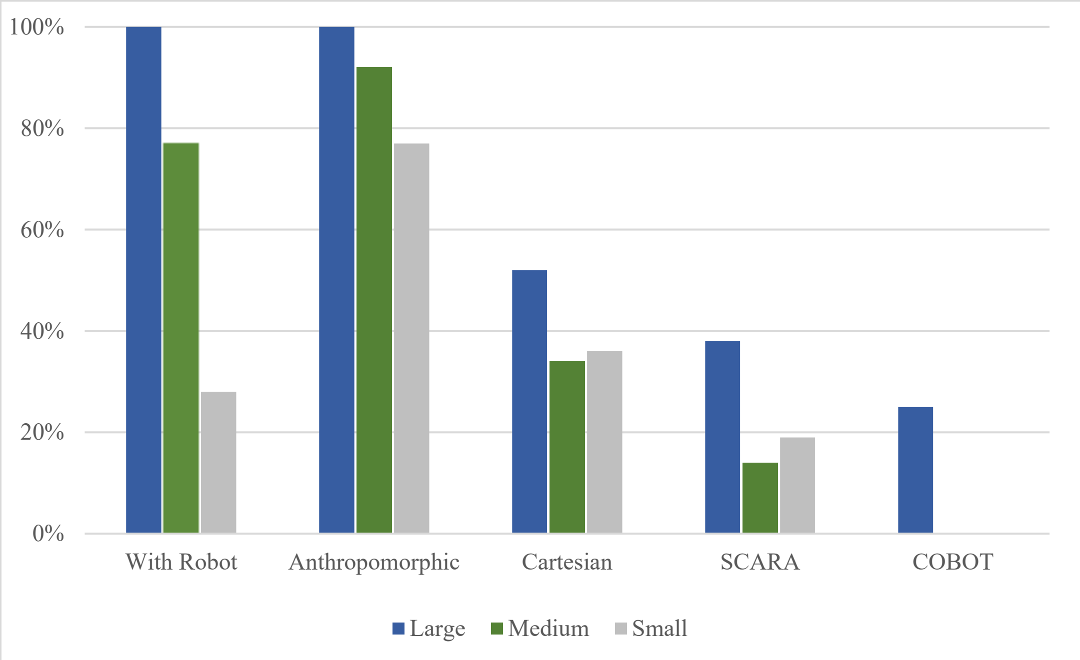


Figure 35. Type of robot running in the plant.

Unexpectedly, COBOTS, despite their considerable potential and adaptability to various business contexts, remain largely unknown or underutilized, especially in small and medium-sized enterprises. This data is surprising, given their ability to collaborate directly with humans in shared environments without physical barriers, and their easy reprogramming, which makes them extremely versatile and suitable for the needs of the numerous small and medium-sized enterprises present in the survey area.

4.3.2 Q1.3 For which application robots are running in the plant?

The research conducts to explore the prospective applications of robotic cell technology and yields insightful data on its multifaceted utility within industrial settings. Participants are presented with various options, encompassing Handling & Machine Tending, Welding, Dispensing, Processing, Assembling, Inspection, and Transport. Each category reflects a distinct operation in the manufacturing process, showcasing the versatility and potential of robotic cells.

Robotic cells in handling and machine tending are instrumental in automating the transfer and manipulation of materials and components. This technology simplifies the process of loading and unloading production equipment, thus optimizing the throughput and reducing the cycle times of various manufacturing systems. In welding applications, robotic cells contribute to the precision and repeatability of joining parts. By employing automated welding solutions, companies benefit from enhanced joint quality and increased production rates, along with a significant reduction in exposure to hazardous conditions. The application of robotic cells in processing such as cutting, grinding, or polishing transforms raw materials into finished components with exact specifications.

This automation allows for high-volume processing with very low variability and ensuring consistent product quality. In assembly operations, robotic cells are essential for the accurate and efficient combination of parts into a finished product.

	Large	Medium	Small
Handling & Machine Tending	86%	71%	83%
Welding	29%	29%	0%
Dispensing	22%	10%	0%
Processing	26%	10%	13%
Assembling	35%	5%	25%
Inspection	22%	5%	0%
Transport	26%	5%	0%

Table 30. Applications.

They enable complex assembly tasks to be completed with greater speed and precision than manual assembly, resulting in improved productivity and product quality. Robotic cells equipped with advanced vision systems and sensors are increasingly used for the inspection of parts. They provide non-invasive, high-speed quality control that can detect defects or irregularities with greater accuracy than the human eye, ensuring that only parts meeting the highest quality standards proceed to the next stage of production or to the market. The integration of robotic cells in transport involves the automated movement of parts or products between different stages of the manufacturing process. This application is critical for maintaining a smooth and timely flow of materials, which is essential for modern manufacturing processes.

The results presented in **Figure 34** provide insights into the utilization of robotics across various applications in plants of different sizes, Large, Medium, and Small.

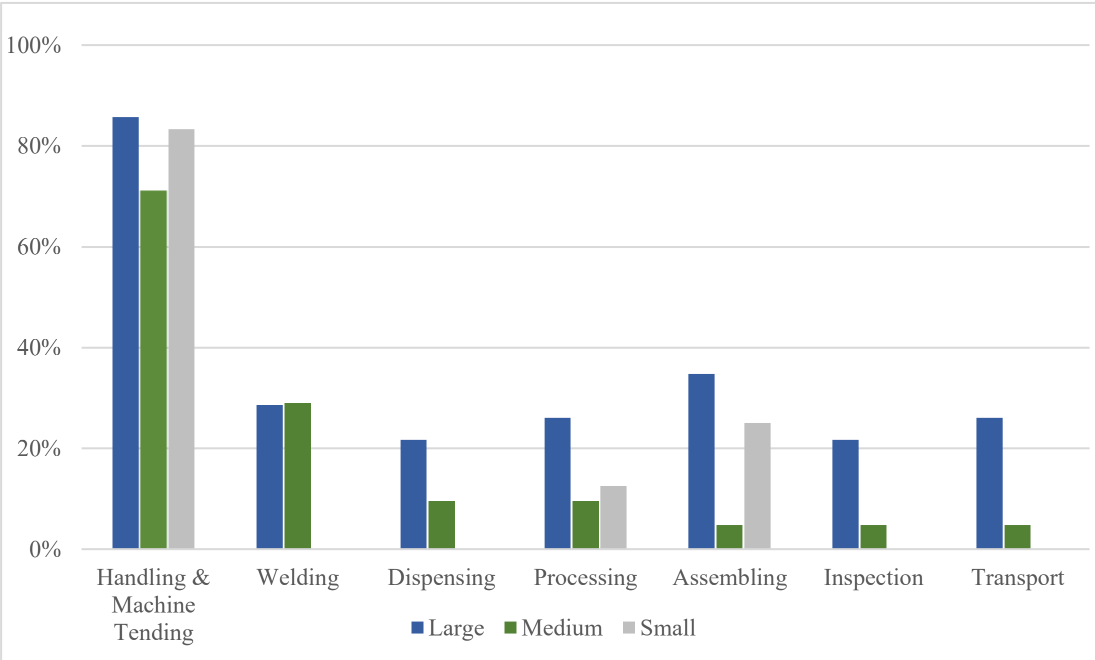


Figure 36. Applications.

In large plants, it is evident that the majority of robot applications are concentrated in the realms of Handling & Machine Tending (86%), Assembling (35%), and Processing (26%). The dominance of Handling & Machine Tending can be attributed to the efficiency and reliability that robots bring to material transport and production processes in larger facilities. Additionally, the substantial presence of robots in Assembling and Processing activities underscores the role of automation in streamlining complex manufacturing operations, ultimately enhancing productivity.

In contrast, medium-sized plants exhibit a somewhat different distribution of robot applications. While Handling & Machine Tending still maintains a significant presence at 71%, the percentage allocation to Dispensing, Processing, and Assembling is remarkably lower. The use of robots in manufacturing varies based on the size of the plant and the specific tasks being performed. Larger plants tend to use robots for a wider range of tasks, while smaller plants rely heavily on robots for handling and assembling. However, there may still be some tasks that require manual labour for precision or lower production volumes.

Small plants, on the other hand, have a distinct pattern of relying heavily on robots for handling and machine tending (83%) and assembling (25%). Notably, welding and dispensing applications are absent in these plants. This trend may reflect the smaller scale of operations in smaller plants, where automated welding or dispensing solutions may not be as cost-effective. The focus on assembling in small plants may also indicate a specialization or customization in production processes, where robots can provide the necessary flexibility and precision. The absence of welding applications in small plants, as well as the limited presence in medium-sized plants, raises questions about the feasibility and cost-effectiveness of deploying welding robots in such contexts. Smaller and medium-sized plants, with their unique and diverse production needs, rely on human welders for greater adaptability or cost savings.

4.3.3 Q1.4 Which are the primary driving factors that lead to install robots?

The aim of this question is to identify the key drivers behind the implementation of robots in industrial operations. It reveals that businesses currently rely on automation to achieve their strategic goals. The findings demonstrate a diverse range of factors motivating the deployment of robotic solutions, including the desire to enhance productivity and support employees in their operations. These drivers often overlap and interact with each other, particularly in the context of cost optimization, which is closely linked to both productivity improvements and capacity expansion.

Companies are installing robots to achieve more efficient production processes, where the goal is to maintain or increase output with less input. Since market demand is not within the direct control of the business, the focus is on maximizing efficiency within the existing parameters. This means producing the same quantity and quality of goods without proportional increases in labour or material costs, often achieved through the speed, consistency, and round-the-clock operational capabilities of robots. When market trends indicate a rise in product demand, companies must scale up their production capabilities to capitalize on these opportunities. In this case, robots provide a scalable solution to increase capacity, enabling companies to meet higher production demands. Although increasing productivity and capacity are distinct objectives, both contribute substantially to cost optimization. Robots can operate continuously, reducing the need for multiple shifts, and minimize waste by improving precision in tasks, resulting in material savings.

	Large	Medium	Small
Increase Productivity	70%	43%	90%
Increase Capacity	65%	64%	63%
Cost Optimization	83%	64%	75%
Quality / Inspection	65%	40%	38%
Support Employees	58%	33%	38%
New project opportunities	22%	10%	13%
Challenging environments	13%	7%	0%

Table 31. Driving factors that lead to install robots.

Moreover, the data collected by robotic systems can be used to refine processes over time, leading to further cost reductions. Robots are not only about speed and volume; they are also about enhancing the quality of production. Automated systems can perform quality checks and inspections with high precision and consistency. This reduces the rate of defects, returns, and rework, leading to improved customer satisfaction. Another key factor in the deployment of robots is the support they provide to the human workforce. Robots take on repetitive, strenuous, or dangerous tasks, thereby reducing workplace injuries and improving overall safety. This shift allows employees to focus on more complex and creative tasks, where human skills are indispensable, ultimately leading to a more fulfilling work environment and potentially increasing employee retention. The adoption of robotic technology often opens up new project opportunities that were previously unfeasible due to technological or resource limitations. Robots can perform tasks with a level of precision and consistency that may not be possible for humans, enabling companies to take on complex projects and expand into new markets or product lines that require advanced manufacturing techniques. Robots excel in operating within environments that are inhospitable or dangerous for humans. Whether it's extreme temperatures, hazardous materials, or hard-to-reach places, robots can be designed to withstand a wide range of challenging conditions. This capability not only ensures the safety of human workers but also expands the realm of possible operations, from deep-sea exploration to handling hazardous substances in pharmaceutical manufacturing. The detailed outcomes are as follows.

Firstly, it is evident that the search of increased productivity is a central driving factor for the implementation of robotic systems across all organization sizes.

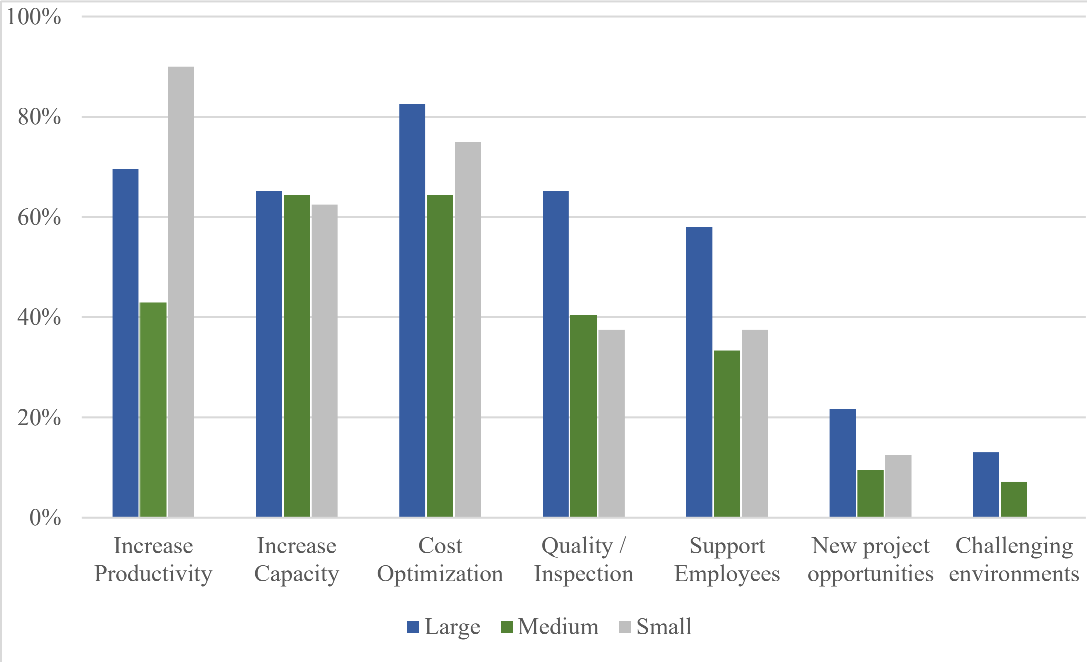


Figure 37. Driving factors that lead to install robots.

This aligns with the belief that automation can deliver consistent and efficient task execution, leading to a boost in overall productivity. Large organizations place significant emphasis on this aspect, with 70% indicating it as a primary driver. However, medium and small enterprises also recognize the potential of robots to enhance productivity, with 43% and 90%, respectively. This highlights the widespread recognition of robots as powerful tools for improving operational efficiency. Another important observation is the desire to augment production capacity, which resonates strongly across all organization sizes. In both large (65%) and medium-sized (64%) enterprises, this is considered a fundamental incentive. This underscores the importance of robots in addressing capacity constraints and improving the ability of organizations to meet increasing demand. The utilization of robotic systems is significant for organizations of all sizes since robots are instrumental in enhancing operational efficiency and achieving organizational objectives by improving productivity and augmenting capacity. Cost optimization has emerged as a primary driver for many organizations, irrespective of their size. A significant factor for 83% of large enterprises, 64% of medium-sized companies, and 75% of small organizations, the strategic use of robots aims to reduce labour and operational costs in the long run. Investing in automation aligns with the economic rationale, where the initial capital outlay is offset by long-term savings. Large organizations consider quality control and inspection an essential driver, with 65% emphasizing this aspect. This underscores the importance of quality assurance, particularly in sectors where precision and reliability are critical, such as manufacturing. The incorporation of robotic technology in the workplace is no longer a mere novelty, but rather a necessity for companies striving to maintain their competitiveness in the market. An emerging paradigm gaining traction is human-robot collaboration, whereby robots are designed to assist employees in their work environment. Larger organizations tend to place a greater emphasis on this aspect, with

58% recognizing the strategic deployment of robots to complement human labour and create a safer and more comfortable work environment. It is important highlight that even smaller organizations, despite having fewer resources at their disposal, are still mindful of the ethical and social implications of automation. This is evidenced by 38% of small organizations and 33% of medium-sized organizations taking these dimensions into account to some extent. However, it is important to note that "New project opportunities" and "Challenging environments" are not high on the list of priorities for organizations of any size. Current focus of companies implementing robotics is more on cost savings rather than exploring new opportunities or operating in challenging environments. This is evidenced by the fact that most companies prioritize cost reduction when considering the implementation of robotics, while placing little emphasis on the latter. This indicate that the majority of companies do not currently perceive new opportunities or the ability to operate in challenging environments as significant drivers for adopting robotics.

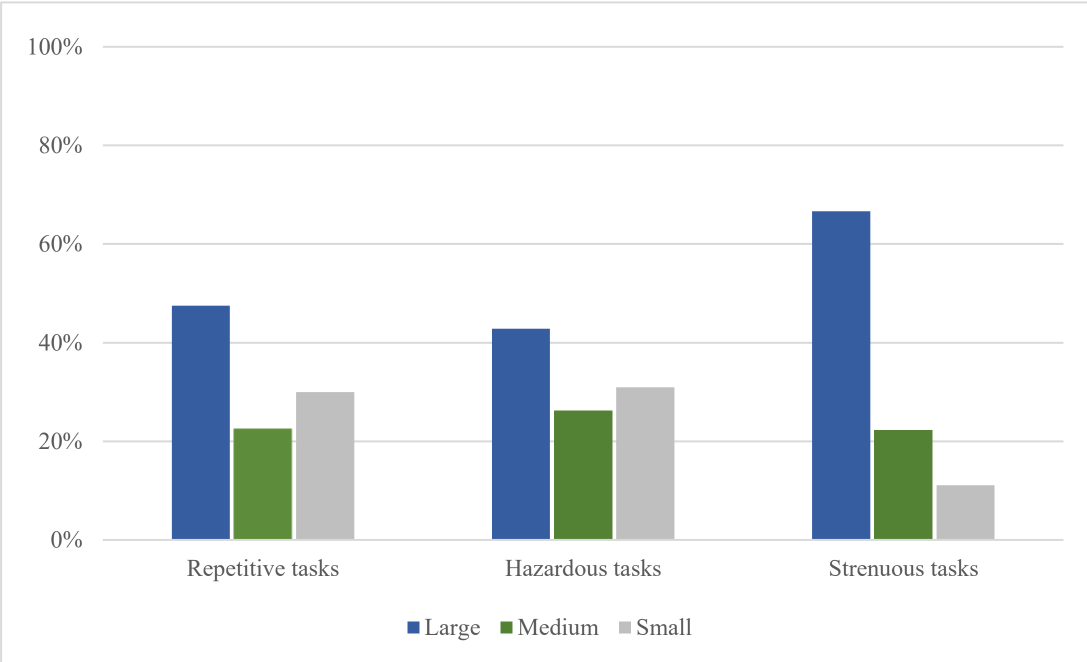


Figure 38. Focus on Support/Substitute operators.

Table 32 reveals the visions into the use of robots across organizations with a specific focus on the aim to support or substitute operators. Robotic implementations in various industries are driven by multiple factors. Safety concerns, industry context, and the physical demands of tasks are just some of the reasons why organizations are adopting these technologies. These findings offer insights into the diverse motivations behind such implementations. Support or substitute operators on repetitive tasks is the major driving force behind the installation of robotic systems across all organization sizes, as robots are perfectly suited to performing monotonous and repetitive tasks. Large organizations, in particular, seem to place a lot of emphasis on this aspect, with 48% stating that it's a key factor. Meanwhile, medium-sized and small organizations also recognize the potential benefits of robots in tackling repetitive tasks, though to a somewhat lesser degree (23% and 30%, respectively). It's interesting to note that automation is universally appealing in terms of relieving workers from routine, repetitive assignments, which not only boosts productivity but also minimizes the risk of errors.

	Large	**Medium**	**Small**
Repetitive tasks	48%	23%	30%
Hazardous tasks	43%	26%	31%
Strenuous tasks	67%	22%	11%

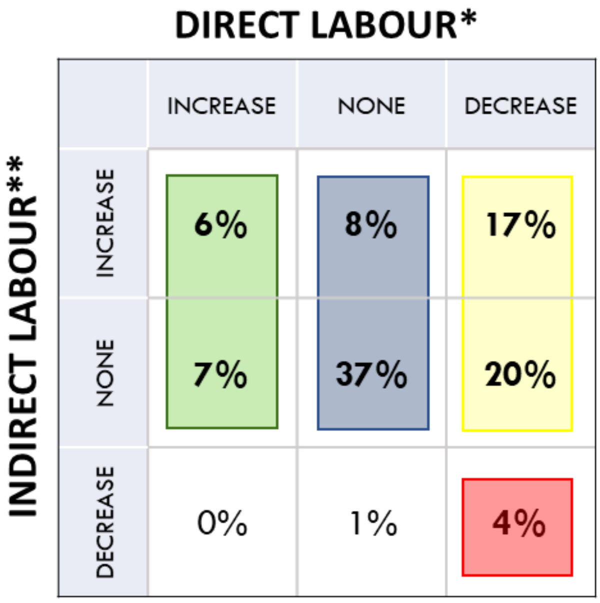
Table 32. Focus on Support/Substitute operators.

Another significant incentive for implementing robotic systems is the ability to handle hazardous tasks. However, the importance of this factor varies across different organization sizes. Large organizations (43%) place a high priority on this aspect, reflecting their commitment to worker safety and compliance with occupational health regulations. The implementation of robots in industries that involve hazardous tasks has become increasingly popular. This is particularly evident in large organizations, where 43% of them recognize the potential of robots in reducing physical risks associated with dangerous operations. However, it's worth noting that medium-sized and small organizations, while showing slightly lower percentages (26% and 31%, respectively), also acknowledge the benefits of using robots in mitigating risks that come with hazardous work. Moreover, the use of robots to handle strenuous tasks has become a primary driver for large organizations, with 67% of them recognizing the importance of introducing these machines to reduce the physical strain on workers. This aligns with the goal of improving occupational health and safety, which is essential in any industry. However, medium-sized and small organizations show relatively lower percentages (22% and 11%, respectively) in this regard, suggesting that the urgency of relieving employees from physically demanding work may be less pronounced in smaller enterprises due to their nature of operations and available resources. Overall, repetitive tasks emerge as a prominent driver across all organization sizes, underscoring the appeal of automation in streamlining routine work and improving efficiency.

4.4 Impact

4.4.1 Q2.1 Which are the impacts led by the robot's deployment? Employees

The initial question of this section of our survey generated relevant data on the impact of robotics integration in production structures on work dynamics. The information, arranged in a matrix structure presented in **Figure 39**, provides a quantitative analysis of the consequences of adopting robotic systems on direct and indirect labour. Through the testimonies of the involved entities, all companies with operational robotic implementations, it is possible to categorize occupational variations into three macro-categories, increase, stagnation, and decrease, each characterized by specific percentages that illustrate the extent of the impact.



(*) Direct Labour: those people working on assembly line or operating on production machinery
(**) Indirect Labour : all other types of support and supervisory labour
Figure 39. Effect on employment

In detail, the distinction between direct work, defined as that performed by operators in direct contact with products, and indirect work, including the remaining professional figures in the company, has been precisely clarified in the formulation of the question. It is possible to observe that a small but significant portion of companies, corresponding to 13%, report an increase in direct work. Of these, 6% report a concomitant increase in indirect work, while the remainder did not show any changes. These circumstances indicate that automation, while present, has not suppressed the need for direct work but has rather generated an expansion of the need for human skills.

The 45% of the surveyed companies maintains the volume of direct work unchanged, and in parallel, 8% highlights an increase in indirect work. This suggests that the introduction of robotic systems has not necessarily led to a reduction in direct human labour, but has rather stimulated occupational expansion, particularly in support and maintenance areas falling under the category of indirect work. Furthermore, 41% of the cases reports a reduction in direct personnel. However, it is critical to notice that within these scenarios, 17% observes an increase in personnel, emphasizing that in specific contexts, robots have been able to replace direct human labour while simultaneously generating the need to integrate new specialized skills in robotics management and maintenance.

The process of robotization in the business environment has triggered a structural transformation of work. While a decrease in direct tasks is observed, there is a significant increase in indirect work requirements. This evolution implies a re-elaboration of the role of employees, who are oriented from direct manual activities towards supervisory, maintenance, and programming roles, requiring greater qualified skills and flexibility. The observed constancy in a considerable percentage of cases for both work categories indicates that automation can coexist with human labour, outlining a new occupational paradigm.

4.4.2 Q2.1 Which are the impacts led by the robot's deployment? Operational

After conducting an analysis on the impact of robotics on employment, we now proceed to examine the incidence of this phenomenon from an operational perspective. The Table 33 shows the percentage of respondents who are fully satisfied of robotic equipment with each size category, Large, Medium, and Small.

	Large	**Medium**	**Small**
Fully satisfied	23%	31%	22%

Table 33. Companies fully satisfied.

The adoption of robotics in the companies that participated in the survey have a distinctive influence on quality and productivity, with different implications depending on the size. As shown in the **Figure 40**, large companies, with an overall satisfaction rate of 23%, testify that the quality of processes and products has increased in 91% of cases, a sign that high technology and automation played a key role in the path of continuous improvement. This data contrasts with the results of medium-sized companies which, while expressing a higher overall satisfaction rate of 31%, recognize an increase in quality in a lower percentage of 67%, suggesting that the benefits of robotics can be perceived differently depending on the available infrastructures and resources.

	Large	**Medium**	**Small**
Quality	91%	67%	31%
Productivity	96%	95%	90%

Table 34. Operational impacts. Quality and Productivity.

Regarding productivity, the numbers are highly positive for all three types of companies. The high percentage of small businesses that have recorded an increase in productivity reveals that robotics can be a great leveller, confirming the democratization process of robotics that is underway. Medium-sized companies report an increase in productivity in 65% of cases, indicating that for companies of this size, the production systems are in a middle ground where there are challenges in robotic integration that do not allow these systems to fully exploit their potential.

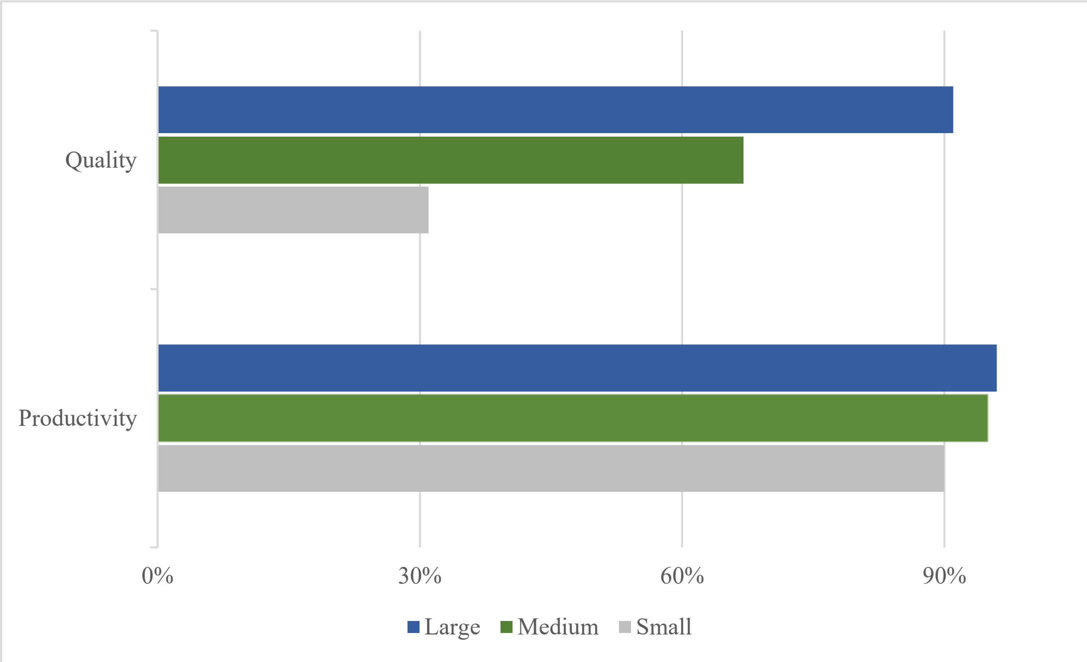


Figure 40. Operational impacts. Quality and Productivity.

While large companies continue to derive obvious benefits from high technology, small businesses demonstrate surprising resilience and adaptability, finding in robotics a key to growth and efficiency. Medium-sized companies, located in an intermediate position, can be the link to better understand how to optimize the implementation of robotics to maximize both quality and productivity.

4.4.3 Empirical outcomes

The aim of the analysis that follows is to examine the possible correlation between the implementation of robots and employment changes in companies adopting such technologies. For this purpose, data on personnel and economic performance of the sample of companies involved in the research are analysed, specifically in terms of total production and added value. Due to the lack of detailed information on robot installations in the Province of Brescia during the considered period, it is assumed that the local trend reflects the national Italian trend. Hence, these data are compared with the number of new robotic installations in Italy. The companies in the sample are classified into two categories: those without robots in their facilities and those using robots in their production lines.

	With Robot	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Personell	N	1.00	1.03	1.07	1.10	1.14	1.16	1.20	1.20	1.20	1.22
	Y	1.00	1.01	1.03	1.05	1.07	1.12	1.15	1.16	1.19	1.24
Value of production	N	1.00	1.04	1.10	1.09	1.14	1.24	1.24	0.99	1.30	1.56
	Y	1.00	1.05	1.05	1.08	1.20	1.37	1.34	1.22	1.67	1.88
Added Value	N	1.00	1.01	1.08	1.11	1.15	1.18	1.21	1.00	1.34	1.52
	Y	1.00	1.02	1.03	1.06	1.17	1.31	1.30	1.20	1.54	1.62
Robots new installations		4,701	6,215	6,657	6,465	7,760	9,847	11,089	8,525	1,4100	23,000

Table 35. With robot vs without robot comparison of empirical outcomes.

The diagram in **Figure 41** compares the employment evolution of the sample companies with the number of annual robot installations in Italy. For companies without robots, there was a constant increase in personnel from 2013 to 2022, with gradual and relatively stable growth, peaking in 2019. However, in 2021, there was a slight slowdown, presumably due to the COVID-19 pandemic, followed by a recovery in 2022.

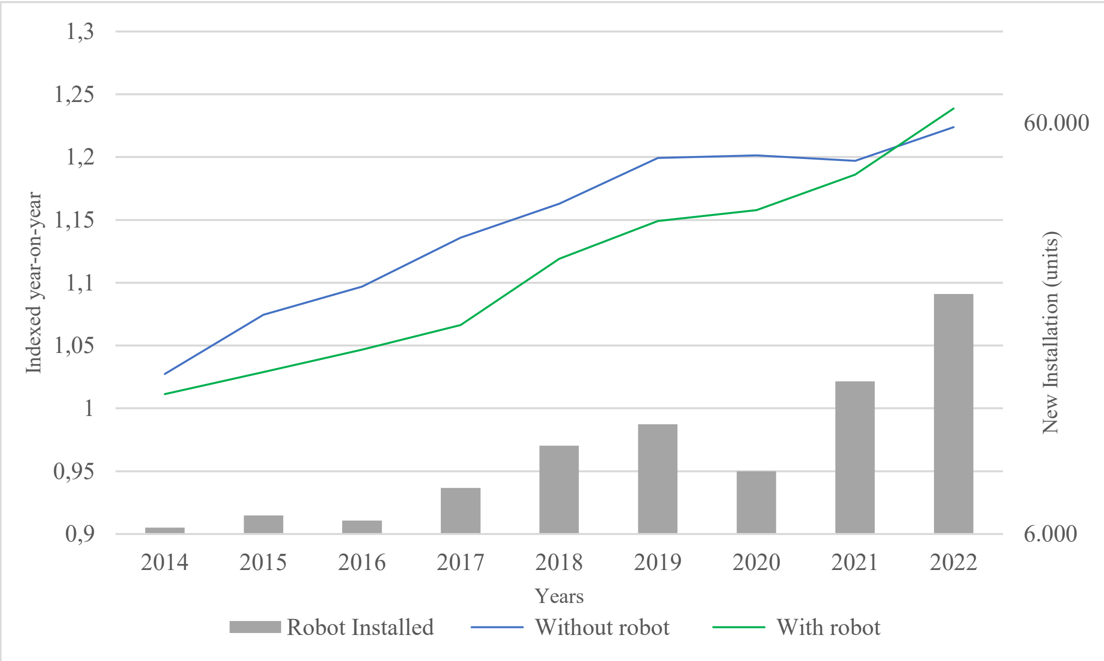


Figure 41. Personell trend comparison.

For companies with robots, a constant upward trend in employee numbers was observed, with a slightly higher growth rate than companies without robots. The most significant growth occurred between 2018 and 2022, suggesting a positive impact of robotics on employment in these companies.

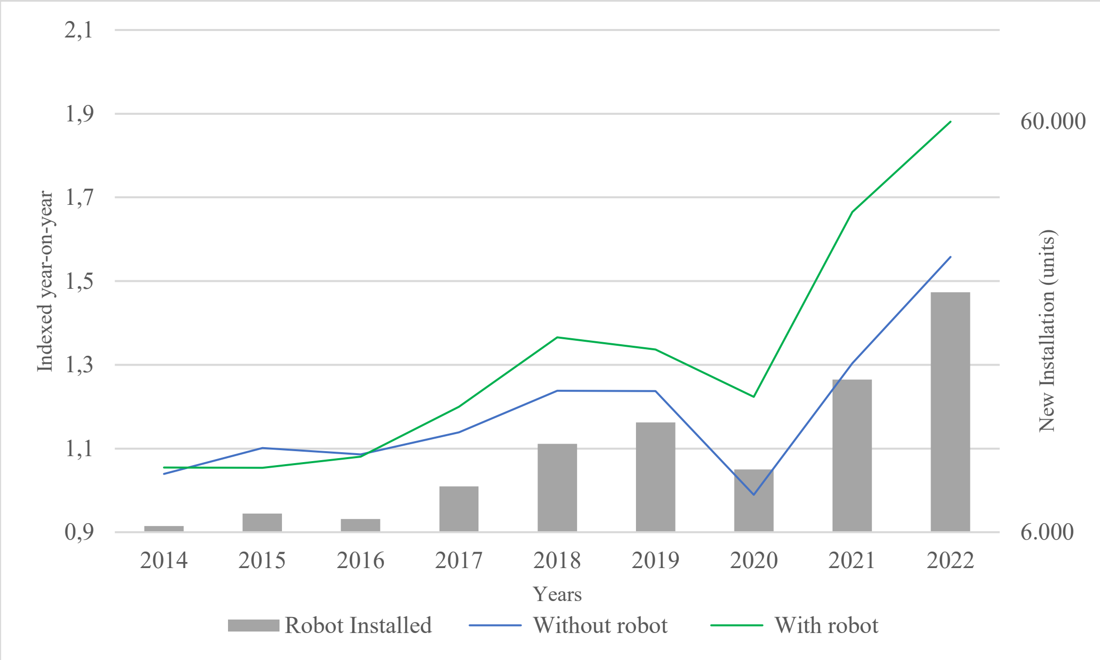


Figure 42. Value of Production comparison.

Extending the previous analysis to economic indicators such as the value of production and added value, the graph in **Figure 44** illustrates the comparison between the number of robots installed in Italy and the evolution of the production value of companies, both with and without robots. Similarly, **Figure 44** compares the number of robots installed in Italy with the changes in added value.

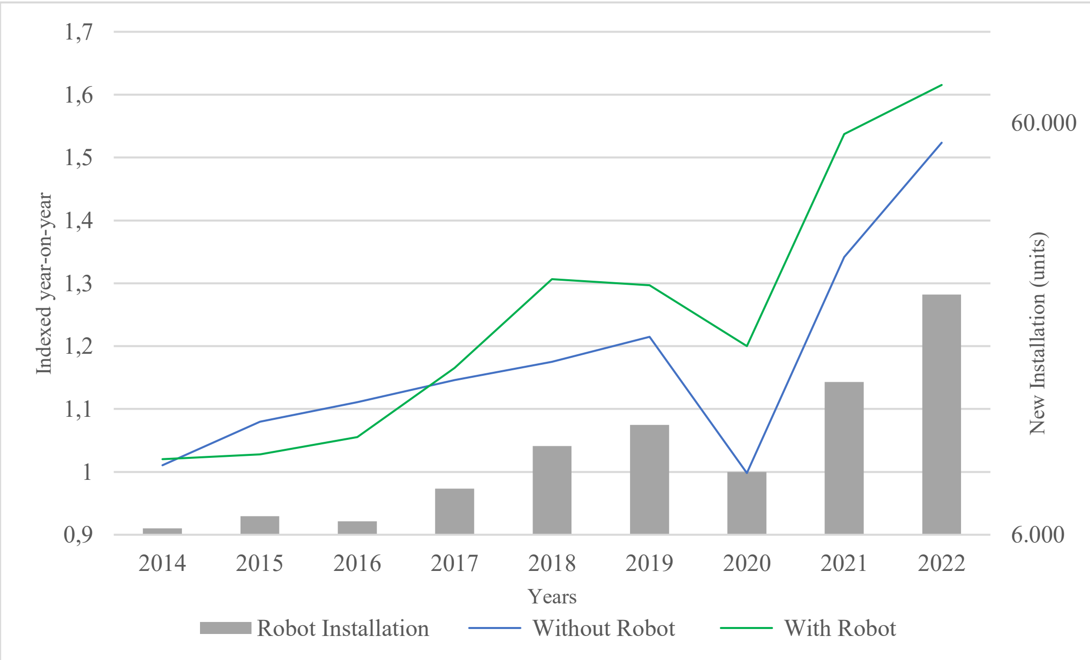


Figure 43. Added-Value comparison.

During the period under review, both the value of production and added value showed similar trends. For companies without robots, there was a variation in the value of production and added value, characterized by annual fluctuations. In particular, there was a marked increase in 2018 and 2022, except for the decline in 2020, which was affected by the economic impacts of external factors of that period. In contrast, in companies equipped with robots, data indicate a more substantial and sustained growth of these economic indicators compared to companies without robots. Particularly noteworthy is the acceleration starting from 2017 and the peak in 2022, both coinciding with an increase in robotic installations.

These empirical observations are consistent with the conclusions of numerous studies in academic literature. Referring back to the statements in the previous paragraph, it emerges that the spread of robotics does not lead to the destruction of jobs, but rather acts as a catalyst for economic growth, which can also translate into an increase in staff. In addition to the increase in personnel, there is also a greater company growth both in terms of production value and added value.

4.4.4 Q2.2 What is not satisfying the expectations?

The data presented reveals a complex picture of the challenges faced by companies of various sizes after integrating robotics into their operations. By delving deeper into this data, we can gain valuable insights into the nature of these challenges and the impact of robotics on industry.

	Large	**Medium**	**Small**
Specialized personnel presence during production	31%	29%	11%
Challenges in programming and managing the robot	9%	24%	40%
Issues caused by sensors	22%	14%	18%
Unexpected maintenances	17%	17%	22%
Assistance	17%	10%	10%
Malfunctioning of accessories	17%	5%	22%
Frequent human intervention	17%	5%	0%
Frequent production interruptions due to robot issues	9%	2%	0%

Table 36. Expectations not met

Large organizations report a requirement of specialized personnel at 31%. This figure, though substantial, is interestingly close to that of medium-sized companies, which report this need at 29%. In contrast, small enterprises indicate a markedly lower requirement, with only 11%. The marginal difference between large and medium-sized companies underscores a potential convergence in the complexities of robotic systems deployed. Conversely, the significantly lower value reported by small companies offers a different point of views. One could surmise that smaller enterprises might be deploying less sophisticated robotic systems, thereby diminishing the necessity for specialized oversight. Alternatively, it's plausible that smaller companies, with their leaner operational structures, might have a more integrated approach where specialized roles are merged with broader operational ones. Smaller companies, on the other hand, are more concerned about the programming and management of robots.

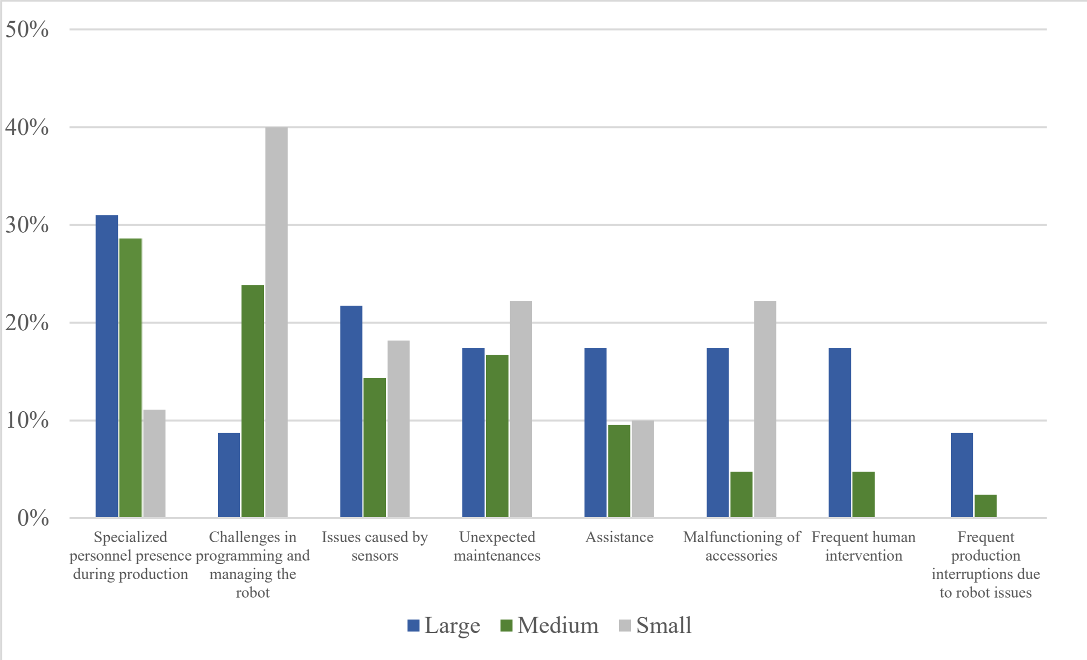


Figure 44. Expectations not met.

Small businesses show the highest percentage of difficulties, at 40%, highlighting the intrinsic challenges that these economic entities face in keeping up with the technical requirements imposed by automation. Medium-sized companies are in an intermediate range, at 24%, demonstrating a higher capacity compared to small ones but not yet up to the self-sufficiency typical of large companies, which only report 9% of problems in this area.

Complications related to sensors are a significant obstacle, with a relatively balanced prevalence among companies of various sizes. Large companies are affected by them in 22% of cases, medium-sized ones in 14%, and small ones in 18%, indicating that sensors, as fundamental elements of robotic systems, can generate operational problems regardless of the level of resources or personnel experience. Unplanned maintenance presents itself as another critical issue, touching all three business dimensions equally: 22% for both large and small companies, and slightly lower for medium-sized ones, at 17%. This indicates that the incidence of unexpected interventions is a constant in the use of industrial robots, influencing the programming and regularity of production processes. Focusing on the concrete consequences represented by the frequent need for human intervention and recurring production interruptions due to robotic problems, significant data can be observed. In large structures, such problems are found in 17% and 9% of cases, confirming that, despite the advanced degree of automation, there is still a need for human interaction and problem resolution. In smaller entrepreneurial contexts, surprisingly, such problems are not detected, a circumstance that could be interpreted as the internalization of a basic assumption: with limited resources, there is a greater need for direct involvement and glitches tend to be considered as inherent elements of the process. In other words, while these incidents do occur, they are not labelled as unexpected, but rather as aspects intrinsic to the adoption of robotic technologies in an environment with more limited resources.

4.5 Competences

In the field of robotics, both in terms of automation and collaboration, we are currently observing a phase of extraordinary technological advancements. The realignment of professional skills to best capitalize on the opportunities offered by these changes is of crucial importance. Academic institutions, along with corporate initiatives, play a fundamental role in achieving this goal through advanced training courses, coupled with targeted up-skilling and re-skilling programs. It is imperative that such training courses focus on the creation of qualified professional profiles. These should include roles specialized in the collaborative design of automated machines, with particular emphasis on the development of robot control logic and the management of electronic components related to modern automation systems. In addition, it is essential to prepare professionals capable of maintaining industrial robotics, combining mechanical, electronic, information technology, and problem-solving skills, as well as thoroughly understanding the potential and safety implications of human-machine interactions.

The architecture of the training courses should be bifocal: on one hand, focused on a theoretical approach that provides conceptual and methodological foundations, and on the other hand, on a practical approach implemented through laboratory experiences. Technological laboratories represent a key element of these programs, thanks to the use of specific solutions designed to safely reproduce real industry conditions. This approach ensures that students are adequately prepared to operate effectively in industrial contexts characterized by automation and digitization processes, ranging from small and medium enterprises to large corporations.

4.5.1 Q3.1 Do existing skills meet the requirements for managing robotic equipment? If not, how do you make up this lack?

The analysis of the data presented Table 37, several trends can be identified regarding companies' aptitude in managing robotic equipment. Large enterprises, often equipped with extensive resources and robust training infrastructures, manifest a commendable proficiency in this domain.

	Large	**Medium**	**Small**
Existing skills lack requirements for managing robotic equipment	18%	24%	38%

Table 37. Lack of requirements for managing robotic equipment

The 82% of such companies have successfully cultivated a workforce adept at handling robotic equipment. This underscores the intrinsic advantages large corporations possess, allowing them to swiftly adapt to technological advancements. On the contrary, the 18% of large enterprises find themselves in a difficulty, facing with a skill deficit. This contrast presents an interesting problem. Despite the abundance of resources, certain intrinsic challenges, such as resistance to technological paradigm shifts, might impede the seamless integration of new technological skills. Medium-sized companies, operating within a more constrained resource environment compared to their larger counterparts, exhibit a similar trend. Approximately three-quarters of these enterprises have successfully upskilled their workforce, while a quarter are yet to bridge this skill chasm.

	Large	Medium	Small
Hiring	26%	20%	5%
Training	90%	90%	58%
None Action	0%	0%	42%

Table 38. Measures to compensate for lack of skills.

The proximity of these figures to those of the large enterprises suggests that the total scale of a company determine its adaptability to technological advancements. Instead, other factors, perhaps organizational agility, or leadership vision, might play a pivotal role. Smaller businesses have a slightly more complicated situation. While 62% of them are capable in handling robotic equipment, they fall behind larger and medium-sized enterprises. These businesses often operate with limited resources and might face difficulties in consistently improving their skills.

Examining the data table detailing how different companies of various sizes respond to technological changes, several findings are evident. Firstly, the predominant approach used by companies, particularly in larger and medium-sized ones, is providing training to their employees, with a notable adoption rate of 90% in both categories.

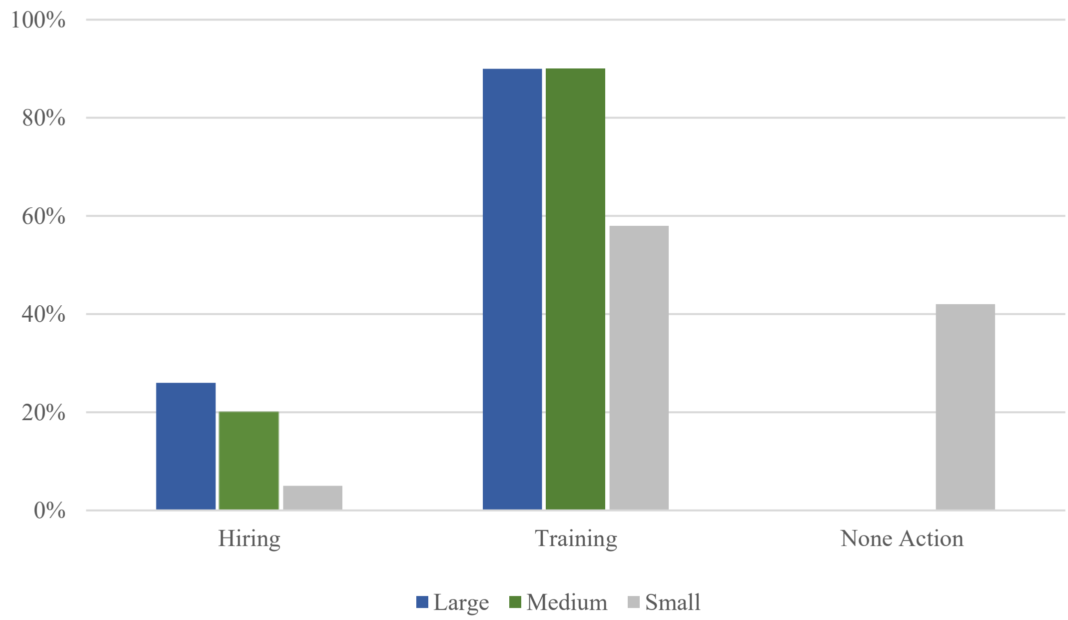


Figure 45. Measures to compensate for lack of skills.

This highlights the importance of investing in the current workforce's skills, not only to address immediate technological skill gaps but also to promote a culture of continual learning and adaptability. As technology advances rapidly, focusing on training is a wise strategic move that can strengthen a company's resilience against future disruptions. Another interesting finding is related to hiring practices. Larger companies tend to hire new employees with the necessary skills at a higher rate of 26%, compared to medium-sized ones at 20%. This could be due to the greater resources and wider access to talent networks that large corporations typically have. On the other hand, small companies have a significantly lower rate of 5% in hiring, which can be attributed to their limited resources and financial constraints, making large-scale hiring efforts impractical.

However, the most striking data point is the column representing "None Action" While larger and medium-sized companies show proactive behaviour by not resorting to inaction, a notable 42% of small companies have refrained from taking any action, whether through hiring or training. This poses important questions about the obstacles that small companies face. It could be due to various reasons, such as financial limitations or lack of awareness about upcoming technological change.

4.5.2 Q3.2 Which tasks are supported by external suppliers?

The data presented in **Figure 46** offers insights into how robotics companies of varying sizes tend to approach outsourcing solutions for different aspects of their operations. By examining into these details, we gain a better understanding of the complex strategies and priorities that lead their decisions. The data trend reveals that companies of all sizes tend to keep ordinary maintenance tasks in-house, with relatively low outsourcing rates. This is likely due to several factors, including the fact that these tasks don't require a high level of specialized skills. As such, they can be efficiently handled by the internal workforce, which reduces the need for external support. Additionally, there's the cost-effectiveness of managing ordinary maintenance internally, as well as the ability to respond quickly to everyday maintenance needs. By relying on their own skilled personnel, companies can ensure a faster turnaround time when addressing issues.

	Large	**Medium**	**Small**
Ordinary maintenance	13%	10%	5%
Extraordinary maintenance	91%	93%	90%
Sensor maintenance	52%	55%	75%
Robot reprogramming	39%	29%	38%
Cell design	83%	64%	90%
Accessory design	52%	55%	75%
Personnel training	57%	50%	50%

Table 39 Tasks supported by external suppliers.

However, the data also shows that regardless of company size, there's a high reliance on external suppliers for extraordinary maintenance. This trend is particularly striking, with 91% of large companies, 93% of medium-sized companies, and 90% of small companies seeking external support for these tasks.

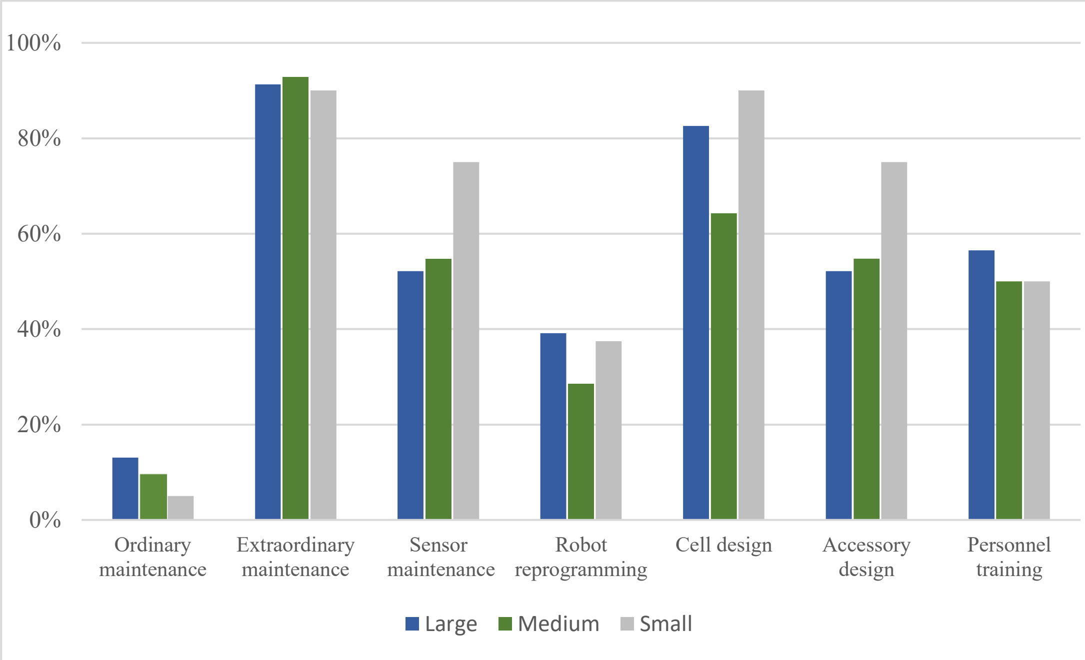


Figure 46. Tasks supported by external suppliers.

This suggests that these tasks require a higher level of specialized skills and expertise that may not be readily available in-house. Interestingly, small companies seem to be leading when it comes to sensor maintenance, with a high outsourcing rate of 75%. This likely reflects their resource constraints, which make it more efficient to engage external expertise. On the other hand, larger companies have the capacity to handle sensor maintenance in-house or have established partnerships with sensor technology providers. Medium-sized companies seem to be the most confident in robot reprogramming with their in-house expertise, with only 29% outsourcing this task. In contrast, small and large companies exhibit a more comparable reliance on external suppliers, driven by the need for specialized skills or flexibility in adapting their robotic systems. When it comes to designing and training personnel for robotic systems, different companies have varying approaches. Large and small companies exhibit a relatively high level of outsourcing when it comes to cell design, suggesting a strategic approach to this critical aspect of their robotics operations accessing specialized external expertise, and enabling them to tackle complex design challenges. On the other hand, medium-sized companies tend to outsource this task only with the 64%. Similarly, for accessory design, small companies outsource the most, with 75% outsourcing this task. Medium-sized companies follow closely behind, with 55% outsourcing, similarly to large companies, with 52%. This pattern suggests that large and medium-sized companies have established internal technical departments capable of accessory design, appear to benefit from greater efficiency and cost savings by utilizing their in-house expertise and resources. Finally, large companies tend to outsource personnel training slightly more, with 57% outsourcing compared to 50% for medium and small companies. This indicate that larger companies prioritize specialized training services, perhaps due to their larger workforce or the diversity of applications for their robotic systems.

4.5.3 Q3.3 Reflecting on the decision-making process, which services would have been helpful?

Below are the results on critical factors that influence the decision-making process of companies during the evaluation phase. To better understand the preferences and needs of companies of different sizes and sectors, we asked participants which services they would find most useful in this decision-making process. Survey responses, like the previous questions, were grouped by size factor: large, medium, and small businesses.

	Large	**Medium**	**Small**
3D cell simulation	43%	29%	13%
Turnkey solution	30%	40%	75%
Technical insights	35%	29%	25%
Time and Methods analysis	52%	43%	25%
Business plan	26%	45%	38%
Tax incentive measures analysis	13%	29%	0%

Table 40 Services would have been helpful during the decision-making process.

The use of 3D simulation of a cell allows for a complete and detailed evaluation of the integration of robotic cells in the design phase, ensuring effectiveness, particularly in large-scale operations. This includes features such as "digital twin" technology and "virtual commissioning" that enable the construction of a model capable of replicating the functioning of the cell. It is often preferred by large companies because they have highly skilled technicians and advanced methodologies for planning new work layouts. This is confirmed by the participants' responses, where large companies attribute the most importance to 3D simulation of the cell, with 43% indicating its significance. In contrast, medium-sized and small-sized companies, with respectively 29% and 13%, consider it less significant due to their resource limitations.

Turnkey solutions offer an all-inclusive package for companies seeking an automation solution. This implies full reliance on external providers for the design and implementation of the robotic cell. This approach is typically adopted by companies that may lack internal skills and have limited staff available to dedicate themselves to the realization and management of a robotic cell. Therefore, small businesses attach great importance to turnkey solutions, with a significant 75%. Growing with the size factor, this option is considered less significant, as stated by 40% of medium-sized businesses and 30% of large businesses because they have the necessary resources and experience to manage the process autonomously. Technical insights have a relatively uniform importance, indicating that companies of all sizes recognize limited value in this activity. This result suggests that robotic cells are increasingly considered as consumer goods that can be implemented and adapted flexibly to their needs, without resorting to particularly complex technical interventions.

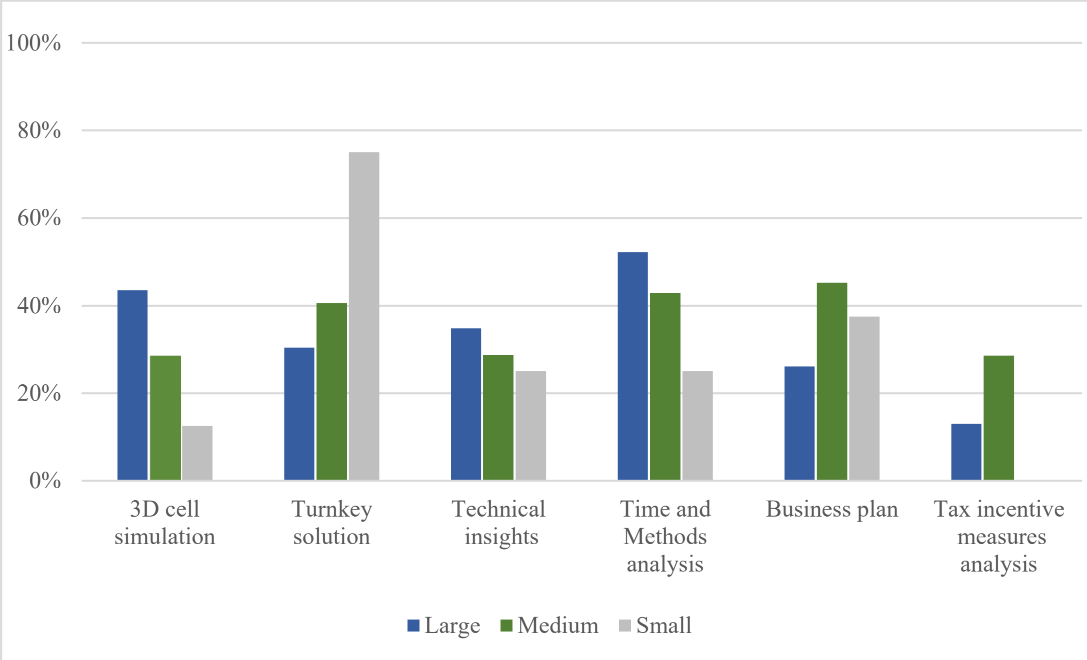


Figure 47. Services would have been helpful during the decision-making process.

The 52% of large companies attach great importance to time and motion analysis, suggesting a strong awareness of the potential impact on production systems. This activity is particularly valuable for ensuring fast and reliable integration into existing workflows, avoiding potential disruptions and inefficiencies. The 43% of medium-sized companies recognize its significance, while 25% of small businesses seem to underestimate this aspect. In many cases, the impact of time analysis is not considered in the initial planning phase of the project. Consequently, companies often find themselves needing to adapt their production systems after the installation of a robotic cell to ensure the planned productivity.

Small and medium-sized businesses, with 38% and 45% of responses, respectively, rate the business plan as a service that would be highly useful. This emphasizes the fact that these companies often do not draw up economic plans because they lack the necessary skills to accurately predict the financial implications of investments in robotic cells. Large companies, on the other hand, with 26% of responses, attach less importance to this because they have more figures dedicated to these tasks. Overall, all three types of companies highlight a relatively minor importance assigned to the analysis of tax incentive measures. This suggests that companies often consider investments in robotic cells to be self-sufficient and that, in many cases, this activity is already carried out by specialized consultants.

4.5.4 Q3.4 Which professional figure does the company consider appropriate for the installation and management of robots?

The evolution of industrial automation has generated an increasing need for qualified professionals capable of managing and supervising robot operations in various business contexts. The presented Table 41reveals which professional profile companies of different sizes consider most suitable for the installation and management of robots. The professional figures presented are: Industrial Technician, Automation Engineer, and Master's in Automation Engineering.

	Large	Medium	Small
Industrial Technician	32%	49%	56%
Automation Engineer	46%	11%	0%
Master's in Automation Engineering	54%	34%	28%

Table 41 Professional figures.

The Master's in Automation Engineering plays a key role in industrial automation, contributing in various ways to the efficiency, reliability, and safety of industrial processes. Specifically, they are responsible for designing automated control systems for industrial processes. This process involves defining specifications, selecting necessary hardware and software components, and creating diagrams and algorithms that enable the automation of production and control operations. Advanced knowledge of process optimization, as well as artificial intelligence concepts, is required for these activities. They write operating manuals, maintenance manuals, and system user guides, ensuring that company personnel can understand and use the system effectively and safely. The Automation Engineer has a less in-depth and transversal technical training than the Master's in Automation Engineering. They have a foundation in electronics, computer science, and control systems. Typically, their knowledge base also includes programming PLCs (Programmable Logic Controllers) and SCADA (Supervisory Control and Data Acquisition). Their role is to work in the technical office, performing design roles as well as testing activities to ensure that everything works correctly, and the automation systems are realized. The Industrial Technician has a more direct and practical professional training, such as the maintenance and repair of automated equipment, ensuring their proper functioning and resolving technical problems. Additionally, they install new automation equipment and support engineers in PLC programming.

Therefore, analysing the data presented in **Figure 48**, it is possible to draw conclusions about the current panorama of automation and the training needs of the job market. At first glance, it is observed that large companies tend to prefer figures with "higher" education, as evidenced by the fact that 54% of large companies consider Master's degree holders, specifically Automation Engineers with five years of training, more suitable. This preference is attributed to the increasing complexity of automation operations in large environments, where process management and optimization require deep technical knowledge and advanced transversal training. On the other hand, the percentage of large companies that prefer an Industrial Technician stands at 32%, suggesting that, although advanced training is valued, there is still ample room for professional profiles with a basic technical training but with practical field experience.

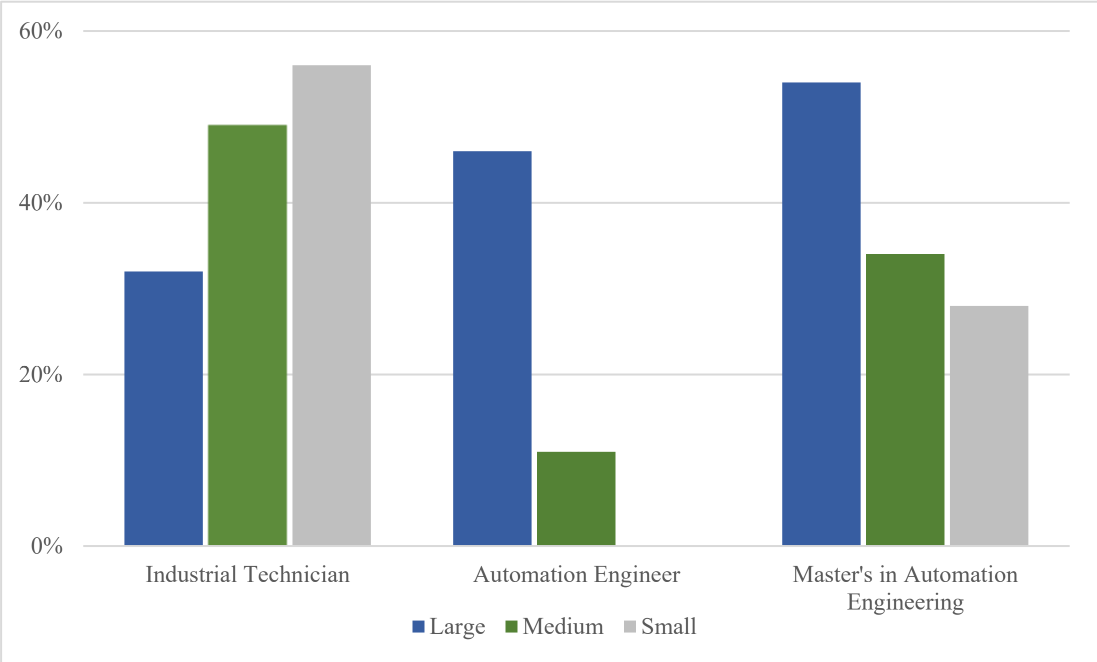


Figure 48. Professional figures considered appropriate for the installation and management of robots.

Medium-sized companies have a more heterogeneous distribution of their preferences. While 49% lean towards an Industrial Technician, only 11% consider an Automation Engineer with three years of training more suitable. It is also interesting to note that the percentage rises to 34% when considering an Automation Engineer with five years of training. This indicates that medium-sized companies have different needs in terms of the complexity of their production systems compared to large companies, as complexity is manageable by professional figures with less in-depth training. Additionally, as we saw in the previous paragraph, when extraordinary operations requiring greater skills are needed, medium-sized companies turn to external providers.

Finally, small companies show a clear inclination towards professional figures with practical training, as evidenced by the 46% that prefers an Industrial Technician. In fact, only 28% of small companies recognize the value of an Automation Engineer with five years of training, considering the competence of an Industrial Technician sufficient and stressing that the limited company size places a budget limit on resource acquisition.

4.6 Future Vision

4.6.1 Q4.1 + Q4.2 Is the company planning to install robots? Is the company planning to hire graduates with a Master's degree in automation engineering within the next three years?

The transition towards a highly automated economy is a global phenomenon, and the forecasts for the period 2023-2026 outlined in the presented table reveal some key trends related to the adoption of robotics and the hiring of specialized figures in industrial automation among companies of different sizes.

Large companies prove to be leaders in terms of adopting advanced technologies. This is demonstrated by the fact that all large companies have expressed their intention to install robots in the next three years. This result also confirms their growing dependence on automation to maximize efficiency, productivity, and ultimately, competitiveness in the market. Moreover, it is interesting to note that 61% of large companies intend to hire an Industrial Automation Engineer in the same time period. This value reflects the obvious demand for qualified personnel generated by the increasing automation of production processes. These figures contribute to creating increasingly qualified teams of engineers, making companies even more flexible and competitive.

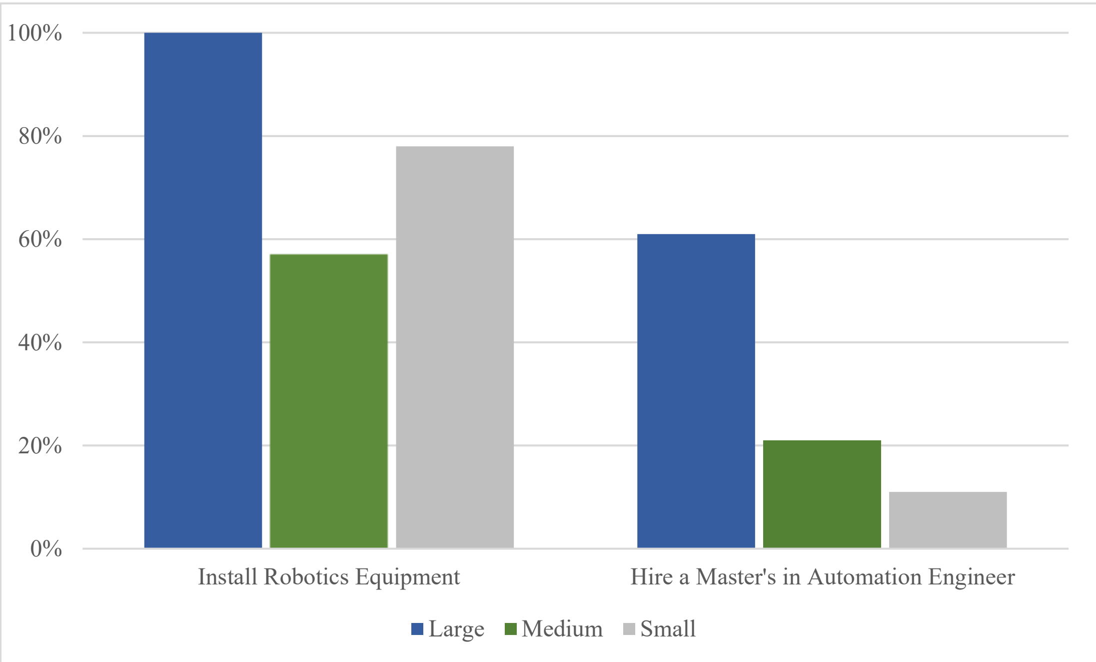


Figure 49. Companies that are planning to install robots or hire graduates with a Master's degree in automation engineering within the next three years

Moving on to medium-sized companies, the expected adoption of robotics stands at 57%, while only 21% of these companies plan to hire an Industrial Automation Engineer. This disparity suggests that medium-sized companies are more cautious in facing this period of economic uncertainty, especially when it comes to increasing their support staff. On the other hand, the forecast for expanding their robot fleet is positive and encouraging, a testament to the general positive effect resulting from the installation of robotic solutions.

Small businesses, representing a significant share of the production fabric, show a surprising and encouraging trend. In fact, 78% of them plan to adopt robotic solutions, confirming that the democratization of robotics is underway. Moreover, this demonstrates that confidence in robotics is growing and is about to spread convincingly even in the smallest realities. However, their inability to reach other skilled profiles is confirmed, as only 11% plan to hire a specialized Engineer. As already hypothesized earlier, while recognizing the importance of having skilled figures within their organization, small businesses demonstrate a lack of financial resources or the infrastructure necessary to support an internal team of specialists. Considering that 2 out of 3 small businesses have not yet adopted robotics but are considering the option, it highlights the enormous growth potential in this segment.

Chapter 5

Discussion and Conclusion

The global expansion of industrial robotics represents a rapidly growing phenomenon, fuelled by continuous technological innovations and global economic growth. This expansion unfolds in two main directions: on one hand, there is a consolidation in already mature markets; on the other, an exploration process in new territories, particularly in developing countries and small businesses, which constitute a significant percentage of the global corporate fabric.

Related to RQ1, in mature markets, industrial robotics has already established a strong presence, with significant applications in sectors such as automotive and electronics, where the precision and efficiency of robots have enabled high-quality mass production. These markets are expected to continue offering growth opportunities through ongoing innovation and optimization of existing production processes. Within the sample of companies surveyed, there is a marked tendency among large enterprises towards the integration of robotic solutions, with a general trend towards advanced-level automation. In contrast, only a minority of small enterprises have embarked on this technological path, highlighting a significant disparity in the adoption of automation strongly influenced by the size of the company.

Anthropomorphic robots emerge as the most prevalent category within companies, regardless of their size. Their high flexibility and precision make them particularly suitable for a wide range of applications in the industrial sector, underscoring the central role these systems play in industrial automation. The use of Cartesian and SCARA robots is more limited and characterized by variable distribution in relation to the specific needs of the business and the applications for which they are intended. The study shows that robots are primarily employed for handling operations and machine servicing, regardless of the business context in which they are installed, demonstrating their effectiveness in automating the transfer and manipulation of materials and components. Developments in the field of miniaturization are leading to the creation of increasingly compact, agile, and flexible robots. This trend towards miniaturization opens new application perspectives, particularly in industrial environments with limited space or in operations that require extreme precision. The reduction in robot sizes not only allows for more efficient use of space in production contexts but also significantly increases their versatility. Smaller robots can be easily transported and adapted to various tasks, proving particularly suitable in industrial sectors characterized by high variability in production needs.

Related to RQ2, the key factors driving companies towards the implementation of industrial robotics primarily include the aspiration to increase productivity, expand production capacities, and pursue cost optimization. These elements are closely interrelated: automation allows for the maintenance or increase of production levels while simultaneously reducing the use of resources. Concurrently, the integration of robots into business dynamics is often aimed at enhancing the quality of production and providing support to employees, thereby mitigating workload and increasing workplace safety. It is noted that companies, regardless of their size, tend to significantly rely on external suppliers for a wide range of key services related to robotics. This includes the reprogramming of robots, the design of robotic cells, and the design of accessories. A marked dependence on such external suppliers is particularly evident in the area of extraordinary maintenance, due to the requirement of specialized skills and knowledge that are often not available internally within the organization.

The incorporation of robotics into the work environment introduces a series of complexities and challenges that companies must face. Some of these challenges, such as issues related to sensors and the need for unexpected maintenance, arise regardless of the size of the enterprise. Others, particularly for small businesses, involve difficulties in programming and operating the robots, raising pertinent questions regarding the ease of use and accessibility of robotic technology for smaller-sized enterprises. The empirical observations are consistent with the conclusions of numerous studies in the academic literature. It emerges that despite the size of enterprise, the spread of robotics does not lead to the destruction of jobs, but rather acts as a catalyst for economic growth, which can also translate into an increase in staff. In addition to the increase in personnel, there is also a greater company growth both in terms of production value and added value. The analysis conducted on survey results reveals that the use of robots transcends mere issues of speed and volume, significantly contributing to the enhancement of production quality and the creation of a more gratifying and safer work environment. The progressive adoption of robotics in businesses has triggered a change in the structure of work. On one hand, there is a trend towards a reduction in direct labour activities, while on the other, there is a notable increase in indirect work. This shift highlights a transformation in the role of workers, who move from manual tasks to roles of supervision, maintenance, and programming, implying the need for more advanced skills and greater versatility.

The advent of robotics in the industrial and everyday context brings about the emergence of new issues and challenges. aspects such as security and cybersecurity are gaining increasing importance. With the rise in connectivity and interoperability of robotic systems, protection against cyberattacks becomes a primary priority. Anti-hacker systems are essential to ensure that industrial robots are safeguarded from external intrusions and illicit manipulations. This area includes the protection of robot control software and the security of data exchanged between robots and centralized management systems. Anomaly detection plays a critical role in preventing and mitigating potential security risks. Advanced monitoring systems will be able to identify unusual behaviours in robots, signalling possible intrusion attempts or system malfunctions, thereby allowing for timely interventions to prevent damage or operational interruptions. Furthermore, efficient backup and restoration systems will ensure a prompt recovery of robotic activities following interruptions, minimizing downtime and preserving productivity in the industrial context.

Related to RQ3, the study indicates that the ability of companies to effectively manage robotic equipment varies according to their size. Large enterprises, often beneficiaries of abundant resources and established training infrastructures, demonstrate significant competence in this area, highlighting the link between available resources and effectiveness in managing industrial robotics. As industrial automation continues to evolve, the training needs of the labour market follow a parallel trajectory. Large-scale business entities, characterized by complex systems and extensive operations, require highly qualified professional profiles. Regardless of the company size, there is a growing recognition of the intrinsic value of robust training, both technically and academically, reflecting the challenges and opportunities presented by the fourth industrial revolution. Thus, the implementation of industrial robotics induces substantial changes in every area of the enterprise, leading to a global need for training that involves the entire workforce and all organizational functions. It becomes essential for companies to proceed with an accurate identification of the specific training needs for each individual professional profile. This process aims to provide the staff with adequate tools to effectively face technical and organizational challenges, through the development of customized and targeted training programs. In conclusion, the introduction of robots into the workplace is perceived as a complex learning process that involves the entire work structure, not limited to the individual. This view underscores the importance of an integrated, holistic, and multidimensional approach to innovation, taking into account the technical, relational, and existential implications of robots in the work context.

Related to RQ4, in the 2023-2026 horizon it is predicted that large companies will continue to consolidate their leadership in adopting advanced technologies, while medium and small enterprises face strategic decisions regarding the balance between investments in automation and human resource management. Regarding COBOTs, the new generation of industrial robotics, despite their significant potential for adaptability and application in various fields, an underutilization of these is observed, especially in small and medium-sized enterprises. Nevertheless, the evolution towards greater collaboration between humans and robots emerges as a key perspective outlined by robot manufacturers and the scientific community. Currently, the sales and presence of COBOTs in companies are limited, especially when compared to traditional robots; however, their adoption is expected to become more widespread in the future, particularly in developed countries. This will represent a radical shift from the traditional model of industrial robotics, where robots were confined to separate areas for safety reasons. COBOTs are increasingly capable of integrating into diverse work environments and collaborating directly with staff, offering new opportunities in terms of operational and application flexibility. To facilitate this integration, the development of intuitive user interfaces is necessary, aiming to make robots accessible to a broader audience, including those without previous experience in robotic programming. Modern interfaces tend to focus on usability, often incorporating features such as touchscreen control, visually guided programming, or even gesture-based control. In this expansion process, technological innovation plays a fundamental role. Emerging technologies, such as artificial intelligence (AI), advanced sensors, and artificial vision systems, are revolutionizing the field, making robots progressively smarter and capable of operating autonomously in complex environments. These technologies not only enhance the functionalities of robots but are also accelerating the entry of robotics into previously unexplored sectors. Particularly, technological challenges in the field of industrial robotics focus on machine learning and artificial intelligence.

Next-generation robots will be characterized by their increasing ability to learn autonomously and adapt to new contexts and situations. This translates into a significant increase in their operational autonomy and the ability to dynamically adapt to variations in the production environment. This will not be possible without an evolution of sensors. The robots of the future will be equipped with cutting-edge sensors that will provide a more precise and detailed perception of the environment. This includes the implementation of artificial vision systems and tactile sensors that will enable robots to "see" and "feel," significantly improving their capabilities. Moreover, integrated AI algorithms will allow robots to process sensory data in real time and make independent operational decisions, minimizing the need for human intervention.

5.1 Developing Competencies in Industrial Robotics

5.1.1 Skills and Competencies

This paragraph provides insight into the skills required in the field of robotics, placing particular emphasis on the educational prerequisites for professionals involved in automated industrial work environments. These individuals are expected to assume key roles in design and management, which are fundamental for the effective management of robotic systems and automated plants. This context is characterized by advanced integration of computer systems, measurement devices, transmission, and actuation mechanisms, where the required skills go beyond traditional technical abilities. Therefore, operators must possess a background in STEM (Science, Technology, Engineering, and Mathematics) [89], which includes:

- Scientific foundations: a robust understanding of mathematics, physics, and chemistry is essential for comprehending and applying the principles that govern industrial and information sectors related to robotics.
- Mechatronics engineering: comprehensive knowledge of mechanics, electronics, and computer science is crucial for understanding the functioning of components, devices, and automated machinery.
- Systems control: expertise in control methodologies applied to machines and systems, essential for optimizing operational efficiency and safety.

- Industrial communications: an understanding of industrial communication systems to ensure efficient management of information flow in production processes.

Beyond technical skills, transversal abilities are also necessary [212], including:

- Managerial and organizational skills: an understanding of business contexts, with particular attention to production environments, and the capability to optimize systems or processes.
- Communication and interpersonal skills: effectiveness in communicating with specialists from various disciplines, vital for the coordination of multidisciplinary teams.
- Leadership: the ability to lead and instruct teams, critical for active management of production lines and robotic cells.

These competencies provide employees with a broad interdisciplinary perspective, enabling them to address and solve complex problems without excessive specialization, but with a strong aptitude for rapid adaptability to situations.

5.1.2 Remember Knowledge and Understanding

At the conclusion of the training program, it is essential to demonstrate a thorough understanding and the ability to enumerate the fundamental disciplines that constitute the theoretical and practical foundation of industrial automation. This requires precise knowledge of various branches of automation, such as applied mechanics, control, and measurement, which are crucial for comprehending and operating effectively within the field. Furthermore, one must be able to recognize and articulate the theoretical principles underlying these disciplines. Such an understanding allows for an appreciation of how these theories support practical applications and innovations. Additionally, it is important to possess the ability to identify and describe the technologies currently employed for the analysis, design, development, and management of industrial automation systems. This competence ensures effective contribution to the creation and enhancement of complex systems. Beyond these technical skills, it is necessary to emphasize the importance of having a solid understanding of the principal criteria for production organization and resource management. This ability enables the optimization of processes and the improvement of operational efficiency. Understanding these aspects is a prerequisite for successfully navigating the challenges of new industrial work environments and is a cornerstone for promoting a corporate culture focused on innovation and continuous improvement.

5.1.3 Apply Knowledge

In the practical application of theoretical knowledge, one must demonstrate the ability to use acquired skills effectively and relevantly. This requirement manifests in various operational domains, such as in the design and implementation of industrial automation systems, where the integration of mechanical and electronic components is necessary to optimize system performance and efficiency. Additionally, the capability to manage and lead complex systems, such as production facilities, is required, applying a strategic vision to enhance and optimize production output, as well as to raise the quality level of the results.

There is also a need to extend these application skills to various technological sectors typical of industrial robotics. These include mechatronics, which demands the development of advanced technological solutions integrating disciplines such as mechanics, electronics, and computer science; the reduction of energy consumption in components and systems, which involves adopting engineering methods to maximize energy efficiency; and finally, the use of advanced sensors for the implementation of monitoring and control technologies that optimize data collection, sharing, and information analysis.

Ultimately, these skills should be applied in a practical and concrete manner, to facilitate the transition from theoretical knowledge to operational solutions that not only improve performance but also stimulate innovation.

5.1.4 Analyse and Evaluate

Following the completion of the training program, a capacity for critical analysis and evaluation of systems integrating mechanical and electronic components has been developed. It becomes important to possess a profound competence in configuring these components in order to identify the most effective solutions for the design of complex electronic machines and systems, including automation and control devices, numerical controls, machine tools, and robotics.

Furthermore, there must be an ability to perform the selection and accurate interpretation of data extracted from various databases, applying a critical method that ensures the relevance and adequacy of the data in relation to the specific requirements of the project. It is fundamental to systematically analyse the results obtained from computer processing or experiments, assessing the suitability of the procedures used and suggesting improvements where necessary. Additionally, the capacity to critically evaluate the introduction of innovative or emerging technologies in the field of industrial automation must be developed, considering not only the technological efficacy but also the implications associated with adopting such technologies. In conclusion, a critical and open attitude should be developed, oriented towards identifying the most appropriate and sustainable solutions.

5.1.5 Communication skills

At the end of the educational process, professionals are expected to develop the ability to articulate conclusions and the fundamental principles supporting them in an unequivocally clear and unambiguous manner. They must be capable of conveying such information to both specialized interlocutors and those lacking specific technical training, including colleagues from diverse backgrounds. In particular, it is essential that the professional be able to: appropriately contextualize their work within broader scopes and justify decisions taken in a comprehensible and persuasive manner. Disseminate their expertise using the most advanced methodologies and technologies for presentation and documentation, tailoring communication to meet the needs of the audience. Collaborate effectively within both homogeneous and heterogeneous work teams. Coordinate and actively participate in project groups, train colleagues in the industrial sector, and manage staff training. Such an approach requires strategic communication that not only conveys information but also facilitates interdisciplinary dialogue and promotes a collaborative environment.

5.2 Limitations of the study and future work

The current research presents limitations that require attention. In particular, the analysis focuses exclusively on large, medium, and small enterprises, excluding partnerships and micro capital companies. This aspect could limit the overall understanding of the phenomenon under study, since these entities, although they do not have large individual turnovers, are numerous and could offer interesting research insights, especially considering their potential openness to adopting advanced technologies such as industrial robotics, which could have a significant impact on their production processes. Moreover, the research was limited to a single industrial sector, thus compromising the ability to generalize the results. The dynamics of adoption and the impact of robotics can vary significantly across different sectors, suggesting the need to extend the analysis to include a variety of productive fields.

In light of these limitations, several directions for future research emerge. A deeper focus on micro-enterprises and partnerships could better illuminate the challenges and opportunities related to the adoption of robotics in less structured business contexts. Such studies could prove particularly useful, as direct contact and interviews can be challenging but extremely revealing in these environments. Expanding the field of investigation to additional industrial sectors could also enrich the understanding of robotics adoption, providing a more comprehensive and generalizable view. Examining other sectors such as the food, chemical, or textile industries could reveal distinct adoption dynamics and stimulate new insights into specific needs and responses to technological innovation. Finally, a broader geographical perspective, extending the analysis to other regions or even internationally, could offer a more detailed view on the adoption of industrial robotics and the various policies and economic incentives influencing such adoption. These insights could significantly contribute to the existing literature, enhancing our understanding of the potential and challenges associated with integrating robotics into the modern production.

ANNEX

ANNEX I. Nr. of Employees per ATECO category (units).

Code	ATECO	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
A	AGRICULTURE, FORESTRY, AND FISHING	692	821	1,019	1,048	1,204	1,520	1,910	2,026	2,551	2,533
B	MINING AND QUARRYING	1,001	750	762	736	745	762	748	731	746	738
C	MANUFACTURING ACTIVITIES	73,303	77,368	80,996	84,781	88,375	94,067	98,090	104,046	106,349	109,979
D	ELECTRICITY, GAS, STEAM, AND AIR CONDITIONING SUPPLY	2,719	2,732	2,752	3,687	3,746	3,828	3,950	4,009	4,166	4,299
E	WATER SUPPLY; SEWERAGE, WASTE MANAGEMENT, AND REMEDIATION ACTIVITIES	2,763	3,319	3,461	3,636	3,976	4,291	4,587	4,826	5,118	5,290
F	CONSTRUCTION	11,042	11,827	12,679	13,501	15,121	16,590	18,604	20,562	23,343	24,274
G	WHOLESALE AND RETAIL TRADE; REPAIR OF MOTOR VEHICLES AND MOTORCYCLES	15,454	16,370	18,328	19,866	21,528	22,559	24,324	27,589	29,286	29,924
H	TRANSPORTATION AND STORAGE	3,926	4,196	4,543	5,118	5,817	6,540	7,249	7,805	8,510	8,789
I	ACCOMMODATION AND FOOD SERVICE ACTIVITIES	6,108	6,625	7,306	8,468	10,630	12,156	13,102	11,750	13,297	16,423
J	INFORMATION AND COMMUNICATION SERVICES	2,270	2,481	2,724	3,045	3,348	3,678	4,085	4,435	4,636	5,022
K	FINANCIAL AND INSURANCE ACTIVITIES	2,964	2,998	3,183	3,320	3,479	3,389	3,403	3,455	3,658	3,681
L	REAL ESTATE ACTIVITIES	3,099	3,086	3,098	3,068	2,740	2,691	2,608	2,417	2,227	2,133
M	PROFESSIONAL, SCIENTIFIC, AND TECHNICAL ACTIVITIES	4,514	4,805	5,263	5,645	6,079	6,393	6,806	7,683	8,365	8,278
N	RENTAL, TRAVEL AGENCIES, AND BUSINESS SUPPORT SERVICES	14,016	13,866	11,959	17,153	16,880	21,094	20,838	22,324	26,449	28,328
P	EDUCATION	849	923	1,036	1,173	1,422	1,629	1,640	1,618	1,736	1,733
Q	HEALTH AND SOCIAL ASSISTANCE	4,201	5,188	5,431	6,214	6,614	6,784	7,068	6,963	7,379	7,469
R	ARTS, ENTERTAINMENT, AND RECREATION	1,361	1,377	1,387	1,695	1,990	2,306	2,593	2,386	2,348	2,433
S	OTHER SERVICE ACTIVITIES	1,514	1,577	1,771	2,090	2,076	2,323	2,488	2,352	2,428	2,553
U	EXTRATERRITORIAL ORGANIZATIONS AND BODIES	0	0	0	0	0	0	0	0	0	0

ANNEX II. Value of Production per ATECO category ('000 of EUR).

Code	ATECO	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
A	AGRICULTURE, FORESTRY, AND FISHING	432,760	388,446	398,634	419,408	448,963	485,034	575,937	553,932	657,659	761,197
B	MINING AND QUARRYING	197,471	181,006	185,106	186,933	205,316	232,185	238,856	211,113	278,945	319,366
C	MANUFACTURING ACTIVITIES	23,920,217	24,921,697	25,713,880	26,427,678	29,528,411	32,607,595	32,800,267	29,964,664	40,818,834	48,573,858
D	ELECTRICITY, GAS, STEAM, AND AIR CONDITIONING SUPPLY	1,581,740	1,681,392	1,616,963	4,247,203	4,794,258	5,760,279	6,424,852	5,809,545	10,311,591	22,407,185
E	WATER SUPPLY; SEWERAGE, WASTE MANAGEMENT, AND REMEDIATION ACTIVITIES	1,318,322	1,297,811	1,277,556	1,327,224	1,556,008	1,709,462	1,756,399	1,770,100	2,310,494	2,560,092
F	CONSTRUCTION	2,344,824	2,460,623	2,589,528	2,818,894	3,218,666	3,591,951	4,001,905	4,084,633	5,592,151	6,995,932
G	WHOLESALE AND RETAIL TRADE; REPAIR OF MOTOR VEHICLES AND MOTORCYCLES	10,050,448	10,852,774	11,882,043	13,059,179	15,246,336	16,778,927	17,039,480	16,738,153	21,510,285	24,967,156
H	TRANSPORTATION AND STORAGE	860,317	953,065	1,042,684	1,138,151	1,322,975	1,465,326	1,532,447	1,589,486	2,030,304	2,326,333
I	ACCOMMODATION AND FOOD SERVICE ACTIVITIES	496,640	539,169	614,419	730,811	854,206	971,691	1,051,313	666,522	1,001,474	1,365,303
J	INFORMATION AND COMMUNICATION SERVICES	370,318	401,217	443,594	484,919	537,737	637,575	711,939	707,677	780,522	878,532
K	FINANCIAL AND INSURANCE ACTIVITIES	761,464	870,317	744,149	686,701	665,742	690,587	748,494	846,171	899,521	927,839
L	REAL ESTATE ACTIVITIES	1,090,739	1,090,292	1,116,750	1,077,130	1,092,516	1,209,390	1,158,399	1,033,164	1,190,694	1,237,294
M	PROFESSIONAL, SCIENTIFIC, AND TECHNICAL ACTIVITIES	943,695	986,022	1,118,015	1,250,260	1,375,667	1,386,932	1,381,861	1,376,209	1,569,207	1,599,937
N	RENTAL, TRAVEL AGENCIES, AND BUSINESS SUPPORT SERVICES	634,005	694,890	803,374	883,311	1,020,709	1,246,332	1,285,510	1,118,768	1,429,037	1,745,479
P	EDUCATION	74,405	79,773	81,910	92,469	103,179	117,544	122,336	109,248	135,444	156,377
Q	HEALTH AND SOCIAL ASSISTANCE	272,224	349,456	409,152	439,597	463,941	495,077	524,990	504,537	605,440	642,608
R	ARTS, ENTERTAINMENT, AND RECREATION	153,556	154,757	157,697	185,997	207,919	235,152	254,137	188,150	234,847	305,482
S	OTHER SERVICE ACTIVITIES	105,488	114,342	127,774	144,434	160,051	174,453	187,214	156,957	190,683	234,742
U	EXTRATERRITORIAL ORGANIZATIONS AND BODIES	0	0	0	0	0	0	0	0	0	0

ANNEX III. Added-Value per ATECO category ('000 of EUR).

Code	ATECO	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
A	AGRICULTURE, FORESTRY, AND FISHING	51,923	57,535	61,288	59,152	60,313	62,823	80,384	90,184	125,497	154,422
B	MINING AND QUARRYING	68,290	69,183	67,662	64,867	71,493	83,859	76,778	71,181	102,515	114,151
C	MANUFACTURING ACTIVITIES	5,191,656	5,628,046	6,011,186	6,511,520	7,043,305	7,720,836	7,947,430	7,353,513	9,462,570	10,828,836
D	ELECTRICITY, GAS, STEAM, AND AIR CONDITIONING SUPPLY	551,465	552,618	535,643	950,574	868,471	846,513	948,947	820,696	984,504	976,882
E	WATER SUPPLY; SEWERAGE, WASTE MANAGEMENT, AND REMEDIATION ACTIVITIES	396,195	388,512	392,875	483,223	495,410	538,769	596,788	630,803	707,733	759,094
F	CONSTRUCTION	725,970	697,965	739,452	813,623	911,254	1,027,754	1,135,379	1,162,149	1,571,564	1,866,431
G	WHOLESALE AND RETAIL TRADE; REPAIR OF MOTOR VEHICLES AND MOTORCYCLES	947,063	1,003,688	1,087,969	1,265,347	1,436,842	1,518,615	1,595,911	1,671,074	2,270,226	2,532,729
H	TRANSPORTATION AND STORAGE	201,120	222,900	266,550	291,062	328,014	358,068	379,806	482,624	641,081	706,948
I	ACCOMMODATION AND FOOD SERVICE ACTIVITIES	183,255	198,454	223,693	276,744	321,483	364,293	388,910	191,102	357,952	502,529
J	INFORMATION AND COMMUNICATION SERVICES	136,296	146,183	164,487	191,245	214,413	251,254	282,611	298,333	340,538	375,100
K	FINANCIAL AND INSURANCE ACTIVITIES	554,506	665,590	560,115	468,963	479,349	507,357	561,479	653,354	678,654	696,524
L	REAL ESTATE ACTIVITIES	286,192	296,851	269,941	277,313	273,672	321,396	318,142	289,919	330,694	402,585
M	PROFESSIONAL, SCIENTIFIC, AND TECHNICAL ACTIVITIES	285,170	277,746	307,253	345,375	370,756	382,322	397,025	397,919	454,438	474,456
N	RENTAL, TRAVEL AGENCIES, AND BUSINESS SUPPORT SERVICES	308,847	344,916	405,718	460,476	565,123	645,810	667,406	650,762	842,389	980,517
P	EDUCATION	32,987	34,453	33,209	38,398	42,816	50,448	52,998	51,403	62,690	69,411
Q	HEALTH AND SOCIAL ASSISTANCE	125,838	159,109	183,841	193,018	204,967	213,502	227,833	219,450	258,819	265,019
R	ARTS, ENTERTAINMENT, AND RECREATION	56,355	51,782	43,719	60,902	69,417	79,170	75,880	56,102	86,084	90,294
S	OTHER SERVICE ACTIVITIES	46,169	51,349	57,647	66,296	72,372	79,310	84,511	61,387	80,739	99,607
U	EXTRATERRITORIAL ORGANIZATIONS AND BODIES	-2	-2	-2	-3	-6	-6	-6	-6	-6	-7

ANNEX IV. Labour cost per ATECO category ('000 of EUR).

Code	ATECO	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
A	AGRICULTURE, FORESTRY, AND FISHING	20,598	22,073	23,889	25,477	28,802	34,910	49,483	52,657	61,501	63,237
B	MINING AND QUARRYING	36,208	36,978	37,620	38,027	38,274	40,862	41,530	37,656	41,766	42,212
C	MANUFACTURING ACTIVITIES	3,219,273	3,428,996	3,620,174	3,846,659	4,125,149	4,468,304	4,714,494	4,473,158	5,235,512	5,414,771
D	ELECTRICITY, GAS, STEAM, AND AIR CONDITIONING SUPPLY	196,326	208,462	198,850	304,887	268,064	282,092	299,001	299,757	306,603	335,404
E	WATER SUPPLY; SEWERAGE, WASTE MANAGEMENT, AND REMEDIATION ACTIVITIES	137,408	150,820	156,596	164,891	183,191	201,292	219,432	227,482	244,184	250,569
F	CONSTRUCTION	392,584	417,229	442,406	488,449	547,721	619,855	710,416	722,866	903,393	952,509
G	WHOLESALE AND RETAIL TRADE; REPAIR OF MOTOR VEHICLES AND MOTORCYCLES	564,359	596,485	650,333	726,911	798,636	879,257	932,704	943,045	1,103,401	1,153,043
H	TRANSPORTATION AND STORAGE	154,895	167,861	187,274	204,679	233,032	265,791	295,450	315,411	366,590	378,515
I	ACCOMMODATION AND FOOD SERVICE ACTIVITIES	129,395	138,047	151,297	179,934	211,977	246,036	274,135	177,135	239,883	284,014
J	INFORMATION AND COMMUNICATION SERVICES	97,015	105,732	111,255	123,291	132,225	155,579	174,311	176,585	202,898	212,803
K	FINANCIAL AND INSURANCE ACTIVITIES	27,845	28,348	28,421	34,659	33,538	36,099	37,085	37,640	44,855	46,052
L	REAL ESTATE ACTIVITIES	95,729	93,565	93,284	79,591	80,632	78,174	74,426	62,336	65,014	61,820
M	PROFESSIONAL, SCIENTIFIC, AND TECHNICAL ACTIVITIES	181,014	186,452	200,178	211,987	226,679	238,115	257,094	262,436	289,426	301,058
N	RENTAL, TRAVEL AGENCIES, AND BUSINESS SUPPORT SERVICES	254,710	282,586	333,644	377,132	466,622	546,210	550,184	534,602	691,816	753,346
P	EDUCATION	25,386	26,692	27,904	30,626	34,536	40,894	45,545	41,405	47,556	49,807
Q	HEALTH AND SOCIAL ASSISTANCE	100,105	121,240	136,531	146,540	155,220	164,495	174,903	167,801	192,081	195,538
R	ARTS, ENTERTAINMENT, AND RECREATION	33,554	32,015	32,048	38,169	42,449	52,725	58,107	51,631	52,215	60,948
S	OTHER SERVICE ACTIVITIES	34,259	37,427	42,388	46,585	52,715	57,601	62,466	49,194	55,093	61,655
U	EXTRATERRITORIAL ORGANIZATIONS AND BODIES	0	0	0	0	0	0	0	0	0	0

ANNEX V. Cobot Models.

Producer	Model	Class	DoF	Payload [kg]	Reach [mm]	Accuracy [mm]
ABB	CRB 11000 SWIFTI	Anthropomorphic	6	4,0	580	0,01
	CRB 15000 GoFa	Anthropomorphic	6	5,0	950	0,05
	IRB 1400 Yumi	Torso	14	0,5	1.200	0,02
	IRB 14050 Yumi	Anthropomorphic	7	0,5	559	0,02
Acutronics	MARA	Anthropomorphic	6	3,0	656	0,10
AIRSKIN	Kuka Agilus Fenceless	Anthropomorphic	6	10,0	1.100	0,02
Airskin	Kuka Cybertech Fenceless	Anthropomorphic	6	24,0	2.020	0,04
AUBO Robotics	I10	Anthropomorphic	6	10,0	1.350	0,10
	I3	Anthropomorphic	6	3,0	625	0,03
	I5	Anthropomorphic	6	5,0	924	0,05
	I7	Anthropomorphic	6	7,0	1.150	0,05
Automata	EVA	Anthropomorphic	6	1,3	600	0,50
Automationware	AW-Tube 5	Anthropomorphic	6	5,0	900	0,03
	AW-Tube 8	Anthropomorphic	6	8,0	1.000	0,04
	AW-Tube 12	Anthropomorphic	6	13,0	1.300	0,05
	AW-Tube 15	Anthropomorphic	6	15,0	1.000	0,05
	AW-Tube 18	Anthropomorphic	6	18,0	1.700	0,06
	AW-Tube 20	Anthropomorphic	6	20,0	1.500	0,07
Bosch	APAS	Anthropomorphic	6	4,0	911	0,03
Comau	Aura	Anthropomorphic	6	170,0	2.790	0,10
	e.Do	Anthropomorphic	6	1,0	478	0,00
	Racer 5 0.80 Cobot	Anthropomorphic	6	5,0	809	0,03
Denso	Cobotta	Anthropomorphic	6	0,5	342	0,05
Dobot	CR10	Anthropomorphic	6	10,0	1.525	0,03
	CR16	Anthropomorphic	6	16,0	1.223	0,03
	CR3	Anthropomorphic	6	3,0	795	0,02
	CR5	Anthropomorphic	6	5,0	1.096	0,03
	M1	SCARA	4	1,5	400	0,02
	Magician	Anthropomorphic	4	0,3	320	0,20
	Magician	Anthropomorphic	4	0,5	340	0,20
	MG 400	Anthropomorphic	4	0,8	440	0,05
Doosan Robotics	A0509	Anthropomorphic	6	5,0	900	0,03
	A0912	Anthropomorphic	6	9,0	1.200	0,05
	H2017	Anthropomorphic	6	20,0	1.700	0,10
	H2515	Anthropomorphic	6	25,0	1.500	0,10
	M0609	Anthropomorphic	6	6,0	900	0,10
	M0617	Anthropomorphic	6	6,0	1.700	0,10
	M1013	Anthropomorphic	6	10,0	1.300	0,10
	M1509	Anthropomorphic	6	15,0	900	0,10
Efort	ECR5	Anthropomorphic	6	5,0	928	0,03
Elephant Robotics	C3	Anthropomorphic	6	3,0	500	0,50

	E5	Anthropomorphic	6	5,0	810	0,50
	myCobot	Anthropomorphic	6	0,3	280	0,20
	Panda 3	Anthropomorphic	6	3,0	550	0,50
	Panda 5	Anthropomorphic	6	5,0	850	0,50
Elite Robot	CS612	Anthropomorphic	6	12,0	1.304	0,05
	CS63	Anthropomorphic	6	3,0	624	0,02
	CS66	Anthropomorphic	6	6,0	914	0,03
	EC612	Anthropomorphic	6	12,0	1.304	0,03
	EC63	Anthropomorphic	6	3,0	624	0,02
	EC66	Anthropomorphic	6	6,0	914	0,03
ESI	C-15	Anthropomorphic	6	15,0	1.323	0,05
	C-7	Anthropomorphic	6	7,0	900	0,05
F&P Personal Robotics	2R 24V	Anthropomorphic	6	3,0	775	0,10
	2R 48V	Anthropomorphic	6	5,0	775	0,10
Fanuc	1CR4iAL	Anthropomorphic	6	14,0	911	0,03
	CR15iA	Anthropomorphic	6	15,0	1.411	0,02
	CR35iA	Anthropomorphic	6	35,0	1.813	0,08
	CR4iA	Anthropomorphic	6	4,0	550	0,02
	CR7iA	Anthropomorphic	6	7,0	717	0,02
	CR7iAL	Anthropomorphic	6	7,0	911	0,02
	CRX10iA	Anthropomorphic	6	10,0	1.249	0,05
	CR10XiAL	Anthropomorphic	6	10,0	1.418	0,05
Flexiv	Rizon 4	Anthropomorphic	7	4,0	780	0,01
Franka Emika	Robot	Anthropomorphic	7	3,0	855	0,10
Hans Robot	E10	Anthropomorphic	6	10,0	1.000	0,05
	E15	Anthropomorphic	6	15,0	700	0,05
	E3	Anthropomorphic	6	3,0	590	0,05
	E5	Anthropomorphic	6	5,0	800	0,05
	E5-L	Anthropomorphic	6	3,5	950	0,05
Hanwha	HCR-12	Anthropomorphic	6	12,0	1.300	0,10
	HCR-12A	Anthropomorphic	6	12,0	1.300	0,05
	HCR-3	Anthropomorphic	6	3,0	630	0,10
	HCR-3A	Anthropomorphic	6	3,0	630	0,05
	HCR5	Anthropomorphic	6	5,0	915	0,10
	HCR-5A	Anthropomorphic	6	5,0	915	0,05
HIT Robot Group	T5	Anthropomorphic	6	5,0	850	0,10
HITBOT	Z-Arm 1632	SCARA	4	1,0	452	0,02
	Z-Arm 1832	SCARA	4	3,0	455	0,02
	Z-Arm 2140	SCARA	4	3,0	532	0,03
	Z-Arm 2442	SCARA	4	1,0	617	0,03
	Z-Arm 6140	SCARA	4	1,0	532	0,02
	Z-Arm mini	SCARA	4	1,0	320	0,10
Hyundai	YL005	Anthropomorphic	6	5,0	916	0,10
	YL012	Anthropomorphic	6	12,0	1.350	0,10
	YL015	Anthropomorphic	6	15,0	963	0,10
Inovo Robotics	Robotic Arm 1300	Anthropomorphic	6	3,0	1.340	0,25

	Robotics Arm 650	Anthropomorphic	6	10,0	690	0,25
	Robotics Arm 850	Anthropomorphic	6	6,0	990	0,25
Isybot	SYB3	Anthropomorphic	4	10,0	1.600	0,20
JAKA	Zu 12	Anthropomorphic	6	12,0	1.300	0,03
	Zu 18	Anthropomorphic	6	18,0	1.073	0,03
	Zu 3	Anthropomorphic	6	3,0	498	0,03
	Zu 7	Anthropomorphic	6	7,0	796	0,03
Kassow Robots	KR1018	Anthropomorphic	6	10,0	1.000	0,10
	KR1205	Anthropomorphic	7	5,0	1.200	0,10
	KR1410	Anthropomorphic	7	10,0	1.400	0,10
	KR1805	Anthropomorphic	7	5,0	1.800	0,10
	KR810	Anthropomorphic	7	10,0	850	0,10
Kawasaki Robotics	Duaro	SCARA	8	4,0	760	0,05
	Duaro 2	SCARA	8	6,0	760	0,05
Kinetic Systems	6 Axes Robot	Anthropomorphic	6	16,0	1.900	0,05
	SCARA Robot	SCARA	4	5,0	1.200	0,05
Kinova	Gen2	Anthropomorphic	7	2,4	985	0,15
	Gen3	Anthropomorphic	7	4,0	902	0,15
	Gen3 Lite	Anthropomorphic	6	0,5	760	0,15
KUKA	LBR iisy 3 R760	Anthropomorphic	6	3,0	760	0,01
	LBR iisy 11 R1300	Anthropomorphic	6	11,0	1.300	0,15
	LBR iisy 15 R930	Anthropomorphic	6	15,0	930	0,15
	LBR iiwa 14 R820	Anthropomorphic	7	14,0	820	0,15
	LBR iiwa 7 R800	Anthropomorphic	7	7,0	800	0,10
	LWR	Anthropomorphic	7	7,0	790	0,05
Life Robotics	CORO	Anthropomorphic	6	2,0	800	1,00
Mabi	Speedy 12	Anthropomorphic	6	12,0	1.250	0,10
	Speedy 6	Anthropomorphic	6	6,0	800	0,10
Megarobo	MRX-T4	Anthropomorphic	4	3,0	505	0,05
MIP Robotics	Junior 200	SCARA	4	3,0	400	0,50
	Junior 300	SCARA	4	5,0	600	0,40
Mitsubishi Electric	RV-5AS-D MELFA ASSISTA	Anthropomorphic	6	5,0	910	0,03
MRK Systeme	KR 5 SI	Anthropomorphic	6	5,0	1.432	0,04
Nachi	CZ 10	Anthropomorphic	6	10,0	1.300	0,10
Neura Robotics	LARA 10	Anthropomorphic	6	10,0	1.000	0,02
	LARA 5	Anthropomorphic	6	5,0	800	0,02
Neuromeka	Indy 10	Anthropomorphic	6	10,0	1.000	0,10
	Indy 12	Anthropomorphic	6	12,0	1.200	0,50
	Indy 3	Anthropomorphic	6	3,0	590	0,10
	Indy 5	Anthropomorphic	6	3,0	800	0,10
	Indy 7	Anthropomorphic	6	7,0	800	0,05
	Indy RP	Anthropomorphic	6	5,0	950	0,05
	Indy RP 2	Anthropomorphic	7	5,0	800	0,05
	Opti 10	Anthropomorphic	6	10,0	1.216	0,10

	Opti 5	Anthropomorphic	6	5,0	880	0,10
Niryo	One	Anthropomorphic	6	0,3	440	0,10
Pilz	PRBT	Anthropomorphic	6	6,0	741	0,20
Precise Automation	Direct Drive 6 Axes	SCARA	6	6,0	1.793	0,02
	PAVP6	Anthropomorphic	6	2,5	432	0,02
	PAVS6	Anthropomorphic	6	37,0	770	0,03
	PF3400	SCARA	4	23,0	588	0,05
	PP100	Cartesian	4	2,0	1.270	0,10
Productive Robotics	OB7	Anthropomorphic	7	5,0	1.000	0,10
	OB7 Max 12	Anthropomorphic	7	12,0	1.300	0,10
	OB7 Max 8	Anthropomorphic	7	8,0	1.700	0,10
	OB7 Stretch	Anthropomorphic	7	4,0	1.250	0,10
Rainbow Robotics	RB10 1200	Anthropomorphic	6	10,0	1.200	0,10
	RB3 1300	Anthropomorphic	6	3,0	1.300	0,10
	RB5 850	Anthropomorphic	6	5,0	850	0,10
Rethink Robotics	Baxter	Torso	14	2,2	1.210	3,00
	Sawyer	Anthropomorphic	7	4,0	1.260	0,10
	Sawyer Black Edition	Anthropomorphic	7	4,0	1.260	0,10
Robut Tecnology	Armobot	Anthropomorphic	6	3,0	1.500	0,10
Rokae	X Mate 3	Anthropomorphic	7	3,0	760	0,03
	X Mate 7	Anthropomorphic	7	7,0	850	0,03
Rozum Robotics	Pulse 75	Anthropomorphic	6	6,0	750	0,10
	Pulse 90	Anthropomorphic	6	4,0	900	0,10
Siasun	DSCR3 Duco	Torso	7	3,0	800	0,02
	DSCR5	Torso	7	5,0	800	0,02
	GCR14 1400	Anthropomorphic	6	14,0	1.400	0,05
	GCR20 1100	Anthropomorphic	6	20,0	1.100	0,05
	GCR5 910	Anthropomorphic	6	5,0	910	0,05
	SCR3	Anthropomorphic	7	3,0	600	0,02
	SCR5	Anthropomorphic	7	5,0	800	0,02
	TCR 0.5	Anthropomorphic	6	0,5	300	0,05
	TCR 1	Anthropomorphic	6	1,0	500	0,05
ST Robotics	R12	Anthropomorphic	6	1,0	500	0,10
	R17	Anthropomorphic	6	3,0	750	0,20
Staubli	TX2 Touch 60	Anthropomorphic	6	4,5	670	0,02
	TX2 Touch 60L	Anthropomorphic	6	3,7	920	0,03
	TX2 Touch 90	Anthropomorphic	6	14,0	1.000	0,03
	TX2 Touch 90L	Anthropomorphic	6	12,0	1.200	0,04
	TX2 Touch 90XL	Anthropomorphic	6	7,0	1.450	0,04
Yamaha	YA-U5F	Anthropomorphic	7	5,0	559	0,06
	YA-U10F	Anthropomorphic	7	10,0	720	0,10
	YA-U20F	Anthropomorphic	7	20,0	910	0,10
Techman	Techman TM12	Anthropomorphic	6	12,0	1.300	0,10
	Techman TM14	Anthropomorphic	6	14,0	1.100	0,10

	Techman TM5 700	Anthropomorphic	6	6,0	700	0,05
	Techman TM5 900	Anthropomorphic	6	4,0	900	0,05
Tokyo Robotics	Torobo Arm	Anthropomorphic	7	6,0	600	0,05
	Torobo Arm Mini	Anthropomorphic	7	3,0	600	0,05
UFACTORY	uArm Swift Pro	Anthropomorphic	4	0,5	320	0,20
	xArm 5 Lite	Anthropomorphic	5	3,0	700	0,10
	xArm 6	Anthropomorphic	6	3,0	700	0,10
	xArm 7	Anthropomorphic	7	3,5	700	0,10
Universal Robots	UR10 CB3	Anthropomorphic	6	10,0	1.300	0,10
	UR10e	Anthropomorphic	6	10,0	1.300	0,03
	UR16e	Anthropomorphic	6	16,0	900	0,05
	UR3 CB3	Anthropomorphic	6	3,0	500	0,10
	UR3e	Anthropomorphic	6	3,0	500	0,03
	UR5 CB3	Anthropomorphic	6	5,0	850	0,10
	UR5e	Anthropomorphic	6	5,0	850	0,03
Yaskawa	Motoman HC10	Anthropomorphic	6	10,0	1.200	0,10
	Motoman HC10 DT	Anthropomorphic	6	10,0	1.200	0,10
	Motoman HC20	Anthropomorphic	6	20,0	1.700	0,05
Yuanda	Robotics Arm	Anthropomorphic	6	7,0	1.000	0,10
Svaya Robotics	SR-L3	Anthropomorphic	6	3,0	600	0,03
	SR-L6	Anthropomorphic	6	6,0	850	0,03
	SR-L10	Anthropomorphic	6	10,0	1.300	0,05
	SR-L12	Anthropomorphic	6	12,0	1.100	0,05
	SR-L16	Anthropomorphic	6	16,0	900	0,05

ANNEX VI. Cobot Power Consumption.

Model	Class	Payload [kg]	TCP velocity [m/s]	Power consumption [kW]
OB7 Max 12	Anthropomorphic	12.0	2.0	0.90
OB7 Max 8	Anthropomorphic	8.0	2.0	0.90
AW-Tube 5	Anthropomorphic	5.0		0.75
AW-Tube 8	Anthropomorphic	8.0		0.75
AW-Tube 12	Anthropomorphic	13.0		0.75
AW-Tube 15	Anthropomorphic	15.0		0.75
AW-Tube 18	Anthropomorphic	18.0		0.75
AW-Tube 20	Anthropomorphic	20.0		0.75
SYB3	Anthropomorphic	10.0	1.0	0.70
OB7 Stretch	Anthropomorphic	4.0	2.0	0.65
Zu 18	Anthropomorphic	18.0	3.5	0.60
RV-5AS-D MELFA ASSISTA	Anthropomorphic	5.0	1.0	0.60
GCR20 1100	Anthropomorphic	20.0	1.0	0.60
I10	Anthropomorphic	10.0	4.0	0.50
Racer 5 0.80 Cobot	Anthropomorphic	5.0	6.0	0.50
CS612	Anthropomorphic	12.0	3.0	0.50
EC612	Anthropomorphic	12.0	3.2	0.50
Zu 12	Anthropomorphic	12.0	3.0	0.50
I7	Anthropomorphic	7.0		0.40
SCR5	Anthropomorphic	5.0	1.0	0.40
Gen3	Anthropomorphic	4.0	0.5	0.36
E10	Anthropomorphic	10.0	1.0	0.35
E15	Anthropomorphic	15.0	1.0	0.35
Zu 7	Anthropomorphic	7.0	2.5	0.35
Indy 10	Anthropomorphic	10.0	1.0	0.35
Indy 12	Anthropomorphic	12.0	1.0	0.35
Indy 3	Anthropomorphic	3.0	1.0	0.35
Indy 5	Anthropomorphic	3.0	1.0	0.35
Indy 7	Anthropomorphic	7.0	1.0	0.35
Indy RP 2	Anthropomorphic	5.0	1.0	0.35
UR10e	Anthropomorphic	10.0	2.0	0.35
UR16e	Anthropomorphic	16.0	1.0	0.35
X Mate 3	Anthropomorphic	3.0		0.30
Techman TM12	Anthropomorphic	12.0	1.3	0.30
Techman TM14	Anthropomorphic	14.0	1.1	0.30
EVA	Anthropomorphic	1.3	0.8	0.28
E5	Anthropomorphic	5.0	1.0	0.26
Panda 5	Anthropomorphic	5.0	1.0	0.26
CS66	Anthropomorphic	6.0	2.6	0.25
EC66	Anthropomorphic	6.0	2.8	0.25
Gen2	Anthropomorphic	2.4	0.2	0.25

KR 5 SI	Anthropomorphic	5.0		0.25
Pulse 90	Anthropomorphic	4.0	2.0	0.25
SCR3	Anthropomorphic	3.0	0.8	0.25
UR10 CB3	Anthropomorphic	10.0	1.0	0.25
MRX-T4	Anthropomorphic	3.0		0.24
Techman TM5 700	Anthropomorphic	6.0	1.1	0.22
Techman TM5 900	Anthropomorphic	4.0	1.4	0.22
I5	Anthropomorphic	5.0	2.8	0.20
CR10	Anthropomorphic	10.0	3.0	0.20
CR16	Anthropomorphic	16.0	3.0	0.20
CR3	Anthropomorphic	3.0	3.0	0.20
CR5	Anthropomorphic	5.0	3.0	0.20
ECR5	Anthropomorphic	5.0	2.8	0.20
E3	Anthropomorphic	3.0	1.0	0.20
Gen3 Lite	Anthropomorphic	0.5	0.3	0.20
PAVP6	Anthropomorphic	2.5		0.20
GCR5 910	Anthropomorphic	5.0		0.20
UR5e	Anthropomorphic	5.0	1.0	0.20
C3	Anthropomorphic	3.0	1.0	0.18
E5	Anthropomorphic	5.0	1.0	0.18
E5-L	Anthropomorphic	3.5	1.0	0.18
IRB 14050 Yumi	Anthropomorphic	0.5	1.5	0.17
Panda 3	Anthropomorphic	3.0	1.0	0.16
I3	Anthropomorphic	3.0	1.9	0.15
CS63	Anthropomorphic	3.0	2.0	0.15
EC63	Anthropomorphic	3.0	2.0	0.15
Zu 3	Anthropomorphic	3.0	1.5	0.15
Pulse 75	Anthropomorphic	6.0	2.0	0.15
UR5 CB3	Anthropomorphic	5.0	1.0	0.15
xArm 5 Lite	Anthropomorphic	3.0	0.3	0.12
UR3 CB3	Anthropomorphic	3.0	1.0	0.12
2R 48V	Anthropomorphic	5.0		0.10
T5	Anthropomorphic	5.0		0.10
UR3e	Anthropomorphic	3.0	1.0	0.10
OB7	Anthropomorphic	5.0	2.0	0.09
2R 24V	Anthropomorphic	3.0		0.08
CORO	Anthropomorphic	2.0		0.08
Robot	Anthropomorphic	3.0	2.0	0.06
One	Anthropomorphic	0.3		0.06

Company Name:

Number of employees:		
	☐	1-3
	☐	4-9
	☐	10-35
	☐	36-49
	☐	50-250
	☐	>250

Annual revenue		
	☐	<500,000
	☐	500,000 ÷ 2,000,000
	☐	2,000,000÷ 10,000,000
	☐	10,000,000÷ 25,000,000
	☐	25,000,000÷ 50,000,000
	☐	>50,000,000

Reference person:
Role and years with the company:
Email:

	Yes	No
Q.1.1 Is there any robot running in the plant?	☐	☐

Q1.2 Which type and how many robots are running in the plant?

	None	1-3	4-6	7-10	11-15	>15
Anthropomorphic	☐	☐	☐	☐	☐	☐
Cartesian	☐	☐	☐	☐	☐	☐
Scara	☐	☐	☐	☐	☐	☐
COBOT	☐	☐	☐	☐	☐	☐
Delta	☐	☐	☐	☐	☐	☐
AGV	☐	☐	☐	☐	☐	☐

Q.1.3 For which application robots are running in the plant?

	Yes	No
Handling & Machine Tending	☐	☐
Welding	☐	☐
Dispensing	☐	☐
Processing	☐	☐
Assembling	☐	☐
Inspection	☐	☐
Transport	☐	☐

Q.1.4 Which are the primary driving factors that lead you to install robots?

	Yes	No
Increase Productivity	☐	☐
Increase Capacity	☐	☐
Cost Optimization	☐	☐
Quality / Inspection	☐	☐
Support Employees	☐	☐
New project opportunities	☐	☐
Challenging environments	☐	☐

If Yes to "Support Employees", support employees in:

	Yes	No
Increase Productivity	☐	☐
Increase Capacity	☐	☐
Cost Optimization	☐	☐

Q.2.1 Which are the impacts led by the robot's deployment?

	Yes	No
Increase quality rate	☐	☐
Increase productivity rate	☐	☐
The company is fully satisfied	☐	☐

	Increase	None	Decrease
What has been the variation in the number of direct workers?	☐	☐	☐
What has been the variation in the number of indirect workers?	☐	☐	☐

Q.2.2 What is not satisfying the expectations?

	Satisfied	Not Satisfied
Specialized personnel presence during production	☐	☐
Challenges in programming and managing the robot	☐	☐
Issues caused by sensors	☐	☐
Unexpected maintenances	☐	☐
Assistance	☐	☐
Malfunctioning of accessories	☐	☐
Frequent human intervention	☐	☐
Frequent production interruptions due to robot issues	☐	☐

	Yes	No
Q.3.1 Do existing skills meet the requirements for managing robotic equipment?	☐	☐

If not, how do you make up this lack?

	Yes	No
Hiring	☐	☐
Training	☐	☐
None Action	☐	☐

Q.3.2 Which tasks are supported by external suppliers?

	Yes	No
Ordinary maintenance	☐	☐
Extraordinary maintenance	☐	☐
Sensor maintenance	☐	☐
Robot reprogramming	☐	☐
Cell design	☐	☐
Accessory design	☐	☐
Personnel training	☐	☐

Q.3.3 Reflecting on the decision-making process, which services would have been helpful?

	Yes	No
3D cell simulation	☐	☐
Turnkey solution	☐	☐
Technical insights	☐	☐
Time and Methods analysis	☐	☐
Business plan	☐	☐
Tax incentive measures analysis	☐	☐

	Yes	No
Q.4.1 Is the company planning to install new robots?	☐	☐

	Yes	No
Q.4.2 Is the company planning to hire graduates with a Master's degree in automation engineering within the next three years?	☐	☐

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