Ref. Ares(2024)747475 - 01/02/2024

2024


# VALIDATED FRAMEWORK FOR COLLABORATIVE HUMAN ROBOTS IN ORGANIZATIONS

PHILIPP JENNES, SOPHIE ALTROCK, ALEJANDRA ROJAS, SYED ALI HASSAN

EINST4INE

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

# THE EUROPEAN TRAINING NETWORK FOR INDUSTRY DIGITAL TRANSFORMATION ACROSS INNOVATION ECOSYSTEMS (EINST4INE)

Grant agreement no 956745
Start date of the project: 01/01/2021
Duration: 48 months

## Document information

| WP | 1 | Human side of digital transformation |
|---|---|---|

| Dissemination Level[1] | PU | | Due Delivery Date | 31/01/2024 |
|---|---|---|---|---|
| Nature[2] | R | | Actual Delivery Date | 31/01/2024 |

| Lead Beneficiary | RMIT EU, RMIT University |
|---|---|
| Contributing Beneficiaries | LUT University, AU, UCAM, USTUTT, SSSA and LUISS |

## Document history

| Issue Date | Version | Changes made / Reason for this Issue | Author |
|---|---|---|---|
| 10/01/2024 | 1 | First version | P. Jennes, S.A. Hassan (SSSA), S. Altrock (RMIT), Alejandra Rojas (AU) |
| 15/01/2024 | 2 | Internal Review | A-L. Mention, J. Dabrowska (RMIT), E. Vallejos (RMIT EU) |
| 17/01/2024 | 3 | Updated version | P. Jennes, S.A. Hassan (SSSA), S. Altrock (RMIT), Alejandra Rojas (AU) |
| | | | |

### Disclaimer

Any dissemination of results reflects only the author's view and the European Commission is not responsible for any use that may be made of the information it contains.

Design: Canva templates

1 Dissemination level: **PU** = Public, **PP** = Restricted to other programme participants (including the JU), **RE** = Restricted to a group specified by the consortium (including the JU), **CO** = Confidential, only for members of the consortium (including the JU)

2 Nature of the deliverable: **R** = Report, **P** = Prototype, **D** = Demonstrator, **O** = Other

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

# TABLE OF CONTENTS



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

# EXECUTIVE SUMMARY

The dynamic field of collaborative human-robot interaction (HRI) in organizational settings is thoroughly explored in this report. Presenting a verified framework that gives organizations the means to successfully traverse this changing landscape is the main goal. The report outlines a future where humans and robots work together to stimulate innovation, improve efficiency, and promote success across a range of industries by addressing important questions, challenges, and possibilities related to human-robot interaction (HRI). The report's objective is to analyze and assess current frameworks for Human-Robot Collaboration (HRC). This involves a thorough examination of the elements that constitute a successful HRC framework, a distinction between the viewpoints on HRC from different disciplines, and an understanding of the differences between various robot types.

The study offers a revised and comprehensive framework for HRC, building on earlier conceptual and visual frameworks drawn from theoretical foundations and real-world implementations. The integration of empirical lessons from specific research projects carried out under the European Training Network for Industry Digital Transformation across Innovation Ecosystems (EINST4INE) is a distinctive feature of this report. These realizations provide a useful level of depth and practical applicability to the theoretical foundations covered in the literature, enhancing the proposed framework. The report begins with an introduction to the concepts of HRC and HRI, highlighting their critical roles across a variety of industries, in order to set the stage for the debates that follow. This lays the groundwork for a thorough investigation of the various facets of cooperative human-robot interaction and gives organizations a road map for realizing the full potential of this game-changing relationship.

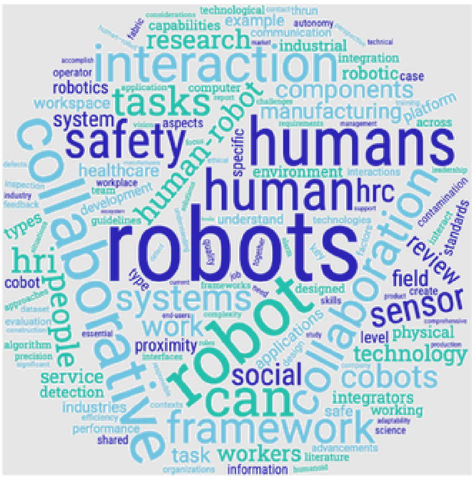



Figure 1 Word Cloud of the Report



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

# 1. INTRODUCTION

> *"The importance of robotics lies in its wide-ranging impact on Europe's capacity to maintain and expand a competitive manufacturing sector with millions of related jobs at stake. Robotics also offers new solutions to societal challenges from ageing to health, smart transport, security, energy and environment."*
>
> – on "Robotics" by the European Commission, 2022

In an era marked by rapid advancements in digital technology, the way humans and robots interact within various industries is undergoing a profound transformation. This paradigm shift has brought about a growing awareness of the importance of collaborative human-robot interaction (HRI) and its significance in organizations worldwide (Fong et. Al, 2003). Figure 2 illustrates the annual installations of robots in the European Union, showcasing the quantitative aspect of this transformative shift. As the field of HRI continues to evolve, novel managerial approaches become crucial to effectively harness the potential of this collaborative synergy. This report embarks on a journey to explore and present the key aspects surrounding the development of such approaches for HRI, shedding light on a future where humans and robots work together seamlessly to achieve common objectives.

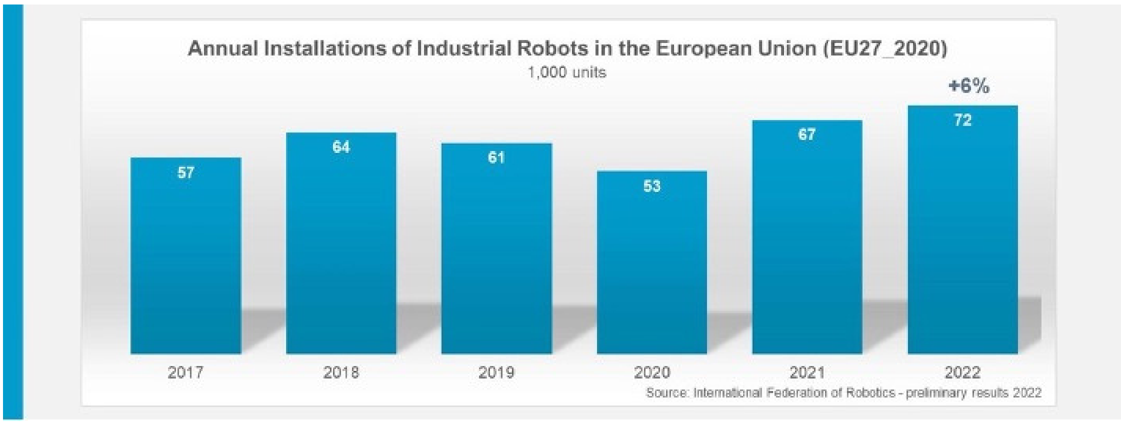



Figure 2 Annual Installations of Industrial Robots in the EU, IFR, 2022

> *"Industrial robots in Europe are on the rise: The European Union´s (EU) 27 member states installed almost 72,000 units in 2022 – up 6% year-on-year."*
>
> - IFR Press Room, 2023



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

In recent years, there has been a pronounced upswing in the exploration of effective managerial approaches for fostering collaboration between humans and robots. This heightened interest is a direct response to the substantial growth in the integration of robots into diverse workplace settings. The origins of this field can be traced back to the early stages of robotics when research was primarily focused on the development of robots capable of working in tandem with humans to achieve common tasks. As a result, a variety of management strategies for human-robot partnerships has organically evolved over time, encompassing concepts such as shared control, contextual communication, and the distribution of tasks (Alami et al., 2006). Researchers have remained dedicated to the ongoing pursuit of inventive techniques to enhance HRI, applying and adapting these strategies to a wide array of contexts.

To illustrate the practical applications of these managerial approaches, Figure 3 provides a comprehensive overview of the use of service robots in the European Union. This graph highlights the integration of service robots across various sectors, with warehouse management systems, transportation of people and goods, cleaning or waste disposal tasks, and assembly works emerging as the most utilized domains.

***"25% of large enterprises in the EU use robots"*** – Eurostat, 2019

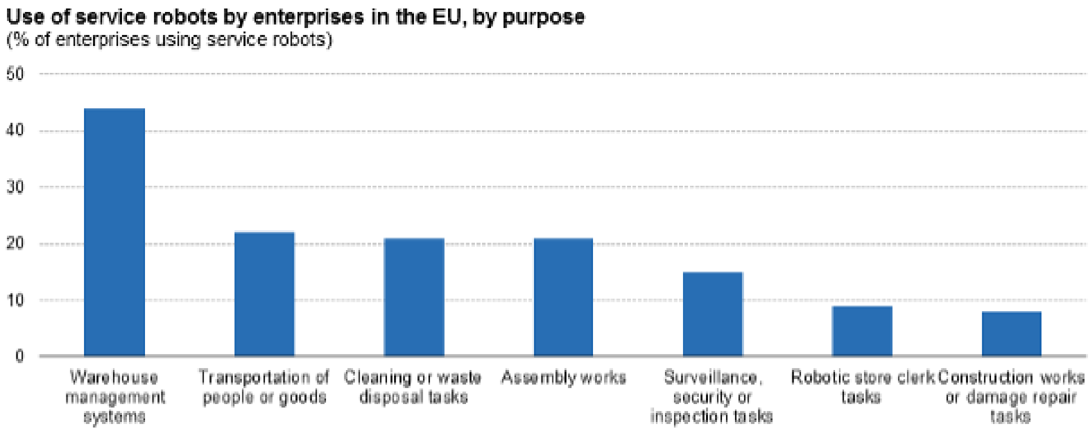



Figure 3 Use of Service Robots by Enterprises in the EU, Eurostat, 2019

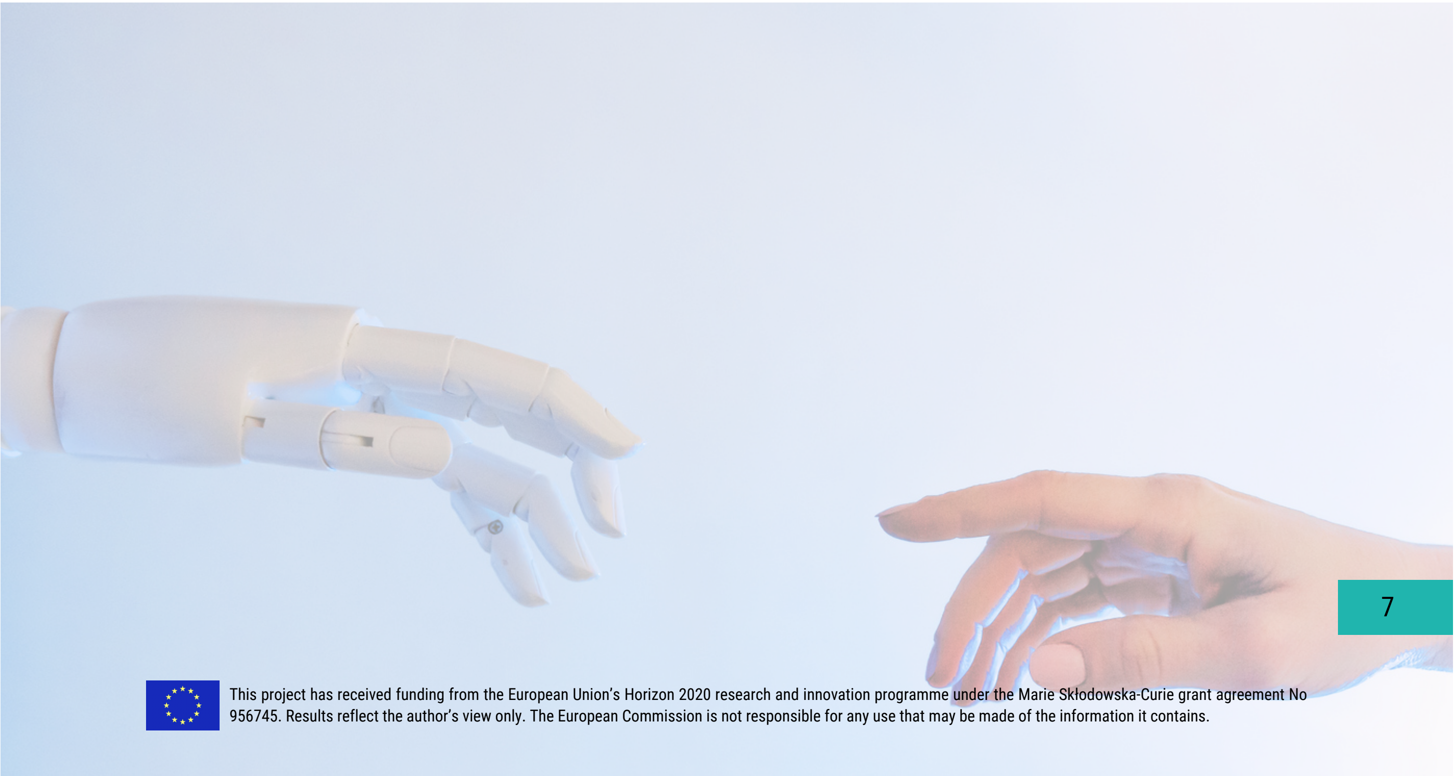
One key strategy that has garnered significant attention in the quest to improve HRI is the development of interfaces that facilitate effective communication between humans and robots. By providing robots with contextual information about their environment and tasks, we empower them to understand and execute their roles more proficiently. To effectively manage collaborative HRI, it is essential for managers to have a comprehensive understanding of the unique opportunities and challenges inherent to this form of collaboration (Fraune et al., 2022). Managers play a pivotal role in ensuring that human-robot teams can collaborate effectively and accomplish their goals by implementing the appropriate methodologies and technologies.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

In the wake of technological advancements, a notable decline in earnings has been observed following job loss, and this decline can be partially attributed to technological change. A thorough analysis of detailed skill requirements extracted from a comprehensive dataset of online job vacancies has estimated that technological change accounts for a significant portion, approximately 45 percent, of the decrease in earnings after job loss (Braxton et a., 2023). As technology evolves, it necessitates workers to acquire new skills to perform newly created jobs within their previous occupations. However, when workers lack the necessary skills, they often transition to alternative occupations where their existing skills remain employable. Understanding the impact of technological change on job loss is essential for developing effective managerial approaches that address the challenges and opportunities arising from human-robot collaboration. By doing so, we can create a work environment that is not only viable for humans but also conducive to the seamless integration of robots, fostering a harmonious coexistence between the two entities.

This report delves into the heart of the transformative landscape of collaborative human-robot interaction in organizations, aiming to provide a validated framework that helps organizations navigate this evolving terrain. By addressing the pressing questions, challenges, and opportunities associated with HRI, this report strives to illuminate a path forward, where humans and robots join forces to drive innovation, productivity, and success across diverse industries. Following this objective, this report provides a review and evaluation of established frameworks in the field of HRC. This includes an exploration of the components defining a framework for HRC, a differentiation of multidisciplinary perspectives on HRC, and an understanding of variations across robot types. As a result, an updated framework for HRC is suggested that combines the fundamentals of prior conceptual and visual frameworks originating from theory and practice. In support of the literature, we add empirical insights from individual research conducted within the European Training Network for Industry Digital Transformation across Innovation Ecosystems (EINST4INE). To start, the following section introduces the concepts of HRC and HRI and their role across industries.





This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

# 2. KEY CONCEPTS IN HRI
AN OVERVIEW

**What is a Robot under EU Law?**

On the basis of these five features, the European Parliament agreed on the following characteristics of a "smart robot":

- the acquisition of autonomy through sensors or by exchanging data with its environment (inter-connectivity) and the trading and analyzing of that data;
- self-learning from experience and by interaction (an optional criterion);
- at least a minor physical support (as opposed to virtual robots, e.g., software);
- the adaptation of its behavior and actions to the environment; and
- the absence of life in the biological sense.

Molyneux & Oyarzabal, 2017; DRAFT REPORT with recommendations to the Commission on Civil Law Rules on Robotics (2015/2103(INL)), Committee on Legal Affairs, Rapporteur: Mady Delvaux, 2015/2103(INL)

## 2.1 Key concepts in HRI

The interaction and cooperation between humans and robots in a shared workplace is referred to as human-robot collaboration (HRC). It includes integrating robots into human work situations in order to increase efficiency, safety, and production. HRC can take many forms, ranging from robots supporting humans in manufacturing processes to robots collaborating with humans in healthcare, logistics, or even home situations (Sheridan, 2016). Here are the fundamental distinctions between collaboration and interaction in human-robot relationships.

*„More than any other research discipline, the field of robotics has striven to empower robots with an ability to make their own decisions in broad ranges of situations."*

- Thrun, 2004, p.10

### 2.1.1 Interaction

The general exchange of information, directives, or feedback between people and robots is referred to as interaction. Interaction can be one-way (for example, a human instructing a robot) or two-way (for example, a robot providing information or aid to a person) (Frijns et al, 2023). Interaction may not always indicate a common objective or a collaborative endeavor; it can be more transactional in nature.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

### 2.1.2 Collaboration

Humans and robots collaborate to achieve a same goal, which often involves shared activities or responsibilities. Coordination and cooperation are frequently required, with each party providing their own skills and capacities. Collaboration suggests a higher level of interdependence, where the task's success may be dependent on the effective contributions of both humans and robots (Sheridan, 2016).

Consider the following principles to efficiently manage human-robot collaboration:

1: **Task Analysis**: Determine the precise activities that humans and robots will accomplish in collaboration. Determine how the strengths and capabilities of each party can be used to accomplish the desired results (Kadir et al., 2018).

2: **Implement stringent safety standards** to safeguard the safety of humans and robots in the collaborative workspace. Sensor systems, physical obstacles, emergency stop mechanisms, and human operator training may all be included (Caruana & Francalanza, 2021).

3: **Human-Robot Interface**: Create user-friendly interfaces that allow people to efficiently communicate with and control robots. This could include user-friendly touchscreen interfaces, voice instructions, and even brain-computer connections (Ajaykumar et al., 2021).

> *"The design of the interface, although dependent on the specific target application, will require substantial consideration of the end user of the robotic device."*
>
> - Thrun, 2004, p.14

4: **Human operators and users** should receive proper training and instruction to ensure they understand the capabilities and limitations of the robot. This will aid in the prevention of accidents and the enhancement of task performance (Wolfartsberger et al., 2018).

5: **Feedback systems**: Create feedback systems that allow people and robots to communicate with one another. This can aid in real-time modifications, error correction, and task enhancement overall (Paxton et al., 2017).

6: **Communication Protocols**: Establish unambiguous communication protocols between humans and robots. This involves how data is transferred, commands are issued, and feedback is received (Ajaykumar et al., 2021).

7: **Continuous Monitoring and Evaluation**: Monitor and evaluate the collaboration on a regular basis in order to find areas for development and refinement. Adjust as needed based on real-world experiences (Paletta et al., 2017).



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

8: **Ethical Considerations**: Address ethical and social issues of human-robot collaboration, such as privacy, job displacement, and the impact on the workforce. Determine that the collaboration is consistent with social values and standards (Wallace, 2021).

9: **Scalability and adaptability**: Create systems that are both scalable and adaptable to a variety of jobs and contexts. This adaptability allows robots to be integrated into a wide range of industries and applications (Fasth et al., 2019).

Managing human-robot collaboration is a dynamic topic, and as technology improves, it is critical to stay updated with best practices and research in this area to ensure safe and efficient human-robot collaboration.

## 2.2 Key sectors of HRI

The following illustrative examples serve to underscore how robots have emerged as indispensable collaborators, contributing to the execution of tasks across a diverse spectrum of industries (Sheridan, 2016):

**Manufacturing**: In manufacturing, robots work alongside human workers to improve efficiency and precision. For example, automotive companies like Tesla use robots for tasks like welding and assembly, augmenting the workforce and increasing productivity.

**Healthcare**: Robots are assisting in surgeries, patient care, and medication dispensing. The da Vinci Surgical System, for instance, allows surgeons to perform minimally invasive procedures with robotic assistance, enhancing surgical precision.

**Logistics and Warehousing**: E-commerce giants like Amazon employ robots for order fulfillment and warehouse management. Amazon's Kiva robots, now known as Amazon Robotics, help optimize the movement of goods in their fulfillment centers.

**Agriculture**: Agriculture is benefiting from robots for tasks like planting, harvesting, and crop monitoring. The use of drones and autonomous tractors, such as those by John Deere, exemplifies this trend.

**Construction**: Robots are used in construction for tasks like bricklaying and demolition. The SAM100 bricklaying robot by Construction Robotics is an example of how robots can assist in construction projects.

**Retail**: Robots are used for inventory management, customer service, and even as greeters in some retail stores. The robot "Marty" can scan store shelves to check for out-of-stock items and potential hazards.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

### 2.2.1 HRC with Service and Social Robots

***Service Robots***

Advancements in AI, speech recognition, and more affordable and sophisticated mobile computing devices have all come together to make service robots, which are designed to assist service workers (Hinds et al., 2004). Service robots are designed to perform tasks for humans, often in a functional or practical way. They can be used for cleaning, delivery, security, or other service-oriented tasks. While service robots may also interact with humans, their primary function is to complete a task or provide a service.

***Social Robots***

Social robots may engage significantly with humans in a workplace context, aiming to contribute to task completion to the extent that it becomes conceivable to regard the robot as a team member, for example care robots, police robots, and military robots (Nyholm and Smids, 2020). Social robots are designed to interact with humans in a social or interpersonal way. They may be used for companionship, entertainment, or even therapeutic purposes. These robots are designed to engage with people on an emotional or social level.

***Difference Between Service and Social Robots***

Social robots, which can interact socially like humans, may, over time, replace humans in certain tasks (Šabanović, 2010). For instance, a social robot could assist a healthcare worker in the interaction with the elderly. In contrast, service robots generally have lower autonomy and perform simpler tasks with limited interactions, such as a mobile telepresence robot. The distinction between social and service robots lies in their interaction abilities, e.g., social robots can understand and follow social cues, including physical boundaries and group behavior rules, whereas service robots may not have such capabilities (Yan et al., 2014). Nonetheless, both types of robots are used in similar contexts and are thus socially embedded.

In the case of social robots, collaboration revolves around robots engaging with humans in a way that complements human abilities or fulfills social needs. Humans and robots may possess complementary capabilities, while humans excel in reasoning and planning in unstructured contexts, robots are proficient in repetitive and precise task execution (Hirche & Music, 2017). Therefore, a key aspect for human-robot collaboration entails how to integrate the decision-making and task execution abilities of human-robot teams to leverage their complementary skills (Hirche & Music, 2017). Even when robots were originally created for simple and repetitive tasks considered hazardous for humans, they were viewed as followers or subordinates; however, as computing capacity and machine-learning algorithms advanced, robots evolved to perform intricate sequences of actions (Tsai et al., 2022). Consequently, robots can help humans to achieve a variety of goals in a collaborative way.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

AI and machine learning advancements are improving robots' ability to learn, enabling them to understand human intent quickly and accurately and respond to behavioral variations which, enhances the effectiveness of Human-Robot Interaction (HRI), contributing to better team performance (Kim, 2022). However, it is still challenging to ensure that social robots can understand human intentions and respond appropriately and safely. This requires more technological advancements in sensors, artificial intelligence, and programming to enable seamless interaction.

### 2.2.2 HRC with Collaborative Robots

The adoption of collaborative robots (cobots) within the manufacturing sector has experienced substantial growth in recent years, with a notable doubling of their integration in the past six years (IFR, 2023). Traditional industrial robots, recognized for their speed and precision, come with significant costs and demand comprehensive safety measures and physical guarding, constraining their adaptability. This constraint has prompted a surge of interest in cobots, particularly among smaller manufacturing firms seeking cost-effective, lightweight, and flexible automation solutions (Xu et al., 2018).

Cobots, short for collaborative robots, are designed to function seamlessly alongside human operators in a shared workspace, leveraging the strengths of both machines and human skills. These robots feature lightweight construction, improved kinematics, and user-friendly programmable interfaces, aiming to enhance user satisfaction, safety, health, and overall performance (Kopp et al., 2020). Despite their growing market potential, the concept of industrial Human-Robot Collaboration (iHRC) remains relatively new, with limited research and practical implementation still in its nascent stages (Kopp et al., 2020). This chapter delves into the realm of collaborative robots in manufacturing, exploring their origins, types, applications, and the overarching challenges and opportunities they present.

The advent of collaborative robots, commonly referred to as "cobots," can be attributed to Northwestern University professors J. Edward Colgate and Michael Peshkin in 1996 (Colgate et al., 1996). Subsequently, in 1997, a patent provided a definition of cobots as "an apparatus and method for direct physical interaction between a person and a general-purpose manipulator controlled by a computer" ("Cobots: History and Applications of Collaborative Robots," 2020). It was only nearly a decade later, in 2008, that the Danish company Universal Robots introduced the first commercially available collaborative robot, equipped with adequate safety measures to work alongside human operators, effectively eliminating the need for physical barriers.

To achieve a comprehensive understanding of collaborative robots, it is essential to delve into their interactions with human workers. The International Federation of Robotics (IFR) classifies four distinct types of collaboration between robots and human workers (Caruana & Francalanza, 2021). These collaboration types include:

- **Coexistent collaboration**: This form of collaboration entails humans and robots working together in a shared workspace without physical barriers, ensuring the highest level of safety during their interaction.

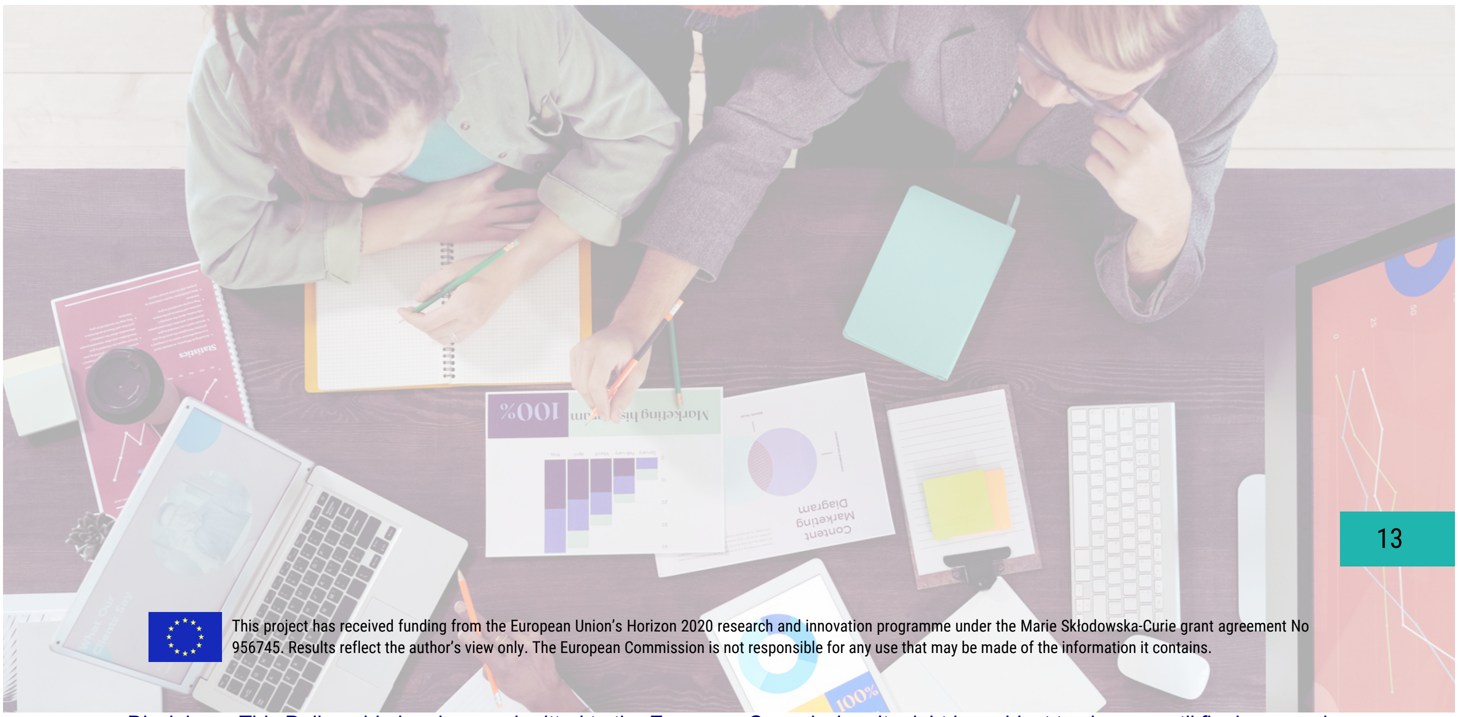


This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

- **Sequential collaboration**: In sequential collaboration, human and robot partners synchronize their work processes and movements in a shared workspace, with only one partner present at a time.
- **Cooperative collaboration**: Cooperative collaboration involves humans and robots working simultaneously but not concurrently on the same task, sharing a workspace while focusing on different aspects of the work.
- **Responsive collaboration**: Responsive collaboration signifies robots reacting to human movements in real-time during tasks, emphasizing the use of sensor technology, worker safety, and security standards.

In manufacturing, the most prevalent forms of collaboration are coexistent and sequential collaboration. The integration of cobots not only enhances production efficiency but also alleviates workers' biomechanical strain, thereby enhancing ergonomics (Blankemeyer et al., 2018). Cobots find extensive applications in various industries, offering versatility and multifunctionality. Key tasks associated with cobots include: Assembly, Pick and Place, Machine Tending, Quality Inspection, and Palletizing. The adaptability and multifunctionality of cobots make them invaluable assets for streamlining operations, boosting productivity, and promoting a safer working environment.

The successful implementation of collaborative robots, especially within manufacturing environments, necessitates a heightened focus on security. European conformity assessment of machinery encompasses three primary fields of regulations and standards: Type A, Type B, and Type C. Type A standards provide universal safety guidelines, as exemplified by ISO 12100. Type B standards address specific safety aspects, while Type C standards identify risks associated with particular machine types, as illustrated by the ISO 10218 family for industrial robots. With the advent of commercially accessible cobots, the technical specification ISO/TS 15066:2016 has been introduced as a supplement to ISO 10218. This specification delineates safety requirements applicable to collaborative industrial robot systems, with a specific focus on their work environment, in addition to providing operational guidance (Caruana & Francalanza, 2021).





This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

# 3. FRAMEWORKS FOR HRC
## REVIEW AND ANALYSIS

This report investigates the topic of collaborative human-robot interaction in organizations, aiming to provide a framework that helps navigate this evolving terrain. Therefore, this section reviews and analyses current frameworks designed to explain the interaction between and collaboration of human workers and robots.

**What is a framework?**

According to the Cambridge dictionary:

framework

*noun*

UK /ˈfreɪm.wɜːk/ US /ˈfreɪm.wɝːk/

Add to word list

[ C ]

**a supporting structure around which something can be built**

C2

**a system of rules, ideas, or beliefs that is used to plan or decide something:**

*"A conceptual framework, which is simply a less developed form of a theory, consists of statements that link abstract concepts to empirical data. Theories and conceptual frameworks are developed to account for or describe abstract phenomena that occur under similar conditions."* - Rudestam and Newton, 1992, p. 6



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

## 3.1 A Multidimensional HRC Framework

Research field: Engineering, cognitive and social sciences
Industry: Manufacturing sector
Type of robot: Cobots

Summary: This framework was proposed by Gervasi et al. (2020). They argue that Human-Robot Collaboration (HRC) aims to leverage the combined skills of both actors to accomplish a task. While existing research has delved into specific facets like safety and task organization, a significant challenge remains in establishing a comprehensive framework to assess collaboration in HRC. Their paper contributed by: (i) identifying distinct dimensions characterizing the HRC problem and (ii) creating a conceptual framework for evaluating and comparing different HRC configuration profiles.

Components:
1. Autonomy
2. Information exchange
3. Adaptivity and training
4. Team organization
5. Task
6. Human factors
7. Ethics
8. Cybersecurity

Review: The key aspects in the suggested conceptual HRC framework include the integration of diverse HRC aspects from various disciplines and the capability to compare different HRC applications based on evaluation metrics while considering various aspects, with flexibility to assess HRC tasks beyond the manufacturing domain. Also, certain dimensions primarily belong to the collaborative robotic system, e.g., autonomy. Meanwhile, dimensions such as Human factors and Ethics are closely associated with the humans engaged in the collaboration. This means that the framework has a socio-technical perspective that goes in line with the nature of human-robot interaction. This framework is therefore useful for assessing collaboration and identifying the specific evaluation metrics that need to be improved.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

## 3.2 A Levels-of-Analysis Perspective on HRC

Research field: Leadership
Industry: Industrial and nonindustrial work settings
Type of robot: Not specified (physically embodied)

Summary: From a leadership lens, Tsai et al. (2022) explore the role of robots in task accomplishment and relationship support. Using a levels-of-analysis framework, human-robot collaboration is analyzed across disciplines and a framework suggested looking at the individual, dyad, group/team, and organization/collective level.

Components: Level of analysis (individual, dyad, group/team, and organization/collective level), Collaborative role, Leadership entity, Leadership mechanism, Human fundamental process, Robot fundamental process

Review: The framework provided by Tsai et al. (2022) emphasizes that to understand and explore HRC there are various levels of analysis to consider. In each of the levels provided by the researchers, the different role of robots is defined. For instance, on an individual level robots can represent a follower or leader, whereas on an organizational level, a robot rather becomes an organizational member or manager. Each level is further classified by a human and a robot fundamental process. What this overall framework highlights is how human-robot interaction varies significantly depending on the respective perspective taken. The role of each will differ and the interaction will shift. Therefore, in order to understand HRC, the context and the counterparts involved are of significant importance.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

## 3.3 Human Resource Considerations for HRI

Research field: Human resources
Industry: Not specified (organizations overall)
Type of robot: Not specified (robotic technology)

Summary: This paper applies a human-centered perspective from the field of human resource development to review the literature on current knowledge on HRI. As a result, it identifies relevant considerations for implementing effective HRI in three human-centered domains: human capabilities, collaboration configuration, and attributes related to contact. Overall eight considerations include employees' attitudes toward robots, their readiness for robot technology, communication with robots, human–robot team building, leading multiple robots, systemwide collaboration, safety interventions, and ethical issues. Theoretical implications, practical implications, and limitations are discussed (Kim, 2022).

Components: employees' attitudes toward robots, their readiness for robot technology, communication with robots, human–robot team building, leading multiple robots, systemwide collaboration, safety interventions, and ethical issues

Review: The framework suggested by Kim (2022) provides a multidisciplinary lens on HRI in organizations. Considering the effect of HRI on human workers suggests an interaction of individual, group, and organizational level. As such, the integration of robots along workers requires an integrative view on all three levels. The framework presented is rather simplistic but highlights the interaction of different aspects affecting workers when introducing HRI. It highlights the need for organizations to move beyond the organizational level where safety, ethics, and systemwide collaboration are positioned, and act furthermore on attitude of workers towards robots, their readiness, their communication with robots, as well as the building and leading of human-robot teams.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

## 3.4 An USUS Evaluation Framework for HRI

Research field: HRI, HCI, psychology, and sociology
Industry: Not specified
Type of robot: Social or service

Summary: The framework proposed by Weiss and colleagues (2009) focuses on evaluating the usability, social acceptance, user experience, and societal impact of humanoid robots engaged in collaborative tasks. The overarching aim is to assess whether people perceive robots as supportive in cooperative work and accept them as integral parts of society, providing a holistic perspective on the evaluation of humanoid robots.

Components:
1. Usability
2. Social acceptance
3. User experience
4. Societal impact

Review: The chosen factors aim to pinpoint collaborative work situations with humanoid robots that are socially acceptable. The goal is to demonstrate the positive benefits of deploying humanoid robots, convincing society to support their integration into human working environments. Each factor or component has multiple indicators or evaluation metrics to understand the different subdimensions that compose them. The subdimensions have been carefully selected from case studies and literature review.

This framework highlights the need to measure not only in a quantitative way, but also qualitative, e.g., focus groups, to understand different perspectives and experiences in human-robot collaboration scenarios. It is also relevant to consider that when using the USUS framework for human-robot collaboration, it is important to gather feedback from both the human users and any stakeholders involved. This could include end-users, developers, and those responsible for implementing and managing the robotic system.

Unlike other frameworks, USUS integrates aspects that evaluate the broader impacts of human-robot collaboration, which is interesting given that humanoid robots have significant societal and psychosocial effects. For instance, the framework looks at working conditions and employment to understand more about the growing possibility of replacing certain roles, such as assembly-line workers, with robots, as they can execute specific physical tasks more rapidly and accurately than humans.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

## 3.5 Complexity Levels of Influencing Factors in HRI

Research field:
Industry: Various industries with a focus on manufacturing
Type of Robot: Collaborative

Summary: Simões et al. (2022) discuss hardware like a flexible robot skin and a dual-arm robotic system. The paper covers software recommendations for control, safe interaction, communication, and cooperative behaviours.

- Human-Robot Team's Performance:
  - Addresses task allocation strategies for generic, cognitive disability, and multi-human scenarios. Provides insights for improving team performance and wellbeing.
- Integrated Approaches:
  - Advocates a holistic approach considering physical, cognitive, social, organizational, environmental, and economic factors.
  - Highlights frameworks, including morphological, human-machine cooperation, and suitability assessment models.

Framework: Multiple frameworks are discussed, emphasizing a comprehensive understanding of HRI, covering aspects like objectives, economics, product, process, safety, and ergonomic risk assessment.

Components: Human operator (cognitive and social processes, human comfort and safety), technology (hardware, software), human operator team's performance (workspace, task, performance, HRI strategies, integrated approach to design HRC

Review: This framework stems from a meticulous analysis of selected articles, aiming to systematize recommendations and guidelines for HRI contexts. The authors categorize influencing factors into three main groups: single factors (Category 1), studies involving multiple factors (Category 2), and holistic approaches (Category 3). The breakdown within each category provides detailed insights, such as trust dynamics, attribution of blame, and technology acceptance in Category 1a, and collaborative workspace, task allocation, and HRI strategies in Category 2. The framework emphasizes the importance of a multidisciplinary approach for future research and the development of validated tools to assess the sustainability of HRC in manufacturing. Overall, it offers a structured understanding of HRI complexities and provides valuable insights for designing effective collaborative workspaces.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

## 3.6 Arbitration Regulation in HRI

Research field: Engineering, Robotics
Industry: Manufacturing, healthcare
Type of robot: Collaborative

Summary: The study by Losey et al. (2018) examines the expanding subject of physical human-robot interaction (pHRI), which is becoming more prevalent as robotic devices are used in non-traditional situations such as healthcare. Emphasizing the physical link between humans and robots, the focus is on circumstances where human-robot collaboration and cooperation are required. Three primary motifs in these shared control settings include:

Intent Detection:
- Investigates techniques for the pHRI system to determine a person's intents.
- Examines how human intent might be inferred from the physical coupling itself.

Arbitration:
- Examines methods for allowing the robot and human operator to share and modify control of the connected system.
- After determining human purpose, the evaluation explores the allocation and modification of control.

Feedback:
- Examines ways to provide the human operator with information about the coupled system's state.
- Discusses about giving details on the features of the surroundings that the pHRI system interacts with.

Components: 1: Arbitration, 2: Feedback, 3: Intent Detection, 4: human, 5: Information exchange, 6: Tasks

Review: This study delves into human-robot shared control in physically connected cooperative tasks, broadening the scope of physical Human-Robot Interaction (pHRI) frameworks. It emphasizes "intent detection" for robots to understand human objectives, introduces "arbitration" to govern communication, and highlights the importance of providing humans with context and task knowledge. The framework suggests using haptic feedback for existing physical connections, with a schematic illustrating arbitration as a control-modifying knob. The two-way communication enhances teamwork by allowing the robot to identify human intentions and provide feedback.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

# 4. HUMANS AND ROBOTS
INDUSTRY INSIGHTS

## 4.1 Food Packaging Industry: Robots for Identification

In the food and medical packaging industries, clean packaging is crucial to both customer satisfaction and hygiene. An operational Quality Assurance Department (QAD) is necessary for detecting contaminated packages. Manual examination becomes tedious and may lead to instances of contamination being missed along the production line. To address this issue, a system for contamination detection is proposed using an enhanced deep convolutional neural network (CNN) in a human–robot collaboration framework. The proposed system utilizes a CNN to identify and classify the presence of contaminants on product surfaces. A dataset is generated, and augmentation methods are applied to the dataset for nine classes such as coffee, spot, chocolate, tomato paste, jam, cream, conditioner, shaving cream, and toothpaste contaminants. The experiment was conducted using a mechatronic platform with a camera for contamination detection and a time-of-flight sensor for safe machine–environment interaction. The results of the experiment indicate that the reported system can accurately identify contamination with 99.74% mean average precision (mAP).

Food contamination such as coffee, chocolate, and other stains must be quickly identified at the packaging stage. The frequency with which packaged food arrives on the Quality Assurance floor is too high for manual detection, and therefore it requires a smart solution for detecting contamination related to outer surfaces of the product. When a product is not clean, the buyer will avoid purchasing it, creating a poor impression in the customer's mind about that product. Before goods are permitted to hit the market, they must undergo thorough and accurate inspection. The proposed algorithm is set up to raise the alarm when contamination is detected, at which point the Quality Assurance Department (QAD) personnel must remove the contaminated object from the conveyor belt for detailed cleaning. To ensure safe machine–environment interaction, it is proposed that a proximity sensor be used to detect unwanted human intervention and raise the alarm if it occurs. The experimental setup and the proposed algorithm are discussed in the following paragraphs.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

## 4.2 Textile Industry: Robots for Defect Detection

The emergence of modern technology has caused a transformation in the textile sector, where human robot interaction and artificial intelligence are essential for improving quality control and production. Manual inspection of fabric is time-consuming and might result in defects being missed during inspection. To address this, an algorithm is implemented for fabric defects detection by utilizing deep convolutional neural networks (DCNNs) in an environment of safe human-robot interaction (HRI). The proposed method integrates advanced DCNN architectures to automatically classify and detect different types of fabric defects, assuring high accuracy and efficiency in the inspection process. The dataset is created, augmentation techniques are applied, and a model is fine-tuned on a large dataset of annotated images using transfer learning approaches. The experiment was carried out using Universal Robot 5 that is programmed to move above the fabric, and an algorithm operating on an attached camera on the robot is responsible for detecting defects on the fabric and triggering an alarm. A photoelectric sensor was installed on the conveyor belt and linked to the robot to notify it about an impending fabric. The experimental findings show that the reported system can detect fabric defects with acceptable accuracy and mean average precision (mAP).

## 4.3 Healthcare Industry: Robots for Mobile Telepresence

The following is a case study about mobile telepresence robots in healthcare conducted by Rojas and Nørskov (2023). Robots that enable communication and mobility from a remote location, known as Mobile Telepresence Robots (MTRs), are utilized in healthcare to improve interactions among physicians, patients, and family members. While MTRs can enhance healthcare quality and efficiency, their interactions need thorough examination to address design, development, and implementation issues, considering the physical affordance space. Thus, the study aimed to identify interaction types provided by two MTR types in healthcare, assess their relevance in different healthcare settings, and understand perceived differences between the two MTRs.

The study collected empirical data in Spain from two hospitals, a nursing home, and professionals in different private clinics. Employing a qualitative approach, 25 semi-structured interviews were conducted with individuals using GoBe, an MTR from the Danish company Blue Ocean Robotics, as stimuli. The study also gathered data through observations, two focus groups, and archival sources. The findings highlight two types of interactions: displacement and simultaneity.

Workers from the nursing home found organizing video calls between residents and family members burdensome. The displacement interaction, where MTRs can independently manage video calls and healthcare workers can focus on job-related tasks, is thus highly relevant in nursing homes compared to hospitals. In hospitals, this interaction is crucial for isolated or physically disabled patients making video calls. Some believe it contributes to patient well-being.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

As for the simultaneity interaction, which is used in telemedicine when the MTR and the clinician coexist simultaneously, interviewees from the hospital argued that MTRs could be more useful in in such settings due to the large number of patients and limited health workers. MTRs could help alleviate the workload by enabling mobile telepresence for remote health professionals, enhancing healthcare effectiveness. In this case, even when MTRs are being teleoperated by the remote clinicians, there is a case for human-robot collaboration in which the healthcare workers that are located in the hospital will interact with the remote clinician through the robot and thus be assigned different tasks depending on their capabilities. The on-site clinicians will have to oversee the MTRs smooth navigation by opening doors or pushing the button for the elevator. The remote clinician might send images or information through the robot's screen and ask for feedback from the on-site staff. This way, there is a form of human-robot collaboration that is not autonomous but teleoperated. Studying human-robot collaboration in teleoperated robots involves examining the interaction between humans and robots when the human operator is controlling the robot remotely. Here, it is important to identify the tasks that require collaboration between the human operator and the robot, as well as the strengths and limitations of human-robot collaboration.

## 4.4 Manufacturing Industry: Robots for Multifunctionality

Cobots, have demonstrated extensive applicability across diverse industries. The following table provides a condensed overview of the principal applications commonly associated with cobots (Javaid et al., 2022).

| Task | Description |
|---|---|
| Assembly | Cobots frequently contribute to manufacturing processes by engaging in the assembly of parts or components. They operate alongside human operators, offering assistance with tasks that involve repetition or delicacy. |
| Pick and place | Cobots exhibit exceptional proficiency in retrieving objects from one location and depositing them in another. This application is prevalent within industries such as logistics, warehousing, and packaging. |
| Machine tending | Cobots are adept at managing and attending to various machines, including CNC machines or injection molding machines. Their capabilities encompass tasks such as material loading and unloading, process monitoring, and quality control inspections. |
| Quality inspection | Cobots equipped with advanced vision systems undertake product inspections to ascertain consistent quality throughout the manufacturing process. They possess the capacity to detect flaws, measure dimensions, and identify anomalies. |
| Packaging and palletizing | Cobots are widely employed in the packaging sector to facilitate the arrangement of products within boxes or containers, as well as the palletization of goods for efficient shipment. Their versatility enables them to handle diverse shapes and sizes with proficiency. |

Table 1 Key Applications of Cobots, adapted from Malik and Bilberg, 2019

This summary serves to encapsulate key applications that cobots are commonly employed in across various industries. The adaptability and multifunctionality of cobots make them invaluable assets for streamlining operations, boosting productivity, and promoting a safer working environment (Malik and Bilberg, 2019).



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

EINST4INE

## 5. Special Section | Systems integrators: Key players for HRC

*Alejandra Rojas, ESR 5*

The cobot ecosystem consists of various stakeholders and components that support the development, deployment, and use of collaborative robotic systems. For example, end-users, cobot manufacturers, system integrators, software developers, sensor and vision system providers, end-effectors providers, safety solutions providers, regulatory bodies, among others.

A systems integrator is a company or individual that specializes in integrating various technologies, components, and systems to create a cohesive and functional solution. In the context of cobots and human-robot collaboration, systems integrators are responsible for designing, developing, and implementing systems that enable robots and humans to work together safely and efficiently in a shared workspace. As mentioned by Andrea Firrincieli, Chief Technical Officer of Mediate Srl company, "**Robots are not collaborative as robots alone. Collaborative Robotics is not about the robot, but the application […] A robot without tools is not a machine**". Sensor and vision system providers are essential for enabling cobots to sense their environment and interact safely with humans. Systems integrators collaborate with sensor and vision system providers to select and integrate the appropriate sensors and vision technologies into the robotic systems.

Systems integrators play a specific role within this ecosystem, and their contributions are vital. As mentioned by Andrea, there are some cobot manufacturers that are promoting the creation of cobots that can be installed by the end-users, by small medium enterprises. "They are simplifying the part of programmation, programming the robot, but in my opinion, the supervision of someone who has expertise and experience on the design of robot cells is very, very important because people generally could make decisions without considering some problems that can cause, for example, without considering the complete application into the cell design process, people typically underestimates the real workspace and could buy components with a wrong size, included the cobot".

**Systems integrators are a crucial component of the cobot ecosystem, as they bridge the gap between cobot manufacturers and end-users, between available technologies and specific applications**. They bring together hardware, software, safety solutions, and expertise to create custom cobot systems (robotic cells) that meet the specific needs of their clients while adhering to safety regulations. Their role is pivotal in the successful implementation of collaborative robot technology across various industries.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

## The Case of Mediate Srl

Mediate Srl. is a spin-off company of Scuola Superiore Sant'Anna and was established with the aim of bringing to the market revolutionary technological and scientific advancements in collaborative and industrial robotics. They work as systems integrators with a strong R&D approach. Additionally, they are developing an innovative, modulare and versatile proximity sensing technology designed for engaging with humans over a high distance range, suitable for both personal and professional settings. With this new approach, Mediate aims for humans and robots to collaborate as team members through the integration of novel technologies that can adapt to various surfaces, ensuring a strong awareness of the environment. As put by Andrea, "We are developing sensors for proximity detection, that have the aim to overcome the current "contact" paradigm. For now cobots are designed to be certified when a contact occurs, in fact if the robot touches you is safe, it means that the energy of interaction of the robot with you is safer for humans, based on the contact […] it is related to the cobot as stand-alone unit, but when you transform the cobot in an application, you need to demonstrate that the cell is safe and we are working for creating products on this topic".

## Compliance with Certifications for Safety

Safety is a paramount concern in human-robot collaboration. Safety solution providers offer components such as safety sensors, interlock systems, and protective barriers. Systems integrators incorporate these safety features to ensure that the collaborative robot systems comply with safety standards and protect human workers. "Other companies sell the robot along as a collaborative tool, but in the end, the people that bring the systems together has to certify that this is a collaborative application, if something happens and people get hurt the responsibility is yours", as commented by Andrea.

Andrea mentioned the technical specification 15066 for collaborative solutions with cobots. ISO/TS 15066 is an international technical specification that provides guidelines for the safety of human-robot collaboration (collaborative industrial robots and applications). Specifically, it focuses on robots designed to work alongside humans in a shared workspace. ISO/TS 15066 outlines safety requirements and measures to ensure that humans can work safely with these robots. For example, ISO/TS 15066 specifies limits for the forces and pressures that a robot can exert on a human to ensure that these forces do not cause harm. The limits are categorized based on different parts of the body and the expected contact duration. Andrea illustrated how tools, like a gripper, are not collaborative by themselves, and to turn it in a collaborative gripper, the first thing to be managed are the edges and some specific pressure and energy characteristics that have to be respected for peoples' safety. In that way, the used technology is desihned on requirements and specifications so that there could be harm but not serious damage. "If you want a knife that cuts something on your tool, currently is impossible to demonstrate that your tool is collaborative, and a system integrator and designer has to design the cell in a way that is not harmful and respect safety requirements", he mentioned.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

**Synchronizing Human and Robot Tasks is the Heart of Collaboration**

Collaborative robotics has different applications that depend on the level of interaction between people and the robot. Coordinating tasks between humans and robots often involves intricate interactions. It is therefore essential to define clear roles, responsibilities, and communication protocols to avoid misunderstandings or conflicts. However, there are applications in which the workspace of the robot and the workspace of the people are not intersected, in which robot and human do not make things synchronized. “Generally, in the current market, cobots are mainly used for independent tasks. […] for example, creating the pallets for product delivery […] that is not a strict collaboration […] the people can go around in a safe way. Like coexistence but not real dependency or collaboration”. In this line, tasks can be divided between humans and robots because they have different capabilities and limitations. Humans possess flexibility, adaptability, and the ability to make complex decisions, while robots excel at precision and repetitive tasks. Finding the right balance between these capabilities can be complex.

Andrea mentions that understanding how to put robotics into the human scenario is the most difficult part because "**people are not only workers, but they also have feelings, colleagues, etc., and if you put a robot into a workplace with people, it is not like putting an additional trash bin […] it has to be accepted**”. Some organizations may face resistance or reluctance from workers who are concerned about job security or who are uncomfortable with the introduction of robots into their work environments.

The timing of activities is also a challenging aspect to consider when designing human robot collaboration. According to Andrea, cobots cannot work at the same pace as industrial robots because they are made for working continuously, whereas cobots have to wait according with the interactions with people. As he puts it, “people have to go out to the bathroom, people have to know how to manage, for example, a block of the system. People can see something that the robot cannot see, for example, when something is blocked or when material is not good.”



This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author’s view only. The European Commission is not responsible for any use that may be made of the information it contains.

# KEY LEARNINGS

The cobot ecosystem involves various stakeholders and components that support the development, deployment, and use of collaborative robotic systems. This includes end-users, cobot manufacturers, system integrators, software developers, sensor and vision system providers, safety solution providers, and regulatory bodies, among others.

Systems integrators specialize in integrating different technologies and components to create cohesive and functional solutions.

Collaborative robotics is not just about the robot itself but also the tools and applications it is used for. The integration of appropriate tools and technology is crucial for safe human-robot collaboration.

Safety is paramount in human-robot collaboration. Systems integrators incorporate these safety features to ensure compliance with safety standards, such as ISO 15066, which provides guidelines for the safety of collaborative industrial robots.

Synchronizing tasks between humans and robots is the core of collaboration. The level of interaction between people and robots varies depending on the application, with some tasks being more independent and others requiring close collaboration.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

# 6. AN HRC FRAMEWORK REVISITED

## 6.1 Challenges for designing an HRC framework

The examination of six frameworks within the HRI domain provides a nuanced understanding of collaborative system design involving humans and robots. Gervasi et al.'s Multidimensional HRC Framework takes a comprehensive approach, identifying dimensions like autonomy, information exchange, and ethics, offering a holistic perspective tailored to the manufacturing sector. In contrast, Tsai et al.'s Analysis Perspective on HRC adopts a leadership lens, emphasizing diverse roles at various levels. Kim's Human Resource Considerations for HRI focuses on human-centric factors crucial for effective collaboration. Weiss and colleagues' USUS Evaluation Framework assesses humanoid robots' usability, social acceptance, and societal impact, considering broader implications. While not explicitly labeled, the Complexity Levels of Influencing Factors in HRI framework concentrates on hardware, software, and team performance, extending to collaborative robots in various industries. The Arbitration Regulation in HRI framework, which emphasizes shared control, introduces key themes like intent detection, arbitration, and feedback. These frameworks, contributed by Gervasi, Tsai, Kim, Weiss, and other collaborators, collectively enrich our understanding of the multifaceted challenges and opportunities in implementing successful HRI systems. Analyzing them together highlights their distinctive focuses—ranging from leadership perspectives to human resource considerations—and underscores the interdisciplinary nature of HRI research, emphasizing the need for adaptable frameworks to cater to the diverse landscape of collaborative scenarios.

However, creating a holistic framework for HRC presents a challenge due to the inherently diverse and dynamic nature of the collaboration landscape. The spectrum of challenges encompasses a wide array of robot types, each with unique capabilities and functionalities, ranging from traditional industrial robots to more advanced social or service robots. Moreover, the varied working environments, spanning sectors like manufacturing and healthcare, demand adaptable frameworks that can account for the distinct contextual nuances. Additionally, the challenge extends to different levels of analysis, necessitating considerations at the individual, team, organizational, and societal levels. The multidimensionality of HRC, coupled with the rapid evolution of robotic technologies and the dynamic interplay between human and machine, adds layers of complexity that hinder the development of a one-size-fits-all framework. Consequently, crafting a holistic framework necessitates navigating this intricate web of variables to ensure versatility, effectiveness, and relevance across the diverse landscape of human-robot collaboration scenarios.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

## 6.2 A Novel Integrated Framework

After reviewing the different frameworks, an analysis was conducted by the ESRs in a working session to create an integrated framework that includes the essential aspects of HRC. Acknowledging that even when all the analyzed frameworks are related to HRC and HRI, each one comes from a specific research field and serves a different purpose, therefore, the analysis had to consider the different perspectives and how they complement each other. Thus, the decision was to choose one framework that represents the organizational and managerial perspective of HRC and then complement it with the components of the rest of the frameworks. This way, the framework proposed by Tsai et al. (2022) served as a foundation for the integration of key factors that form HRC. This foundational framework focuses on the robots' role and how they contribute to completing tasks and fostering relationships, proposing a framework that assesses interactions at the individual, dyadic, group/team, and organization/collective levels.

The leadership perspective is considered the foundation of this integrated framework, as HRC involves managing technology integration, fostering a collaborative culture, and addressing the psychological and social aspects of team dynamics. Effective leadership will require a balance between leveraging robots' strengths in terms of efficiency and precision while recognizing and accommodating the unique qualities that humans bring, such as creativity, emotional intelligence, and adaptability. Therefore, we find useful that the framework of Tsai et al. (2022) clarifies leadership mechanisms, and we aim to enhance that perspective with other key factors that are essential for HRC success. Some of these factors apply to specific levels of analysis, for example, at the individual or group level, and some to all levels of analysis.

HRC represents a multifaceted interplay between technologies and human experience. Various factors shape the dynamics of this collaboration, influencing its effectiveness, efficiency, and overall success. Therefore, the planning of HRC must carefully consider the factors that are presented in this integrated framework. To begin, there are factors that apply for the individual level of analysis. First, the readiness for robot technology (Kim, 2022) shows the willingness and preparedness of individuals and organizations to embrace and integrate robot technology. Assessing and managing readiness ensures a smoother transition and effective utilization of robotic capabilities. Then, the information exchange with robots factor (Kim, 2022; Gervasi et al., 2020) will depend on the choice of communication medium and format. Understanding how information is exchanged is crucial for seamless collaboration. Also, cognitive and social processes (Simoes et al., 2022) from an individual level may involve understanding how humans process information, make decisions, and engage socially, ensuring that robotic systems align with and enhance these processes. Last, human comfort (Simoes et al., 2022) involves the comfort of individuals interacting with robots and is a key determinant of successful collaboration so that humans and robots can work together harmoniously.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

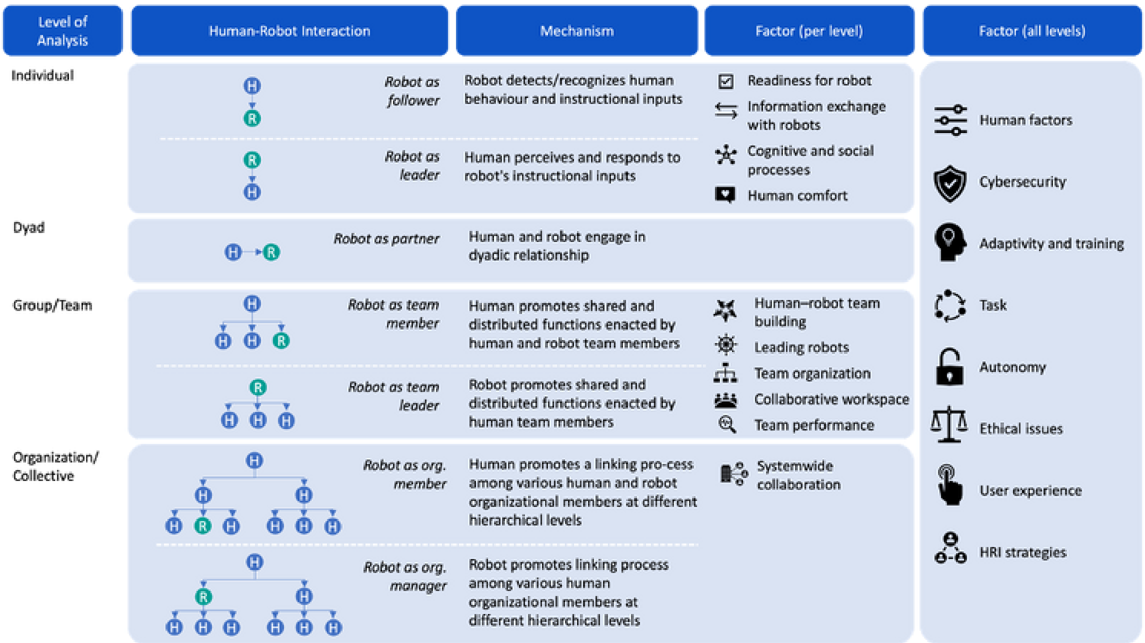



Figure 10 A Novel Framework for Collaborative Human Robots in Organizations, adapted from Tsai et al., 2022

Factors that apply for the group and organizational level are as follows. Human-robot team building (Kim, 2022) may include initiating and cultivating a collaborative team dynamic between humans and robots with considerations of interpersonal communication. Then, leading multiple robots (Kim, 2022) tells us that as technology advances, the ability to manage and lead multiple robots simultaneously forces us to understand the complexities of orchestrating a team of robots efficiently for achieving collective goals. Similarly, team organization (Gervasi et al., 2020) will be necessary for goals' achievement by securing the organization of the collaborative team, including its structure and the defined roles of human and robotic team members. Collaborative workspace, proposed by Simoes and colleagues (2022) entails the design and configuration of the workspace where humans and robots collaborate to enhance communication, accessibility, and overall synergy. Team performance (Simoes et al., 2022) will require evaluating and optimizing workflows and continually adapting to meet challenges. From an organizational level, systemwide collaboration (Kim, 2022) is necessary to extend beyond immediate team dynamics and emphasize the importance of integrating HRC into broader organizational systems.

As mentioned before, there are factors that apply for the overall levels of analysis. First, human factors entail understanding and addressing human aspects such as workload, trust, robot morphology, and physical ergonomics are pivotal in designing a collaborative environment that complements human capabilities (Gervasi et al., 2020). Then, usability is related to the system's ease of use, as outlined by Weiss et al. (2009), and is a critical factor ensuring that users can interact seamlessly with the technology. Usability includes effectiveness, efficiency, and learnability, which evaluate the robot's ability to perform tasks, utilize resources optimally, and facilitate user acquisition of necessary skills, respectively. Furthermore, usability is about flexibility and robustness of the robot to adapt to varying contexts and maintain performance in the face of unexpected challenges. The last element of usability is utility, which means that the practical value and usefulness of the HRC determine its overall impact and acceptance.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

Cybersecurity is another factor highlighted by Gervasi et al. (2020). Ensuring the security of the collaborative system against cyber threats is essential for safeguarding sensitive information. The same authors propose adaptivity and training, which encompasses the adaptability of robots, the methods employed in robot training, and the training of operators, all contributing to the system's resilience and user competence (Gervasi et al., 2020). Moreover, task considerations are essential factors including the field of application, organization of tasks, and overall performance metrics. Such elements play a crucial role in defining the scope and success of HRC (Gervasi et al., 2020; Simoes et al., 2022). Safety, as emphasized by Kim (2022) and Simoes et al. (2022), is paramount to prevent accidents and ensure a secure working environment. Autonomy, the degree of independence and decision-making capabilities of the robot, may influence collaborative dynamics (Gervasi et al., 2020).

*„Autonomy refers to a robot's ability to accommodate variations in its environment. Different robots exhibit different degrees of autonomy; the degree of autonomy is often measured by relating the degree at which the environment can be varied to the mean time between failures and other factors indicative of robot performance."*

*- Thrun, 2004, p.14*

In relation to safety and autonomy, there may be ethical issues that have to be considered in HRC. Examining the ethical implications of collaborating with robots, as proposed by Kim (2022), ensures responsible development and deployment of technology.

Likewise, it is crucial to consider broader societal implications, including quality of life, working conditions, employment, education, cultural context, and social acceptance (Gervasi et al., 2020; Weiss et al., 2009).

*„What is technologically possible? And what is desirable?"*

- Thrun, 2004, p.10

Social acceptance involves attitudes and expectations toward robots, performance expectancy, effort expectancy, self-efficacy, forms of grouping, attachment, and reciprocity (Gervasi et al., 2020; Weiss et al., 2009). Last, user experience is a factor proposed by Weiss et al. (2009), which serves to contribute to a comprehensive understanding of user interaction. Incorporating elements such as human-oriented perception, embodiment, motion, feeling of security, and co-experience enhances the HRI and enriches the overall user experience.

*"The management does not have to dispose of or change employees' religious beliefs but to respond to the challenge of convincing employees to adopt the right behaviour according to organization's objectives, finding ways to convince human to work with new technologies, especially robots."*

- Firescu et al., 2022, p. 6



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

## 6.3 Future research avenues

In navigating the complex terrain of collaborative Human-Robot Interaction, the comprehensive integrated framework we have presented serves as a guiding compass. It consolidates diverse perspectives to address the dynamics of collaborative human-robot interactions within organizational settings. As we ponder the current state of HRC and distill insights from our exploration, it becomes evident that the field is in a state of continual evolution, offering exciting prospects for future research. In this chapter, we outline potential research avenues stemming from the integrated framework, illuminating uncharted dimensions, challenges, and advancements that will influence the trajectory of HRC in the years to come. These research directions are designed to move the field forward, fostering a more profound comprehension of the complexities involved in effectively orchestrating human-robot collaborations within organizational contexts.

#### Human Factors in HRC

In the pursuit of future research avenues, a pivotal area of focus revolves around the exploration of human factors influencing HRC acceptance within diverse organizational settings. Delving deeper into this realm entails investigating the psychological and social determinants that mold individuals' attitudes and perceptions regarding collaboration with robots in the workplace. The impact of such technologies on organizational, managerial, psycho-social, and socio-cultural aspects warrants further investigation (Ulhøi & Nørskov, 2021).To facilitate positive user acceptance and foster effective collaboration, it is essential to develop targeted interventions and strategies. Previous research has uncovered a positive correlation between human personality and robot acceptance (Esterwood et al., 2022). However, the nuanced nature of this connection necessitates further exploration. The existing gaps identified in the literature, spanning specific personality traits, demographic factors, task dynamics, and global regions, underscore the need for additional studies. Moreover, recognizing the pivotal role of trust in HRC acceptance, future investigations should continue to scrutinize the influences of human, robot, and environmental characteristics. Previous studies highlight the predominant impact of robot performance and attributes on trust development in HRI (Hancock, 2011), signaling the importance of ongoing research to refine our understanding of these dynamics and enhance the acceptance and efficacy of collaborative human-robot interactions.

#### Long Term Impact of HRC

In exploring future research directions, another important area of focus pertains to uncovering the prolonged effects of HRC on individuals and their well-being. Prior investigations have diligently probed how extended and repeated interactions with social robots shape people's self-disclosure behavior toward the robot, influence their perceptions of the robotic entity, and impact broader well-being factors (Laban et al., 2023). To advance this line of inquiry, forthcoming studies could utilize additional physiological measures. This approach aims to provide a more comprehensive assessment of participants' well-being and emotional changes over an extended period. By integrating objective physiological and behavioral indicators, researchers can delve deeper into understanding the interplay between affective interactions with social robots and their lasting effects on individuals' well-being.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

### Cross-Cultural Studies in HRC

In the sphere of future research avenues, an essential focus lies on Cross-Cultural Studies in HRC. Previous investigations have illuminated connections between culture and human cognition within the context of HRC, surpassing conventional east–west cultural distinctions (Lim et al., 2020; Bröhl et al., 2019). These studies delve into the factors influencing individuals' perceptions of robots, considering the interplay of both national culture and personal experiences. The significance of these findings emphasizes the call for culturally sensitive design and delivery of robots, prompting questions for robotics designers and cultural psychologists alike. To propel this field forward, upcoming research endeavors should focus on validating and expanding upon existing evidence concerning the impact of culture on HRC. Additionally, a more inclusive approach to cultural samples is imperative to address the over- and under-representation of specific countries, transcending the binary Western/European-East/Asian classification and fostering a globally comprehensive understanding of cultural dynamics influencing HRC.

### Human Robot Teaming

In the realm of forthcoming research, Human-Robot Teaming takes center stage, drawing inspiration from prior studies that have initiated an exploration into the challenges and possibilities inherent in collaborative interactions between humans and robots. Recent discoveries emphasize the distinctive advantages that emerge in Human-Robot Teams (Natarajan et al., 2023). However, the nature of HRC demands advancements in algorithms, necessitating consideration and collective endeavors. The delineated challenges identified in Human-Robot Teaming applications encompassing communication, modeling human behavior, scalability, safety, privacy as well as ethics, serve as focal points for upcoming research. Tackling these challenges will pave the way for a future where humans and robots seamlessly collaborate across various societal domains, unlocking the full potential of Human-Robot Teaming while mitigating societal harms.

### User Experience and User Interfaces for HRC

Within the domain of future research avenues, an emphasis revolves around elevating User Experience (UX) and refining User Interfaces (UI) in the realm of HRC. Recent studies on UI in augmented reality (AR) for collaborative assembly explore the effectiveness of visual and haptic cues, providing valuable insights into their impact on work performance, visual attention, and human trust in the robot (Apraiz et al., 2023; Chu & Liu, 2023). This research endeavor lays the groundwork for advancing UI/UX design strategies by delving into user preferences and experiences. Future studies should aim to further innovate UI/UX, exploring novel design approaches that prioritize user feedback, ease of use, and adaptability to diverse contexts.





This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

# 7. CONCLUSION

For centuries the extension and replication of human ability has been of vast interest. Over the past decades finally the application of industrial, collaborative, or social robots has grown significantly across sectors, making working environments more efficient and effective, all while promoting worker health and wellbeing. Yet, developments in the field are still in its infancy. Organizations are still lacking direction in designing workplaces where human and robot co-exist and work collaboratively. Scholars and practitioners alike have thus been exploring questions around human-robot interaction in order to understand and facilitate such encounters. The aim of this report has been to delve into existent frameworks on HRI and HRC and to provide guidance for the development of future HRC.

As this report shows, HRC is a multidisciplinary field on which various perspectives exist. Few frameworks have been suggested by previous scholars from fields such as engineering, computer science, human resources, or leadership. As a result of reviewing the diversity of frameworks we find that in order to create collaborative HRI, what is required is a defined level of analysis (e.g., individual, organizational), understanding the role of robot and human and how they interact (e.g., who provides input and direction for whom), and, finally, what factors will have to be considered on each level and as a whole (e.g., human factors, ethical issues, etc.).

With empirical lessons from research projects carried out under the European Training Network for Industry Digital Transformation across Innovation Ecosystems (EINST4INE), this report provided an in-depth study of the concepts of HRC and HRI, setting the stage for future debates and providing organizations with a roadmap for realizing the full potential of robots in the workplace.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

# REFERENCES


- Ajaykumar, G., Stiber, M., & Huang, C.-M. (2021). Designing user-centric programming aids for kinesthetic teaching of collaborative robots. *Robotics and Autonomous Systems*, 145, 103845. https://doi.org/10.1016/j.robot.2021.103845
- Alami, R., Albu-Schäffer, A., Bicchi, A., Bischoff, R., Chatila, R., De Luca, A., ... & Villani, L. (2006, October). Safe and dependable physical human-robot interaction in anthropic domains: State of the art and challenges. In 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems(pp. 1-16). IEEE
- Apraiz, A., Lasa, G., & Mazmela, M. (2023). Evaluation of User Experience in Human–Robot Interaction: A Systematic Literature Review. *International Journal of Social Robotics*, 15, 187–210. https://doi.org/10.1007/s12369-022-00957-z
- Blankemeyer, S., Recker, T., Stuke, T., Brokmann, J., Geese, M., Reiniger, M., Pischke, D., Oubari, A., & Raatz, A. (2018). A method to distinguish potential workplaces for human-robot collaboration. Procedia CIRP, 76(March), 171–176. https://doi.org/10.1016/j.procir.2018.02.008
- Braxton, J. C., & Taska, B. (2023). Technological change and the consequences of job loss. *American Economic Review*, 113(2), 279-316.
- Bröhl, C., Nelles, J., Brandl, C., Mertens, A., & Nitsch, V. (2019). Human–Robot Collaboration Acceptance Model: Development and Comparison for Germany, Japan, China and the USA. *International Journal of Social Robotics*, 11. https://doi.org/10.1007/s12369-019-00593-0.
- Caruana, L., & Francalanza, E. (2021). Safety 4.0 for Collaborative Robotics in the Factories of the Future. *FME Transactions,* 49(4), 842–850. https://doi.org/10.5937/FME2104842C
- Chu, C.-H., & Liu, Y.-L. (2023). Augmented reality user interface design and experimental evaluation for human-robot collaborative assembly. *Journal of Manufacturing Systems*, 68, 313-324. https://doi.org/10.1016/j.jmsy.2023.04.007
- Colgate, J. E., Wannasuphoprasit, W., & Peshkin, M. A. (1996). Cobots: robots for collaboration with human operators. American Society of Mechanical Engineers, Dynamic Systems and Control Division (Publication) DSC, 58, 433–439.
- Esterwood, C., Essenmacher, K., Yang, H., Zeng, F., & Robert, L. (2022). A personable robot: Meta-analysis of robot personality and human acceptance. *IEEE Robotics and Automation Letters*, 7, 2022. https://doi.org/10.1109/LRA.2022.3178795.
- Fasth, Å., Fast-Berglund, A., & Romero, D. (2019). Strategies for implementing collaborative robot applications for the Operator 4.0. In *Advances in Human Factors and Ergonomics*, 682-689. https://doi.org/10.1007/978-3-030-30000-5_83.
- Fong, T., Nourbakhsh, I., & Dautenhahn, K. (2003). A survey of socially interactive robots. *Robotics and autonomous systems*, 42(3-4), 143-166.
- Fraune, M. R., Leite, I., Karatas, N., Amirova, A., Legeleux, A., Sandygulova, A., Komatsu, T. (2022). Lessons learned about designing and conducting studies from HRI experts. *Frontiers in Robotics and AI*, 8, 772141. https://doi.org/10.3389/frobt.2021.772141
- Frijns, H.A., Schürer, O. & Koeszegi, S.T. Communication Models in Human–Robot Interaction: An Asymmetric MODel of ALterity in Human–Robot Interaction (AMODAL-HRI). *Int J of Soc Robotics* 15, 473–500 (2023). https://doi.org/10.1007/s12369-021-00785-7
- Gervasi, R., Mastrogiacomo, L., & Franceschini, F. (2020). A conceptual framework to evaluate human-robot collaboration. *The International Journal of Advanced Manufacturing Technology*, 108(3), 841–865. https://doi.org/10.1007/s00170-020-05363-1
- Hancock, P. A., Billings, D. R., Schaefer, K. E., Chen, J. Y. C., de Visser, E. J., & Parasuraman, R. (2011). A Meta-Analysis of Factors Affecting Trust in Human-Robot Interaction. *Human Factors,* 53(5), 517-527. https://doi.org/10.1177/0018720811417254




This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

# REFERENCES


- Hassan, S. A., Khalil, M. A., Auletta, F., Filosa, M., Camboni, D., Menciassi, A., & Oddo, C. M. (2023). Contamination Detection Using a Deep Convolutional Neural Network with Safe Machine—Environment Interaction. *Electronics*, 12(20), 4260.
- Hinds, P. J., Roberts, T. L., & Jones, H. (2004). Whose job is it anyway? A study of human-robot interaction in a collaborative task. *Human-computer interaction*, 19(1 & 2), 151-181.
- Hirche, S., & Musi´c, S (2017). Control sharing in human-robot team interaction. *Annual Reviews in Control*, 44, 342-354. https://doi.org/10.1016/j.arcontrol.2017.09.017.
- International Federation of Robotics (IFR), "World Robotics: Industrial Robots 2022," (2022), 52. Available at: https://ifr.org/downloads/press2018/2022_WR_extended_version.pdf.
- International Federation of Robotics (IFR), "European Union: Industries Invest Heavily in Robotics" (2023). International Federation of Robotics. 28(June), Available at: https://ifr.org/ifr-press-releases/news/eu-industries-invest-heavily-in-robotics#:~:text=Munich%2C%20Jun%2028%2C%202023%20 —,Federation%20of%20Robotics%20(IFR).
- Javaid, M., Haleem, A., Singh, R. P., Rab, S., & Suman, R. (2022). Significant applications of Cobots in the field of manufacturing. *Cognitive Robotics*, 2(June), 222–233. https://doi.org/10.1016/j.cogr.2022.10.001
- Kadir, B. A., Broberg, O., & Souza da Conceição, C. (2018). Designing human-robot collaborations in industry 4.0: explorative case studies. In DS 92: Proceedings of the DESIGN 2018 15th International Design Conference (pp. 601-610).
- Kim, S. (2022). Working With Robots: Human Resource Development Considerations in Human–Robot Interaction. *Human Resource Development Review*, 21(1), 48–74. https://doi.org/10.1177/15344843211068810
- Kopp, T., Baumgartner, M., & Kinkel, S. (2020). Success factors for introducing industrial human-robot interaction in practice: An empirically driven framework. *International Journal of Advanced Manufacturing Technology*, 1–20. https://doi.org/10.1007/s00170-020-06398-0.
- Laban, G., Kappas, A., Morrison, V., & Cross, E. (2023). Building Long-Term Human–Robot Relationships: Examining Disclosure, Perception and Well-Being Across Time. *International Journal of Social Robotics*, 1-27. https://doi.org/10.1007/s12369-023-01076-z
- Lim, V., Rooksby, M., & Cross, E. (2020). Social robots on a global stage: Establishing a role for culture during human-robot interaction. https://doi.org/10.31234/osf.io/be2p6.
- Losey, D. P., McDonald, C. G., Battaglia, E., & O'Malley, M. K. (2018). A review of intent detection, arbitration, and communication aspects of shared control for physical human–robot interaction. *Applied Mechanics Reviews*, 70(1), 010804
- Malik, A. A., & Bilberg, A. (2019). Collaborative robots in assembly: A practical approach for tasks distribution. Procedia CIRP, 81(March), 665–670. https://doi.org/10.1016/j.procir.2019.03.173
- Molyneux, C. G., Oyarzabal, R. (2017), "What is a Robot under EU Law?". Available at: https://www.globalpolicywatch.com/2017/08/what-is-a-robot-under-eu-law/
- N.A. "25% of large enterprises in the EU use robots" (2019). Eurostat. 21(January), Available at: https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20190121-1
- N.A. "Cobots: history and applications of collaborative robots" (2020). In Omitech Robot. Available at: https://robot.omitech.it/en/cobots-history-and-applications-of-collaborative-robots/
- N.A. "Robotics" (2022). European Commission. 7(June), Available at: https://digital-strategy.ec.europa.eu/en/policies/robotics 2022
- Natarajan, M., Seraj, E., Altundas, B., Paleja, R., Ye, S., Chen, L., Jensen, R., Chang, K., & Gombolay, M. (2023). Human-Robot Teaming: Grand Challenges. Current Robotics Reports, 4, 1-20. https://doi.org/10.1007/s43154-023-00103-1.




This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

# REFERENCES


- Nyholm, S., Smids, J., 2020. Can a Robot Be a Good Colleague?. Science and Engineering Ethics 26, 2169–2188.. https://doi.org/10.1007/s11948-019-00172-6
- Paletta, L., Dini, A., Murko, C., Yahyanejad, S., Schwarz, M., Lodron, G., Ladstätter, S., Paar, G., & Velik, R. (2017). Towards real-time probabilistic evaluation of situation awareness from human gaze in human-robot interaction. In Proceedings of the 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI '17) (pp. 247-248). https://doi.org/10.1145/3029798.3038322.
- Paxton, Chris & Hundt, Andrew & Jonathan, Felix & Guerin, Kelleher & Hager, Gregory. (2017). CoSTAR: Instructing collaborative robots with behavior trees and vision. 564-571. 10.1109/ICRA.2017.7989070.
- Rojas, A., & Nørskov, S. (2023). Interactions Afforded by Mobile Telepresence Robots in Health Care Settings. In C. Stephanidis, M. Antona, S. Ntoa, & G. Salvendy (Eds.), HCI International 2023 Posters (Vol. 1833, pp. 138–145). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-35992-7_20
- Rudestam, Kjell Erik, and Rae R. Newton. Surviving your dissertation: A comprehensive guide to content and process. Sage publications, 2014.
- Šabanović, Selma. (2010) "Robots in Society, Society in Robots: Mutual Shaping of Society and Technology as a Framework for Social Robot Design." *International Journal of Social Robotics* 2(4):439–50. doi: 10.1007/s12369-010-0066-7.
- Simões, A. C., Pinto, A., Santos, J., Pinheiro, S., & Romero, D. (2022). Designing human-robot collaboration (HRC) workspaces in industrial settings: A systematic literature review. *Journal of Manufacturing Systems*, 62, 28-43
- Thrun, S. (2004). Toward a framework for human-robot interaction. *Human–Computer Interaction*, 19(1-2), 9-24.
- Tsai, C.-Y., Marshall, J. D., Choudhury, A., Serban, A., Tsung-Yu Hou, Y., Jung, M. F., Dionne, S. D., & Yammarino, F. J. (2022). Human-robot collaboration: A multilevel and integrated leadership framework. *The Leadership Quarterly*, 33(1), 101594. https://doi.org/10.1016/j.leaqua.2021.101594
- Ulhøi, J. P., & Nørskov, S. (2021). Extending the Conceptualization of Performability with Cultural Sustainability: The Case of Social Robotics. In K. B. Misra (Ed.), Handbook of Advanced Performability Engineering (pp. 89–104). Springer International Publishing.
- Wallace, J. (2021). Getting collaborative robots to work: A study of ethics emerging during the implementation of cobots. Paladyn, *Journal of Behavioral Robotics*, 12, 299-309. https://doi.org/10.1515/pjbr-2021-0019.
- Weiss, A., Bernhaupt, R., Lankes, M., & Tscheligi, M. (2009, April). The USUS evaluation framework for human-robot interaction. In AISB2009: proceedings of the symposium on new frontiers in human-robot interaction (Vol. 4, No. 1, pp. 11-26).
- Weiss, A., Bernhaupt, R., & Tscheligi, M. (2011). The USUS evaluation framework for user-centered HRI. In K. Dautenhahn & J. Saunders (Eds.), *Advances in Interaction Studies* (Vol. 2, pp. 89–110). John Benjamins Publishing Company. https://doi.org/10.1075/ais.2.07wei
- Wolfartsberger, J., Hallewell Haslwanter, J. D., Froschauer, R., Lindorfer, R., Jungwirth, M., & Wahlmüller, D. (2018). Industrial perspectives on assistive systems for manual assembly tasks. In Proceedings of the 11th PErvasive Technologies Related to Assistive Environments Conference (PETRA '18) (pp. 289–291). Association for Computing Machinery. https://doi.org/10.1145/3197768.3201552
- Xu, L. D., Xu, E. L., & Li, L. (2018). Industry 4.0: State of the art and future trends. *International Journal of Production Research*, 56(8), 2941–2962. https://doi.org/10.1080/00207543.2018.1444806.
- Yan, H., Ang, M. H., & Poo, A. N. (2014). A Survey on Perception Methods for Human–Robot Interaction in Social Robots. *International Journal of Social Robotics*, 6(1), 85–119. https://doi.org/10.1007/s12369-013-0199-6




This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

# AUTHORS

### PHILIPP JENNES

Philipp has an industrial engineering background from Germany and completed his master's degree in France, where he specialized in lean operations management.
During his studies, he gained professional experience in the automotive and supplier industries, as well as in consulting.

LinkedIn: Philipp Jennes philipp.jennes@santannapisa.it

### SOPHIE ALTROCK

Following her studies of digital technologies and their impact on society from various lenses across the globe, Sophie supported clients in their transformation journey in an international IT and management consulting firm. Today she continues to explore organizational approaches to optimize the merging of human and technology capabilities as an EINST4INE Early Stage Researcher.

LinkedIn: Sophie Altrock sophie.altrock@rmit.edu.au

### ALEJANDRA ROJAS

After five years of work experience in various industries and learning in international contexts, Alejandra is currently researching robotics from an organizational perspective for the EINST4INE project. Fascinated by the intersection of humans, technology, and sustainability, she believes in research that contributes to the well-being of people.

LinkedIn: Alejandra Rojas rojas@btech.au.dk

### SYED ALI HASSAN

After 5 years of experience in computer vision domain, Ali is currently doing PhD in Robotics on a Marie Curie project related to human robot collaboration using vision and proximity sensors. He has completed his graduation in Software engineering from Pakistan and completed fully funded post-graduation in I.T. Convergence Engineering from South Korea. His latest projects are revolving around computer vision in Robotics.

LinkedIn: Ali Syed Hassan syedali.hassan@santannapisa.it



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

## About the EINST4INE Project

The European Training Network for InduStry Digital Transformation across Innovation Ecosystems (EINST4INE) is a consortium of universities, research organisations and industry partners working in the domain of industrial digital transformation. EINST4INE aims to develop new concepts, approaches and methods in the area of digital transformation and brings together a unique group of world-leading experts in the areas of Open Innovation, Industry 4.0, digital transformation and innovation ecosystems.

**About the Work Package 1: Human side of digital transformation**

The general objective of WP1 is to develop the knowledge base on the human side of Industry 4.0 - skills, capabilities, knowledge transfer between individuals within and across organisational networks and effects of digital transformation and human/robot interaction on organisational performance and behaviour. It will investigate the effects of the introduction of emerging process technologies (e.g. social, collaborative robotics, mobile telepresence robots, robo-advisors) in terms of organisational and change both at the firm level and at the individual level.

https://www.einst4ine.eu

einst4ine@rmit.edu.au



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745. Results reflect the author's view only. The European Commission is not responsible for any use that may be made of the information it contains.

# PARTNERS & FUNDING

**Acknowledgement**
We would like to thank Prof. Calogero Oddo, Prof. Alberto Di Minin, Prof. Anne-Laure Mention, and Prof. Valentina Cucino for contributing to the development of this report.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956745.