EARASHI

Embodied AI/Robotics Applications for a Safe, Human-oriented Industry

Human factors and UX handbook

By Mondragon

Issued 11/09/2023

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement nº 101069994.

EXECUTIVE SUMMARY

The concept of a human-centered industry is gaining momentum as a driving force for sustainability and inclusivity in industrial sectors. The transition from Industry 4.0 to emerging Industry 5.0 signifies significant transformations in manufacturing. While Industry 4.0 emphasizes efficiency and automation, Industry 5.0 envisions a future where technology and humanity collaborate to foster sustainability and innovation. This evolution presents both opportunities, such as new avenues for value creation and revenue generation, and challenges, including humanizing work, increased automation, and advanced services.

In the context of Industry 4.0, Section 2 discusses Operator 4.0 in smart factories, emphasizing the importance of optimizing human-machine interaction for Industry 4.0's success. Human-centered approaches, including technology acceptance, human factors, and human-robot interaction, are vital for creating safe and efficient workplaces. Section 3 highlights the significance of technology acceptance and human factors in enhancing job satisfaction and performance. A people-centered approach in designing digital systems increases efficiency, while addressing the digital divide ensures equitable technology access.

Section 4 focuses on achieving a positive User Experience (UX) in an increasingly automated Industry 4.0. It stresses trust, satisfaction, and ergonomic considerations for productive human-robot coexistence. Section 5 addresses mental workload management, critical for reducing errors and improving operator satisfaction. Balancing task complexity, information presentation, and user interaction minimizes cognitive load. Section 6 introduces the Human Robot Collaboration Experience (HRCX) model, assessing Human-Robot Interaction in industrial contexts. It emphasizes a holistic approach using expert evaluation, physiological devices, and questionnaires.

In conclusion, as we move into Industry 5.0, prioritizing human-centric approaches, managing cognitive load, ensuring safety, and conducting comprehensive assessments guide us in enhancing productivity and well-being in this new era of industry.

TABLE OF CONTENTS

FIGURES

INTRODUCTION

This document has been elaborated in the frame of the Horizon Europe project EARASHI (https://earashi.eu/), WP2 "*Human centred industry learning paths and didactic material*". This is the public version of the deliverable D2.1 "*Human factors and UX handbook*".

1. HUMAN-CENTERED INDUSTRY

The concept of human-centered industry has gained significant attention in recent years as a potential solution for creating more sustainable and inclusive industrial systems. Human-centered industry places human needs, preferences, and experiences at the core of industrial design and production, which can help to address the negative environmental and social impacts of traditional industrial systems.

By prioritizing human-centered approaches in our industries, we have the potential to build a more equitable and sustainable future for all. This document serves as a starting point for understanding the concept of human-centered industry and its potential to transform industrial systems.

ADDITIONAL INFORMATION

Title: **Human-Centered Design**

Source type: **Webpage**

Description: **Human-Centered Design definition and principles**

Link: https://www.interaction-design.org/literature/topics/human-centered-design

1.1 INDUSTRY 4.0 AND INDUSTRY 5.0

The industrial revolution of the 18th and 19th centuries was a significant event that transformed the world by introducing mass production, mechanization, and new transportation methods. These innovations resulted in increased productivity and improved living standards for many, but they also had negative environmental and social impacts, such as pollution, resource depletion, and poor working conditions. Today, we are on the brink of another technological revolution that promises to transform the way we work, live, and interact with one another - Industry 4.0 and the impending Industry 5.0.

These new manufacturing paradigms seek to create more efficient factories while addressing the negative impacts of previous industrial revolutions (Figure 1). Industry 4.0 represents the integration of advanced technologies to create smarter factories and more efficient production processes, while Industry 5.0 prioritizes the well-being and creativity of workers to create more fulfilling and sustainable work environments. Both Industry 4.0 and 5.0 present significant challenges, such as upskilling the workforce and ensuring technological advances benefit society. Industry 5.0 is complementary to Industry 4.0 and emphasizes research and innovation as drivers for a sustainable, human-centric, and resilient industry. The goal is to create prosperity beyond jobs and growth while respecting planetary boundaries and prioritizing the well-being of the industrial worker.

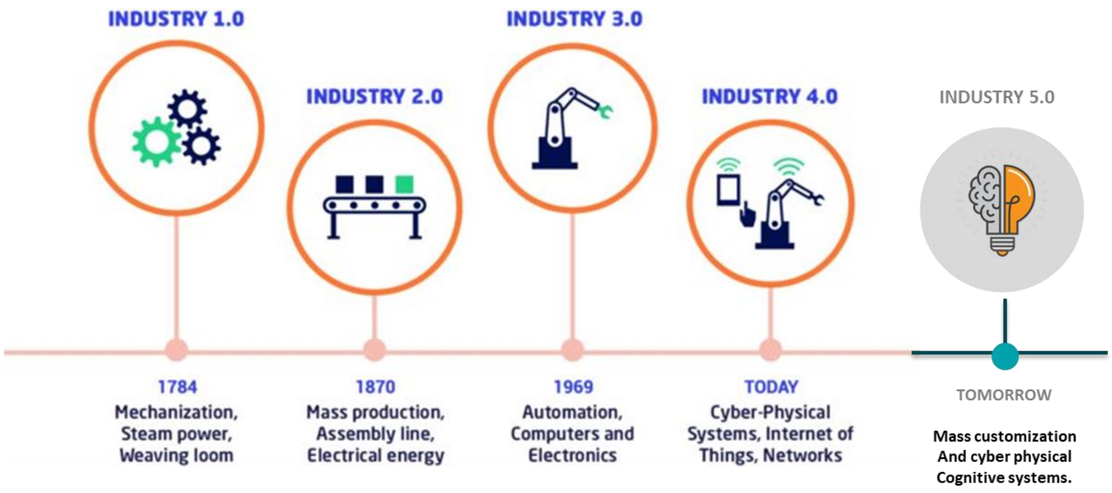

Figure 1: Industry 5.0

Industry 4.0 is a comprehensive digitization project for industrial production that characterizes the 4th industrial revolution through intelligent and digitally connected systems. It represents a new level of organization and controls the entire value chain of product lifecycles. The project is geared toward meeting increasingly individualized customer needs, covering the idea, order, development, manufacturing, delivery, recycling, and related services.

The critical component of Industry 4.0 is the intelligent product, which carries all the information required for its production and communicates independently with the production machines via a chip. Real-time availability of relevant information is the foundation for Industry 4.0. The term "Industry 4.0" was first mentioned publicly in 2011 at the Hanover Fair. It derives from the German Federal Government's Hightech Strategy, where Industry 4.0 is a cornerstone for securing Germany as a production location. The "Research Union Economy-Science," advised by Robert Bosch GmbH and Acatech (German academy of science and engineering), coined the term "INDUSTRIE 4.0."

VIDEO

Title: MADE – **Competence Center Industry 4.0: the Digital and Sustainable Factory**

Duration: **0:52**

Description: **Characteristics of a Digital and Sustainable factories.**

Link: https://www.youtube.com/watch?v=gPeFv6fWg7c

As can be seen in the following figure (Figure 2), industry 4.0 is characterized by a set of advanced technologies that enable the digitalization of industrial production. These technologies are: cybersecurity, augmented/virtual reality, big data, autonomous robots, additive manufacturing, simulation, system integration, cloud computing, internet of things.

Figure 2: Advanced technologies in Industry 4.0

ADDITIONAL INFORMATION

Title: **Industry 4.0 Market – Industry Analysis and Forecast (2022-2029) – by Technology Type, End User Industry, and Region**

Source type: **Webpage**

Link: Maximize Market Research

The manufacturing industry is undergoing a technological revolution, with Industry 4.0 and 5.0 representing two distinct phases. As shown in Table 1, Industry 4.0 aims to increase efficiency and productivity through smart manufacturing, using advanced technologies such as the Internet of Things, cloud computing, big data analytics, and robotics. On the other hand, Industry 5.0 is driven by a desire for a more sustainable and human-centric society, focusing on social fairness, human well-being, and resilience in industries.

In Industry 4.0, the role of humans is limited as machines replace them in many tasks. In contrast, Industry 5.0 aims to bring back the human workforce by respecting their talents, rights, needs, and identities. The core technologies of Industry 5.0 include human-robot collaboration, renewable resources, bionics, bio-inspired technologies, and smart materials. Industry 4.0 typically involves limited interaction between humans and machines, whereas Industry 5.0 aims to create highly adaptable and personalized scenarios where humans and robots can cooperate or collaborate to achieve common goals.

Table 1: Differences between Industry 4.0 and Industry 5.0 (Coronado et al., 2022)

Feature	Industry 4.0	Industry 5.0
Motto	Smart Manufacturing	Human-Robot co-working and Bioeconomy
Motivation	Reach mass production and increase economic benefits	Smart society, social fairness, Resilient industries, Human well-being, and Sustainability
Role of humans	Machines substitute humans.	Bring back the human force to factories by respecting humans' talents, rights, needs, and identities.
Core technologies	Internet of Things, Cloud Computing, Big Data, Robotics, and Artificial Intelligence	Human-Robot Collaboration, Renewable Resources, Bionics, Bio-inspired technologies, and Smart Materials
Typical scenario in robotics	Interaction between humans and machines/robots is limited to offline programming and monitoring.	Highly adaptable and personalized scenarios where humans and robots can cooperate or collaborate to reach common goals.

In conclusion, Industry 5.0 represents a significant shift in the manufacturing industry towards a more sustainable, human-centric, and collaborative approach to production. By prioritizing workers' well-being and using renewable resources, Industry 5.0 aims to create a more equitable and fulfilling work environment while still driving innovation and economic growth. Using advanced technologies such as human-robot collaboration, bionics, and smart materials will enable manufacturers to create highly adaptable and personalized scenarios that balance the needs of humans and machines. While Industry 5.0 is still in its early stages, it holds great promise for a more resilient and prosperous future, where technology and humanity work together for the greater good.

The role of design in Industry 4.0 and Industry 5.0 is crucial in placing people at the center of innovation processes. This approach emphasizes the importance of designing products and systems that meet the needs and expectations of the end users. To achieve this, designers use a set of tools and techniques to develop creative and innovative solutions that balance what is desirable, technologically feasible, and economically viable. These design tools include user research, prototyping, testing, and iteration. By involving users throughout the design process, designers can gain insights into their needs and preferences, leading to the creation of more user-friendly and intuitive products and systems. Design plays a critical role in the success of Industry 4.0, ensuring that technological innovations are not only cutting-edge but also useful and usable to the end users.

1.2 ADVANCED MANUFACTURING AND CHALLENGES

Advanced manufacturing is an emerging field that seeks to leverage technological advancements to enhance efficiency, productivity, and quality in producing goods. While the potential benefits of advanced manufacturing are significant, there are also several challenges that must be addressed to realize these benefits. One of the main challenges is humanization, which involves ensuring that advanced manufacturing systems are designed to support and enhance human workers rather than replace them. Another challenge is advanced automation, which involves leveraging advanced technologies to automate various aspects of the production process. Additionally, making the most of advanced technologies and turning them into advanced services is also a challenge. This entails delivering new value propositions and creating new sources of income.

1.2.1 Humanization

Humanization in advanced manufacturing requires an understanding of the fundamentals of human-machine interaction. This includes the cognitive, physical, and emotional aspects of work, which can affect how workers interact with advanced manufacturing systems. It is crucial to design systems that are simple to use and require minimal training, as there is currently a skills shortage in automation engineering.

The goal is to create interfaces that are easy to use, quick to configure, and do not require extensive prerequisite knowledge. To achieve this, the industry is focusing on developing web interfaces, adapting smartphone technologies, and incorporating voice and gesture recognition. Additionally, low-risk systems are essential to ensure that workers feel safe and comfortable working with advanced technologies. In short, humanization in Industry 4.0 is about putting people at the center of innovation processes and designing systems that prioritize human workers.

KEEP IN MIND

Humanization involves designing advanced manufacturing systems that **prioritize human workers** by ensuring that they are simple to use, low risk, satisfying, and easy to interact with efficiently and effectively.

To achieve humanization, **it is important to understand the fundamentals of human-machine interaction**, including the cognitive, physical, and emotional aspects during tasks execution.

1.2.2 Advanced automation

Advanced automation is another significant challenge in advanced manufacturing. It involves leveraging technologies such as collaborative robotics, autonomous systems, and connected systems to automate various aspects of the production process. The benefits of advanced automation are significant, including increased efficiency, productivity, and quality.

One of the key aspects of advanced automation is accuracy, which involves designing systems that can perform tasks with a high degree of precision and consistency. Collaborative robotics is also essential for advanced automation, as it enables humans and machines to work together to complete tasks. Additionally, flexibility and adaptability are critical for advanced automation, as they enable systems to respond to changing production requirements.

Autonomous systems are also important for advanced automation, as they can perform tasks without human intervention. However, it is essential to ensure that these systems are designed to support and enhance human workers rather than replace them. Finally, connected systems are essential for advanced automation, as they enable real-time monitoring and control of the production process.

VIDEO

Title: **Advanced Automation**

Duration: **1:26**

Description: **Advantages of automation in business.**

Link: https://www.youtube.com/watch?v=ChZsMCSvvgQ

1.2.3 Advanced services

In the rapidly evolving landscape of modern manufacturing, industries and academics are continuously seeking innovative ways to increase market share, stay competitive and meet the ever-changing demands of customers. One such approach that has gained significant attention is servitization, a strategy that involves shifting from traditional product-centric models to providing integrated bundles of products and services. This product-service integration is well known as product-service systems (PSS) where **advanced services** (Figure 3) emerge as a powerful concept, revolutionizing the way manufacturers engage with their customers towards a customer-centric approach.

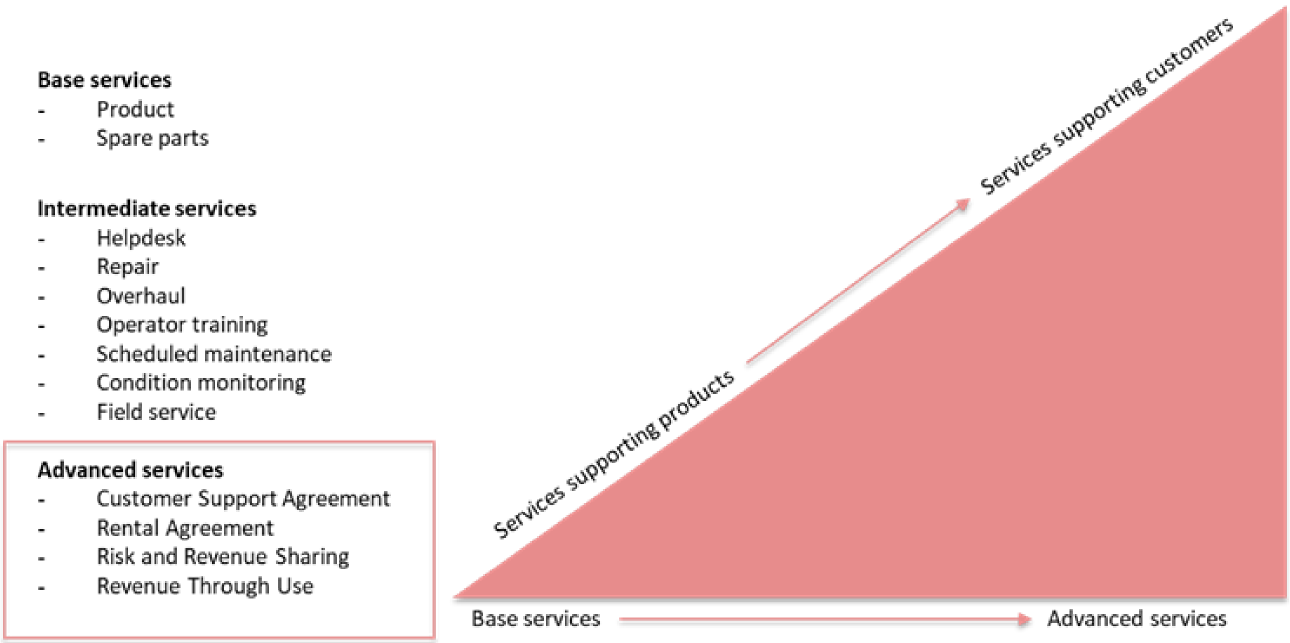

Figure 3: Advanced services

In advanced manufacturing, manufacturers not only focus on *services supporting products*, known as *base services* (e.g., selling physical products like machines or spare parts) and *intermediate services* (e.g., delivering transaction-based services like repair and overhaul). Manufacturers now also strive to provide *services supporting customers* as advanced services with new value propositions through customer support agreement or rental agreement that allows customers to use products instead of buying or owning a product.

These advanced services enabled by the Industry 4.0 technologies (e.g., smart sensors, Big data, AI, machine learning, mixed reality) offer proactive maintenance and support services, real-time monitoring and diagnostics, customized and personalized solutions, and continuous improvement initiatives as part of the comprehensive product-service package. By adopting this approach, manufacturers can not only extend the lifespan and enhance the performance of their products, but also optimize their customers' operations and value propositions through *risk and revenue sharing* (e.g., paying for performance result) and *revenue through use* (e.g., paying for use) as a bundle of products and services.

DEFINITION

Product-Service Systems (PSS) are well known in three typical groups: product-oriented groups (paying for buying pure products); use-oriented groups (paying for use or pay-per-use); and results-oriented groups (paying for performance results or pay-per-performance). The use-oriented and result-oriented groups are known as Advanced Services that offer risk and revenue sharing agreements with customers over the entire lifecycle of the product-services (Baines & W. Lightfoot, 2013).

Therefore, advanced services enable manufacturers to gain new ways of value creation in diverse aspects: smart connected products and services (e.g., advanced maintenance services based on condition monitoring), commercial gains (e.g., new revenue streams through hybrid offerings), and compelling sustainability (e.g., efficiency in material and energy usage).

EXAMPLE

Some typical business cases of advanced services include the “power-by-the-hour” model in terms of which Rolls Royce receives a fixed price for each hour their engines work for customers (Smith, 2013) and the “pay-per-lux” model where the customer buys a subscription from Philips for a certain amount of light per year instead of buying Philips´lamps (Salwin et al., 2018).

However, embracing advanced services and implementing them is not without its challenges. Manufacturers must navigate various hurdles to successfully transition from a traditional product-oriented mindset to a service-oriented one. Some of these challenges include, but not limit to:

Organizational Transformation: Shifting from a product-centric culture to a service-oriented culture requires a fundamental change in mindset and organizational structure. It involves developing new skill sets (*new service development methods*), fostering a customer-centric mindset in *the human-centered design methodology*, and redefining internal processes and workflows with *the life-cycle perspective*.

ADDITIONAL INFORMATION

Title: **Human-centered design for advanced services: A multidimensional design methodology**

Source type: **Article. This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant No. 814078**

Description: **The article provides a novel and holistic human-centered design methodology for design practitioners and engineers to obtain coherence in all the life-cycle design processes to make the design of advanced services more practical.**

Link: **https://doi.org/10.1016/j.aei.2022.101720**

Technology Integration: Advanced services heavily rely on advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics. Integrating these technologies (non-human factors) seamlessly into existing manufacturing processes and infrastructure can be complex and requires further investment in both hardware and software. Moreover, the management of human factors, such as requirements of stakeholder networks (e.g., customers / end users, third parties, suppliers) and internal people capabilities (e.g., skill sets), needs to be taken into account, beyond the non-human factors.

Data Management and Security: With the increased connectivity and data exchange in advanced services, manufacturers must effectively manage and secure large volumes of data. Ensuring data privacy, protecting against cyber threats, and complying with regulations are critical aspects that demand attention.

Business Model Transformation: Moving towards advanced services often necessitates a shift in business models, from one-time product sales to subscription-based models, pay-per-use or pay-per-performance schemes. This requires careful consideration of pricing strategies, revenue forecasting and cost management, the development of new contractual agreements, and proven proof of business cases (e.g., return on investment).

Customer Engagement and Education: Educating customers about the benefits and value proposition of advanced services is crucial. Manufacturers need to actively engage with customers, build trust, and demonstrate the long-term advantages of adopting these integrated solutions among the technology, product and service.

KEEP IN MIND

The journey towards designing advanced services poses challenges that may not always lead to the anticipated profits. This contradictory phenomenon is referred to as the "service paradox" and "deservitization." The service paradox arises when manufacturers implementing servitization fail to generate a profitable service business alongside their existing product business. On the other hand, deservitization occurs when manufacturers reduce or entirely eliminate the service components from their business model (Cheah et al., 2019; Kowalkowski et al., 2017; Valtakoski, 2017).

Despite these challenges, ranging from cultural shifts (product-oriented to customer-centric) to technology-product-service integration, the potential benefits of advanced services are undeniable. Manufacturers who successfully embrace this approach can unlock new revenue streams, improve profitability, increase customer loyalty, differentiate themselves in the market, and drive circular manufacturing and sustainable growth in an increasingly competitive environment.

2. OPERATOR 4.0

The introduction of the Industry 4.0 technologies poses the challenge of defining more precisely the role of the human operator in a context where technological revolutions will have an impact on individuals and their activities (Pacaux-Lemoine & Flemisch, 2021). In this context of Industry 4.0, the operator will continue to play an important role, and will be referred to as operator 4.0 (Romero et al., 2016). This operator's objective is to foster trust-based relationships between humans and machines. It does so by not only harnessing the strengths and capabilities of smart machines but also by equipping their "smart operators" with new skills. This empowers them to capitalize on the opportunities presented by Industry 4.0 technologies (Romero et al., 2016).

DEFINITION

The Operator 4.0 is a smart and skilled operator who performs not only - 'cooperative work' with robots - but also - 'work aided' by machines as and if needed - by means of human cyber-physical systems, advanced human-machine interaction technologies and adaptive automation towards "human-automation symbiosis work systems."

Therefore, human labor plays a pivotal role in smart factories. To enhance this interaction between machines and people, it is essential to optimize interfaces, tailoring them to human needs. This allows individuals to fully utilize their knowledge and skills to leverage the opportunities presented by new technologies. Achieving this goal necessitates addressing essential human-centered approaches, including, but not limited to, technology acceptance and human factors (Section 3), human-robot interaction (Section 4), human performance under mental workload (Section 5), and human factors evaluation (Section 6).

VIDEO

Title: **Soraluce setting new standards**

Duration: **2:23**

Description: **Innovative solutions committed to technological progress.**

Link: https://www.youtube.com/watch?v=y0A1BJC5XQc&t=20s

Human factors, also known as ergonomics, is a science at the intersection of psychology and engineering that focuses on the study of how humans interact with various systems, products, environments, and technologies. The human-centered design (HCD) approach optimizes the design of these systems by addressing human factors—physical, psychological, social, and cultural needs of human beings (ISO 9241-210, 2009)—to enhance human performance, safety, comfort, and overall well-being. Hence, HCD is based on a framework that places the user at the center of the design process and aims to develop creative solutions to problems, considering the human perspective at all stages of the process.

In the industrial environment, adopting an HCD approach means analyzing the human factors to understand the behaviors and actions of humans as they interact with socio-technical systems, and applying the understanding to the design of interactions. Human factors—psychological, social, physical, and biological characteristics that influence the interaction between users, specifically workers—and the surrounding environment—represented by tools, machines, systems, tasks, jobs, and workspaces—must be analyzed.

The goal is to design them for safe, comfortable, and effective human use. Workplace well-being is related to all aspects of working life, including the quality and safety of the physical environment, the way workers feel about their work, their working environment, the work climate, and the organization of work. The aim of assessing workplace well-being is to make workers safe, healthy, satisfied and engaged at work. In fact, workers' well-being is a major factor for the long-term effectiveness of organizations and ensures high levels of productivity.

KEEP IN MIND

Industry 4.0 represents a great opportunity for workers to become part of the intelligence system. Unlike machines, humans are naturally intelligent and flexible, so we can collaborate in creating more powerful and efficient factories (Peruzzini et al., 2018). Therefore, it is considered interesting to integrate human factors in computerized and digital industrial contexts.

However, there are several challenges in terms of integrating Operator 4.0 into work environments. These are listed below.

I. Equipping people with the right skills and providing the tools and interfaces that allow them to employ the functionalities offered by new smart technologies to the maximum (EFFRA European Factories of the Future Research Association, 2020).

ADDITIONAL INFORMATION

Title: **FACTORIES OF THE FUTURE: Multi-annual roadmap for the contractual PPP under Horizon 2020**

Source type: **Report. © European Union, 2013**

Description: **Manufacturing vision 2030, research & innovation strategies and priorities, key technologies and enablers.**

Link: https://www.effra.eu/sites/default/files/factories_of_the_future_2020_roadmap.pdf

II. To design digital solutions to be properly adopted by operators (Kaasinen et al., 2018)

III. The importance of integrating experiential aspects into work environments (Laschke et al., 2020). A holistic view should be adopted to help understand the interaction between the system and the human being.

KEEP IN MIND

The development of **smart factories** needs to be supported alongside the concept of **Operators 4.0 and** the creation of solutions adapted to people with different skills, abilities, and preferences. In this way, workers will be more motivated and productive. In addition, the solutions designed should contribute to well-being at work, increasing satisfaction, motivation, and engagement. The aim is to improve the factories' performance and organization. To this end, technologies and tasks should be designed with an **HCD approach**, so that the technology is satisfactorily adapted by people.

3. TECHNOLOGY ACCEPTANCE AND HUMAN FACTORS

New technological solutions integrated in work environments have an impact on well-being at work, particularly on job satisfaction, motivation, and work engagement. Furthermore, they lead to benefits for the company in terms of optimized processes, productivity, and quality, and help to change the image of the company so that it becomes a more desirable place to work. Therefore, the acceptance of technological innovations plays a very important role in companies.

Vygotsky (1980) discusses that the relationship between the subject and the goal of work is facilitated by tools and instruments. In the industrial context, the subject is a worker, the goal is the control of the factory processes and tasks, and the main tools are automation, robots, and control of user interfaces in the factory. The purpose of a technology is to intuitively provide the work goal to the employee in a way that allows for an appropriate performance in the process. The demands of the task are determined by the content of the task, which in turn depends on the information to be processed by the subject, i.e. the information to which the individual must respond. In short, if the technology is to be adopted by the worker, it is necessary to provide a technology or digital solution that allows users to perform the given task in an easy way. For this, there must be a fit between the task and the technology, i.e., a balance between the demands of the task and the capabilities of the system (Goodhue, 1995).

In this line and following the human and ergonomic factors in interaction design, it is necessary to design for people, creating products and systems suitable for them and not vice versa. Furthermore, Hollnagel & Woods (2005) discuss that the person and the technology/system should not be considered as two separate elements, with interactions between them, instead the way people work in association with technology should be considered as a "joint cognitive system" (Figure 4).

Moreover, it has been shown that employee well-being has a positive impact on organizational performance, and therefore it is necessary to maintain a people-centered approach when designing digital systems and tasks (Becker & Gerhart, 1996). In the end, a digital solution designed to meet the needs of an operator, taking into consideration ergonomics and human factors, increases efficiency and improves performance.

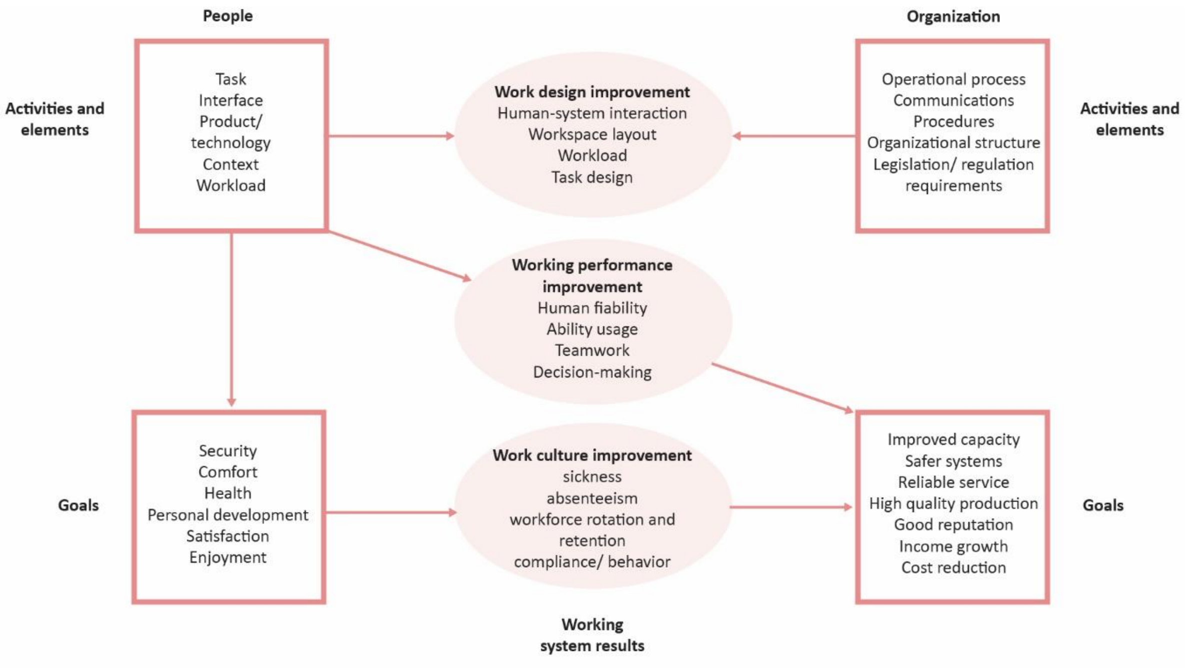

Figure 4: Ergonomic and human factors objectives (Adapted from Hollnagel & Woods (2005))

Following this approach, Wilson & Sharples (2015) describe a human factors and ergonomic framework where people and organizations are the actors in the work system (Figure 5). They define that people perform tasks, interacting with interfaces or technologies in a given context to get a job done.

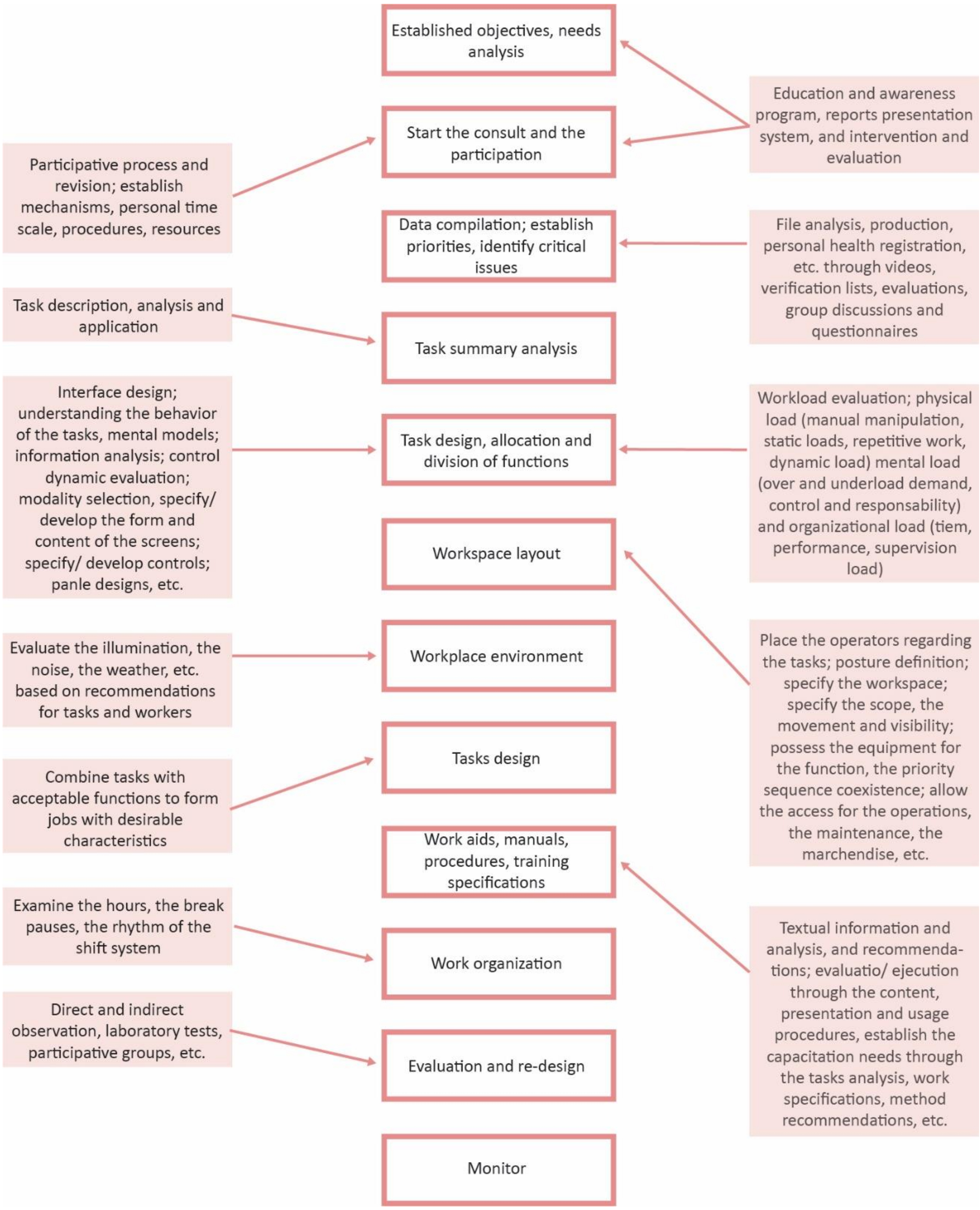

Figure 5: Design process with E/HF approach (Adapted from Wilson & Sharples (2015))

The organization, in turn, fixes these activities through operational processes, communications and procedures, supported by organizational structure and legislation. If these activities are properly designed, people-centered and taking into account human and ergonomic factors, the work will be better designed, i.e. the tasks given will be in line with the requirements and characteristics of the interfaces or technologies.

In this way, there will be a fit between task and technology in the work scenario and technological appropriation will take place.

ADDITIONAL INFORMATION

Title: **Evaluation of Human Work**

Source type: **PDF book**

Description: **Ergonomics and human factors' approaches, tools, methods, assessments and implementation.**

Link: https://doi.org/10.1201/b18362

In addition, it will be possible to meet the personal objectives of the operators, achieving greater safety, comfort, personal development, satisfaction, and enjoyment. Moreover, the company will be able to improve its capacity by creating safer systems, reliable service, high output quality, good reputation, increased revenue, and reduced costs. This will be achieved through improved employee performance and improved work culture.

In order to achieve the goals described above, one of the most interesting lines of research in this regard is the E/HF design process proposed by Wilson & Sharples (2015) (Figure 5). By following the E/HF design process, critical issues can be identified, and the work and tasks can be defined correctly. This will meet the needs of the operators by aligning the tasks to their capabilities. Furthermore, as described above, the company will improve its performance.

3.1 Digital divide

The digital divide is a complex, dynamic, and multidimensional phenomenon in constant evolution (Van hargittDijk & Hacker, 2003). Nowadays the digital divide is defined as the inequality between individuals, communities or countries to the access or capability to reap what the evolution of technology can offer (Angeline et al., 2021; Mavrou & Hoogerwerf, 2016). As the technology and the society advances, there have emerged different levels of digital divide that includes: 1) the access to the ICT in the first level, 2) their use, in the second level and 3) the obtained results, in the third level (Shakina et al., 2021).

Initially, the digital divide only referred to the "gap between those who have and those who do not have access to new ICT technologies."(Van Dijk & Hacker, 2003), which is the digital divide of the first level. Given that access to digital resources is generally widespread, the definition of digital divide has been extended in order to include factors like content accessibility, the knowledge and the user's abilities. This has given rise to the second level digital divide, which refers to the people's skills and their use of ICTs (Hargittai, 2002).

At this time, it can be assumed that having access and use of the ICTs is not enough to be able to reap all of its benefits (Ragnedda & Muschert, 2017). Consequently, it is spoken of as a third level of digital divide that considers the consequences and results of using ICTs (Ragnedda & Muschert, 2017; Tőkés, 2022). This third level of digital divide acknowledges the differences of the benefits of using ICTs (Van Deursen & Van Dijk, 2009).

DEFINITION

Digital divide is defined as the inequality between individuals, communities or countries to the access or capability to reap what the evolution of technology can offer (Angeline et al., 2021; Mavrou & Hoogerwerf, 2016).

The digital inclusion can provide opportunities to overcome barriers and have access to opportunities that otherwise would not be available (Blažič & Blažič, 2020; Park, 2022; Vicente & López, 2010). The ICTs make it possible to reduce distances (Gruzdeva, 2022) and maintain contact and social connection(Tan & Chan, 2018), which reinforces the feeling of belonging and social participation, reducing the risk to suffer from depression, loneliness and social exclusion (Bueno-Sanchez et al., 2019; Engwall, 2023; Mavrou & Hoogerwerf, 2016; Rikard et al., 2018; Vicente & López, 2010).

In the healthcare field, the ICTs makes it possible to have greater accessibility and efficiency in healthcare, enhancing the quality and wellness (Vicente & López, 2010). In addition, they can also have an impact in the improvement of mental health (Rikard et al., 2018), since it is associated with the reduction of dementia and the improvement of cognition and functional capacity (Neter et al., 2021). This is why, according to (Middle & Welch, 2022), digital inclusion must be seen as a determinant of health.

ADDITIONAL INFORMATION

Title**: Using Digital Technology to reduce the prevalence of mental health disorders in populations**

Source type**: Publication**

Description**: Digital technology can improve mental health and reduce disorders by enabling integrated preventive and clinical interventions at scale. Challenges include managing interventions in a changing digital environment and addressing population-wide issues.**

Link**:** https://www.jmir.org/2020/7/e17493

It is known that a favorable attitude towards the use of ICTs, as well as their perceived usefulness and enjoyment, can encourage people to satisfy their needs and achieve the desirable results (Cho & Kim, 2021). In other words, greater digital participation improves people's quality of life (Rikard et al., 2018).

In spite of the fact that in the beginning it was hypothesized that the digital divide would disappear with time, it is becoming increasingly evident that its eradication will not be possible due to the difficulty of keeping up to date in an environment of constant technological evolution (Mubarak & Suomi, 2022).

Listed below (Table 2) are some of the factors that affect the understanding of the technology.

Table 2: Factors of second level of digital divide

Factors		Can be addressed through inclusive design
Demographic characteristics	Age	X
	Gender	X
	Linguistic and cultural origin	X
	Geographical location	
Socioeconomic characteristics	Education	X
	Income, economic constraints	
	Occupation	X
Personal characteristics	Attitude, motivation, interest, attraction	
	Lack of confidence, fears, sadness, anxiety, frustration, lack of control towards technology	
	Risk perception	
	Lack of awareness of benefits, self-efficacy	
	Alphabetization and digital competences	
	Previous experience (lack of experience, negative experience, previous failures, etc.)	
	Communication preferences	
Health characteristics	Health condition	X
	Cognitive load and ability	X
	Memory impairment, spatial orientation	X

Factors		Can be addressed through inclusive design
Health characteristics	Loss of capabilities (physical, of memory, decreased visual and hearing acuity, manual dexterity)	X
	Type of disability	X
Context/ Social characteristics	Lack of support (from people in their environment or materials, such as manuals)	
	Need for assistance	X
	Restrictive control	
	Not having someone to contact, lack of community	
	Legal or political slowness	
Relation with technologies characteristics	Material access	
	Need of support technologies	X
	Technological incompatibility	
	Lack of privacy	
	Frequency, time and level of use	
	Language associated with technology	X
	Inaccessible technology designs, complex interfaces	X
	Fast technology evolution	

ADDITIONAL INFORMATION

Title: **Digital gender gap**

Source type: **Video**

Description: **A thought-provoking video that delves into the intricate complexities of the gender gap, aiming to uncover its root causes and shed light on the underlying factors contributing to this pervasive issue.**

Link https://www.youtube.com/watch?v=H5jYPQzWjrY

The United Nations, together with the International Telecommunications Union during the World Summit for the Information Society, pointed out the different types of digital divide generated by technology: (i) access (ii) generational and (iii) cognitive, among others. These gaps establish major differences in the adoption of technologies, which justify the divergences that exist in this respect between countries, regions within the same country, and even within social sectors of the same population. Considering the problems created by the digital divide and the transformations that society is undergoing in order to adapt to the changes generated by ICTs, it is necessary to analyze the context and find factors that help to interpret the impact generated by technology on the adoption of ICTs.

In this line, it is important to provide people with the necessary competences and skills to take advantage of the transformation process of the productive structure and of companies. In addition, it is necessary to use the instruments for companies to encourage the training of their employees. Companies need to include education and the acquisition of technological skills among their objectives in order to reduce the effects of the digital divide.

ADDITIONAL INFORMATION

Title: **The Digital Divide**

Source type: **Webpage**

Description: **an introduction to the history of expanded internet access across the U.S., who the digital divide affected by the expanded access, and organizations and resources designed to aid in the closing of the digital divide.**

Link: https://open.library.okstate.edu/learninginthedigitalage/chapter/the-digital-divide/

4. HUMAN ROBOT INTERACTION

Industry 4.0 has ushered in a new era of process automation, thus redefining the role of people, and changing existing workplaces into unknown formats (Waschull et al., 2020). The number of robots in the manufacturing industry has been steadily increasing for several decades and in recent years the number and variety of industries using robots have also increased (Karabegović et al., 2020; Marvel et al., 2020). In this context, operators will continue to be of great importance, so optimizing the interactions between persons and robots will be crucial. In contrast to standard automation, collaborative robots (cobots) enable close and safe interactions between humans and machines, taking advantage of the benefits of both sides.

ISO 8373 (ISO 8373, 2012) defined a robot as a powered mechanism controlled via an interface, it is programmable in two or more axes with a degree of autonomy and moves within its environment to perform intended tasks(Dautenhahn, 2013) defined human–robot interaction (HRI) as 'the science that studies people's behavior and attitudes towards robots in relation to the physical, technological, and interactive characteristics of robots, with the aim of developing robots that facilitate the generation of human–robot interactions that are at the same time efficient (in accordance with the original requirements of their intended area of use), acceptable to people, meet the social and emotional needs of their individual users, and respect human values'.

DEFINITION

Human–robot interaction (HRI): The science that studies people's behavior and attitudes towards robots in relation to the physical, technological, and interactive characteristics of robots, with the aim of developing robots that facilitate the generation of human–robot interactions that are at the same time efficient (in accordance with the original requirements of their intended area of use), acceptable to people, meet the social and emotional needs of their individual users, and respect human values (Dautenhahn, 2013).

For robots to become allies in the day-to-day lives of operators, they need to provide positive and fit-for-purpose experiences through smooth and satisfying interactions (Boden, 2017; Chen et al., 2020; Kahn Jr et al., 2007; Lindblom et al., 2020). In this sense, the user experience (UX) serves as the greatest link between persons and robots. ISO 9241-210 [12, sec. 2.15] defined UX as 'a person's perceptions and responses resulting from the use or anticipated use of a product, system or service'. This includes user emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviors, and achievements that occur before, during, and after use (ISO 9241-210, 2019). This means that humans must experience robots as fulfilling existing goals, and as entities that act efficiently and make people feel confident, safe, and comfortable while they are working together (Benyon, 2019).

A clearer understanding of social cognitive constructs (such as determining intentionality, which suggests an intimate connection between social cues and the perception of robots as social agents) is required to fully optimize HRI (Warta et al., 2016). This statement emerges from a shift in the perception of robots as tools that extend human capabilities to teammates that collaborate with people (Morrow & Fiore, 2012; Schaefer et al., 2017; Wiltshire et al., 2013, 2017).

Over the next few years, the coexistence between people and robots will increase (García & del Hoyo Delgado, 2002). This will take place in technologically enriched environments, where information will be exchanged "*naturally*" between humans and robots, giving rise to hybrid environments in which people move between the digital and real worlds(García & del Hoyo Delgado, 2002). The combination of human and robotic skills is becoming increasingly important (Wang et al., 2017). While certain routine tasks or specific skills can be effectively supported by automation, local decisions or exceptional interventions often require human input. This could arise from the extraordinary characteristics of the given situation or the complexity or the implicit nature of the knowledge required to find a feasible solution within a limited period.

To date, the combination of human and artificial resources has not been part of standard automation practice, in which i) robots and people are usually kept at arm's length from each other, and ii) people must adhere to work procedures that are as rigid as the rest of the automated production environment. Symbiotic human–robot collaboration (HRC) goes beyond these constraints and requires a more responsive, transparent, and accessible environment. Thus, for the improvement of HRI, the skills and expertise of humans must be combined with the accuracy and automation of robots, which work not as passive tools but as active partners (Simões et al., 2022).

To this end, it is important to optimize the UX between humans and robots. The evaluation of the UX will enable the continuous improvement of the industry's workplaces.

KEEP IN MIND

Ensuring optimal user experience (UX) between humans and robots is crucial. By evaluating the UX, we can foster ongoing improvements in the industry's work environments.

4.1 Research background on HRI design and evaluation

Numerous contributions have been written on HRI design and evaluation. The recent adoption of the concept industry 5.0 by the European Commission (Breque et al., 2021), increased the interest to incorporate human factors. Nevertheless, the literature reports few attempts to put human factors metrics in a comprehensive way to evaluate the UX on HRI.

A method for performing detailed ergonomic assessments of co-manipulation activities exists, and this could be applied to optimize the design of collaborative robots (Maurice et al., 2017). Maurice et al. (Maurice et al., 2017) defined multiple ergonomic indicators to estimate different biomechanical demands (muscle force, tendon deformation, muscle fiber length…) that occur during whole-body activities (*e.g.,* joint loads, joint dynamics, mechanical energy…). These indicators are measured through virtual human simulations.

There are several literature reviews in the context of HRI. The work by Hentout et al. (Hentout et al., 2019)proposes a rough classification of the content of works in HRI into several categories and subcategories, such as hardware and software design of collaborative robotic systems, safety in industrial robotics and cognitive HRI. They stated that the goal of HRI is to provide robots with three fundamental requirements: i) human intention should be easy to infer by the robot, ii) the control should be intuitive from the human viewpoint, and iii) the designed controller should be safe for both humans and robots.

Simões et al. (2022) listed a number of guidelines broadly classified into: i) human operator and technology, ii) human–robot team performance, and iii) an integrated approach to design HRC. As a generic conclusion, they highlighted the importance of feedback in improving trust and blame attribution. They presented recommendations for the design of safe, ergonomic, sustainable, and healthy human-centered workplaces where not only technical but also social and psychophysical aspects of collaboration are considered. Savela et al. (2018) examined how the social acceptance of robots in different occupational fields had been studied and what kinds of attitudes the studies had discovered regarding robots as workers. Their results imply that attitudes toward robots are positive in many fields of work. Nevertheless, they indicated that there is a need for validated measures. Veling & McGinn (2021) analyzed the use of qualitative methods and approaches in the HRI literature to contribute to the development of a foundation of approaches and methodologies in the research area. Their review revealed six predominant qualitative data gathering methods in the HRI literature: qualitative observations, semi-structured interviews, focus groups, generative activities, reflective and narrative accounts, and textual/content analysis.

According to Moulières-Seban et al. (2017), focusing on humans, tasks, robots, and system interactions when designing a cobotic system is necessary. These authors introduced a method of designing cobotic systems that is composed of four stages: i) activity analysis, ii) basic analysis, iii) detailed design, and iv) realization, setup, validation and putting into service. Numerous studies on robots in industries have been published, but most of them focus on safety and security aspects (Gopinath et al., 2017; Hentout et al., 2019; Tsarouchi et al., 2016). Other researchers have studied standardization to improve workplaces (Gualtieri et al., 2020; Tsai et al., 2014). In this sense, the robotics industry is growing to a level where people and robots will be able to collaborate (Harriott et al., 2013). However, as Harriott et al. (2013) pointed out, there is still no universal model that assesses the effect of this collaboration on people’s performance.

KEEP IN MIND

While studies on robots in industries often focus on safety and security, there is a growing need to explore the collaboration between humans and robots (Harriott et al., 2013). However, the lack of a universal model for assessing the impact of this collaboration on human performance remains a challenge (Harriott et al., 2013). Additionally, the literature lacks attention to the emotional factors resulting from human-robot interaction, such as trust, satisfaction, and mental workload. Assessing these factors is crucial to optimize collaborative robotic systems and adapt robot actions to meet human needs, following a human-centered design approach.

Furthermore, it is noted that no attention has been paid in the literature to the human factors resulting from the human-robot interaction. Emotional factors such as trust, satisfaction or mental workload have been poorly studied for the optimization of collaborative robotic systems. The assessment of these factors is beneficial to know how people feel before, during and after the interaction. In this way, robot actions could be adapted to people's needs, in line with the human-centered design approach.

In this context, interfaces play central roles as the main communication channels. A key aspect of collaboration is interaction and talking about interactions also means talking about interfaces. High-quality HRI requires intuitive user interfaces (Dániel et al., 2014). On the one hand, operators can give robots simple inputs without any distraction from their main tasks. On the other hand, robots provide clear information to users, resulting in an immediate understanding and interpretation of data (García & del Hoyo Delgado, 2002). The adoption of intuitive interfaces becomes even more important in the case of closer collaborations between robots and humans. Humans naturally interact with the world using multiple resources simultaneously (Correia Marques, 2017). Consequently, interacting with cobotic systems should be easy for them (Hentout et al., 2019).

Establishing what effective communication entails and determining the interfaces through which humans and robots can communicate are necessary. In this regard, we should define i) the intended interactions between persons and robots, and ii) the purpose of the information exchange. Both elements are largely outlined by the scope of the application and the functions of humans and robots (Driewer et al., 2007), and they need to be adapted to different contexts. Interfaces can generate different types of interactions (Prati et al., 2021). For example, graphical communication can take place using specific devices (e.g., a monitor or a touch screen), voice-based communication can use natural language interfaces and gesture-based communication can use cameras suitable for tracking human hands. Depending on the typology of communication, human–robot interfaces can be classified into four categories: i) visual displays (e.g., graphical user interfaces and augmented reality [AR] interfaces), ii) gestural (e.g., hand and face movements), iii) voice and natural language (e.g., auditory and text-based responses) and iv) physical and haptic interactions (Goodrich & Schultz, 2008).

HRI has been classified into different areas depending on the authors. Prati et al. (2021) used the classification by Schmidtler et al. Schmidtler et al. (2015), who categorized HRI into: i) human–robot coexistence, ii) human–robot cooperation and iii) human–robot collaboration (HRC). According to Prati et al. (2021), these interfaces can also be related to the level of interaction provided. In particular, the first level of interaction (coexistence) is usually satisfied with graphical interfaces. The second level (cooperation) often requires more advanced interfaces, such as voice and gestures. Finally, the third level (collaboration) may require direct physical or haptic interaction to be both effective and natural (Figure 6).

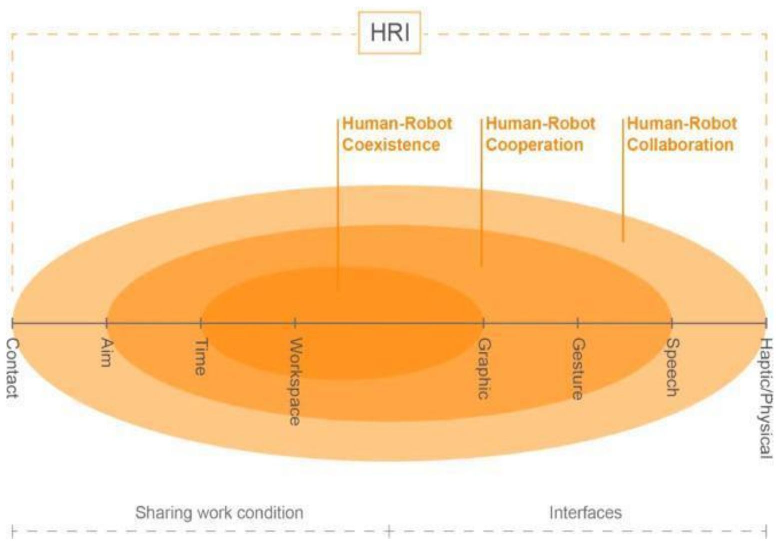

Figure 6: Human Robot Interaction classification (Prati et al., 2021)

4.2 Human factors in HRI

Human factors are the scientific discipline concerned with the interaction between humans and artifacts and design of systems where people participate (Helander, 1997). The purpose is to match systems, jobs, products and environments to the physical and mental abilities and limitations of people (Helander, 1997). According to Beith (Beith, 1999) human factors focus on system usability and designing system interfaces to optimize the users' ability to accomplish their tasks error-free in a reasonable time and, therefore, to accept the system as a useful tool. Considering applying human factors principles leads to designs that are safer, more acceptable, more comfortable, and more effective for accomplishing their given tasks (Beith, 1999).

Listed below (Table 3) are factors to consider when designing a robot interaction space. Four groups of measures have been identified: i) performance, ii) posture, iii) robot-related factors and iv) emotion-related factors.

Table 3: Factors and techniques evaluated in each experimental study.

Factor	Metric	Reference
Performance	Task execution time	(Almeida et al., 2020; Beschi et al., 2020; Colim et al., 2021; Dániel et al., 2014; Harriott et al., 2013; Hietanen et al., 2020; Lasota & Shah, 2015)
	Number of interactions	(Dániel et al., 2014)
	Errors	(Almeida et al., 2020)
	Robot idle time	(Hietanen et al., 2020; Lasota & Shah, 2015)
	Person’s idle time	(Lasota & Shah, 2015)
	Variability in production times	(Colim et al., 2021)
	Production rate	(Colim et al., 2021)
	Ratio between the time needed to complete the task with and without the robot	(Beschi et al., 2020)
Posture	Postural load	(Harriott et al., 2013)
	Variance in posture	(Harriott et al., 2013)
	Total movement	(Harriott et al., 2013)
	Vector magnitude	(Harriott et al., 2013)

Factor	Metric		Reference
Posture	RULA		(Aromaa et al., 2018; Colim et al., 2021; Tang & Webb, 2018)
	RSI		(Colim et al., 2021)
Robot-related factors	Anthropomorphism	Godspeed questionnaire	(Joosse et al., 2021; Schillaci et al., 2013)
	Animacy	Godspeed questionnaire	(Joosse et al., 2021; Schillaci et al., 2013)
	Likeability	Godspeed questionnaire	(Joosse et al., 2021; Schillaci et al., 2013)
	Perceived Intelligence	Godspeed questionnaire	(Joosse et al., 2021; Schillaci et al., 2013)
	Perceived Safety	Godspeed questionnaire	(Joosse et al., 2021; Schillaci et al., 2013)
		Self-generated questionnaire	(Lasota & Shah, 2015)
	Usability	SUS questionnaire	(Danielsson et al., 2017)
		IBM Computer Usability Satisfaction Questionnaire based questionnaire	(Almeida et al., 2020)
	Learnability	SUS Questionnaire	(Danielsson et al., 2017)
Emotion-related factors	Trust	Self-generated questionnaire about Trust	(Daniel et al., 2013)
	Satisfaction	Self-generated questionnaire	(Lasota & Shah, 2015)

Factor	Metric		Reference
Emotion-related factors	Satisfaction	IBM Computer Usability Satisfaction Questionnaire based questionnaire	(Almeida et al., 2020)
	Mental workload	NASA-TLX	(Aromaa et al., 2018; Harriott et al., 2013; Pantano et al., 2020)
		Heart Rate	(Harriott et al., 2013)
		Heart rate Variability	(Harriott et al., 2013)
	Physical and mental stress	Physical and mental stress questionnaire (self-generated)	(Hietanen et al., 2020)
	Perceived risk	Perceived Risk Questionnaire	(Beschi et al., 2020)

DEFINITION

Human factors are the scientific discipline concerned with the interaction between humans and artifacts and design of systems where people participate (Helander, 1997).

5. PERFORMANCE EVALUATION

Mental workload (MWL) has become a crucial issue for industry. MWL can be defined as the amount of mental effort required for an individual to perform a particular task (Gao et al., 2013). It includes not only effort due to the cognitive demands of the tasks, but also due to other factors, such as stress, fatigue, and motivation level.

Human performance can be affected by too high or too low MWL and it is known that optimizing MWL could reduce human errors, increase system safety, and improve operator satisfaction (Moray, 2013). With the rapid development of technology, sophisticated industrial systems have evolved, and operators are often given complex tasks and operating procedures with high mental workload.

When performing a task, with the increase in workload, more cognitive resources are needed therefore the mental capacity of the operator decreases. When the workload becomes excessive, performance can be affected and errors can occur, beginning to happen when temporary stress is excessive, or memory capacity exceeds limits. In addition, in the long term, high workloads can affect the health and well-being of operators (Hancock, P. A., & Desmond, 2001).

DEFINITION

MWL can be defined as the amount of mental effort and mental resources required for an individual to perform a particular task (Gao et al., 2013).

The demand in jobs is determined by factors such as the content of the job, conditions under which the task is performed, psychosocial and organizational factors, and factors related to job design. In addition, there are personal factors and extra-occupational conditions that may have an impact on the responsiveness of users.

It is considered that work demands are closely linked to factors related to technology use, affecting how users adapt to and utilize technological systems in their work. Job content, which encompasses the information available to users, plays a crucial role in helping users understand task objectives and perform them more easily. Furthermore, the design of the system or interface used by users can impact workload and user response, influencing the adoption of the system.

In an industrial work environment, the **signals**—representing various forms of information—that the worker may obtain can be very diverse, such as: work orders, improvement indicators, downloading and use of documents, blueprints, etc. Due to the amount of resources that must be used in order to perform a task, the worker must perceive and interpret correctly all the information to perform a given action.

That is the reason that it is necessary to design tasks in function of the context and the users, lightening up the quantity of information the worker is subjected to and with which they work. On one hand, it is necessary to regulate the quantity of the signals reaching the user, the velocity, the number, and the dispersion of the sources from which they come and the variability of channels.

On the other hand, to facilitate the analysis of information by users, it is essential to consider factors such as the complexity of the information, the reasoning skills required, the level of freedom in their actions, attention and memory demands, logical reasoning, problem-solving abilities, and decision-making processes. With regard to the response, it must be considered the requirement of speed of the response, the liberty in the decision making or the number of alternatives from which the response is to be selected (García & del Hoyo Delgado, 2002).

ADDITIONAL INFORMATION

Title: **The model of technology appropriation: a lens understanding systems integration in a defense context**

Source type: **Article**

Description: **The contribution of this paper is the application of a model that provides a lens for understanding the process through which the design of a technology is completed by humans embedded in a particular organizational context, and which provides insights into how to improve design practices associated with systems integration.**

Link: [The model of technology appropriation]

The content of the work also depends on the time factor, i.e., on the work time organization, the impact of which on the mental workload must be considered from two points of view: (i) the time available to elaborate the response and (ii) the time during which attention must be maintained. The time available to elaborate a response is related to the rhythm of work. If the operator is working quickly, either due to the machine's speed or to meet production goals, the effort required to respond to a task is greater compared to a scenario where the operator could work at a slower pace. The time during which attention must be maintained is related to the possibility of making pauses or alternate work positions when the task requires constant attention, making it possible to recover from fatigue.

ADDITIONAL INFORMATION

Title: **Development and evaluation of design guidelines for cognitive ergonomics in human-robot collaborative assembly systems.**

Source type: **Article**

Description: **This work refers to cognitive ergonomics in the design of human-robot collaborative assembly systems. A set of design guidelines has been developed according to the analysis of the scientific literature.**

Link: https://www.sciencedirect.com/science/article/pii/S0003687022001302

Definitely, the concept of workload is useful to study the perceived difficulty of the task or activity targeted to a specific objective, and the associated effort, including mental, physical and temporal effort invested by the user. Any activity with interactive products will have an influence in the user, and from a design point of view, it is recommended to minimize the unusual workload in order to achieve a better usability and a more positive user experience (UX) (Hollender, N., Hofmann, C., Deneke, M., & Schmitz, 2010). In this way, the quantity of information and the difficulty the user will be subjected to, reducing the work demands and the cognitive load.

Thus, the task can be performed more smoothly, improving the overall UX. In order for the processing to be carried out in an easy way, there must be a proper adjustment between the design of the task and the system. In this line, it is considered interesting to address the concept of workload and information processing with the task design and the way the user and the technology interact.

ADDITIONAL INFORMATION

Title: Workplace application usability

Source type: Video

Description: Usability requirements and tradeoffs for workplace app design

Link: https://www.youtube.com/watch?v=SJtm6t6ko3Y

On the other hand, it is interesting to understand that aside from the work factors like task and technology characteristics, the individual and organization factors that influence the realization of the tasks and the individual performance. If the factors that influence performance (PIF, Performance Influencing Factors) are optimized, the probability of human error will be reduced.

On this basis, the following is a list of the factors that must be taken into consideration when designing tasks and systems with the objective to improve the performance and the personal and organizational factors that influence on the performance (Table 4).

Table 4: Factors for the design of tasks (Bion et al., 2010)

Factor	Considerations
Work factors	• Signals, signs, and instruction clarity • Interface system/equipment (labeling, alarms, error prevention/tolerance) • Difficulty/complexity of the task • Routine or unusual task • Divided attention • Inadequate or inappropriate procedures

Factor	Considerations
Work factors	● Task preparation (for example, permits, risk assessment, verification) ● Required/available time ● Appropriate tools for the task ● Communication with colleagues, supervisors, contractors, and others) ● Work environment (noise, heat, space, lighting, ventilation)
Personal factors	● Physical capacity and condition ● Fatigue (high due to the temporary or chronic situation) ● Work overload or underload ● Competence to cope with the circumstances. ● Motivation versus other priorities
Organizational factors	● Work pressure, for example, production versus security ● Level and nature of the supervision/leadership ● Communication ● Staffing levels ● Group pressure ● Functions and responsibilities clarity ● Efficiency on the organizational learning (learn from experiences) ● Organizational or security culture, for example, everyone breaks the rules

6. TOOLS FOR HUMAN FACTORS EVALUATION

The Human Robot Collaboration Experience (HRCX) model proposes an evaluation framework for HRI contexts. In line with the holistic approach that UX and technology acceptance evaluations should have, it is composed of three phases: i) the before task execution phase (PRE), ii) the during task execution phase, and iii) the after-task execution phase (POST) (Figure 8).

Before task execution phase (PRE): First, participants will be informed of what the test entails and will have to sign a consent form. Then, participants will be prepared and instructed on the tasks they will perform. In addition, physiological devices shall be fitted and calibrated. For instance, an electrocardiogram (ECG) for heart rate monitors is strapped to the chest to make sure the proper placement is secured for accurate measurements while calibration typically involves setting the device to a standard or reference measurement.

In addition, an expert evaluation will be carried out using the HEUROBOX tool. This heuristic evaluation will be based on the inspection of different sections that consists of checking the quality of a set of principles called heuristic principles. In this way it will be possible to know and detect inconsistencies and errors in the robot.

During task execution phase: Participants will perform the assigned tasks while data is being collected. The environment should be controlled to ensure the validity of the data collected. The objective is to collect performance indicators such as i) task completion time and ii) error rate during task execution. These objective indicators serve to provide the model with an objective view on task execution. During experimentation, the expert evaluator will collect the actions performed by the user in each of the tasks and measure the execution time. In addition, including physiological tools will help to make the evaluation more objective.

After task execution phase (POST): Participants will fill in a questionnaire in order to assess the perceptual measures related to the interaction with the robot.

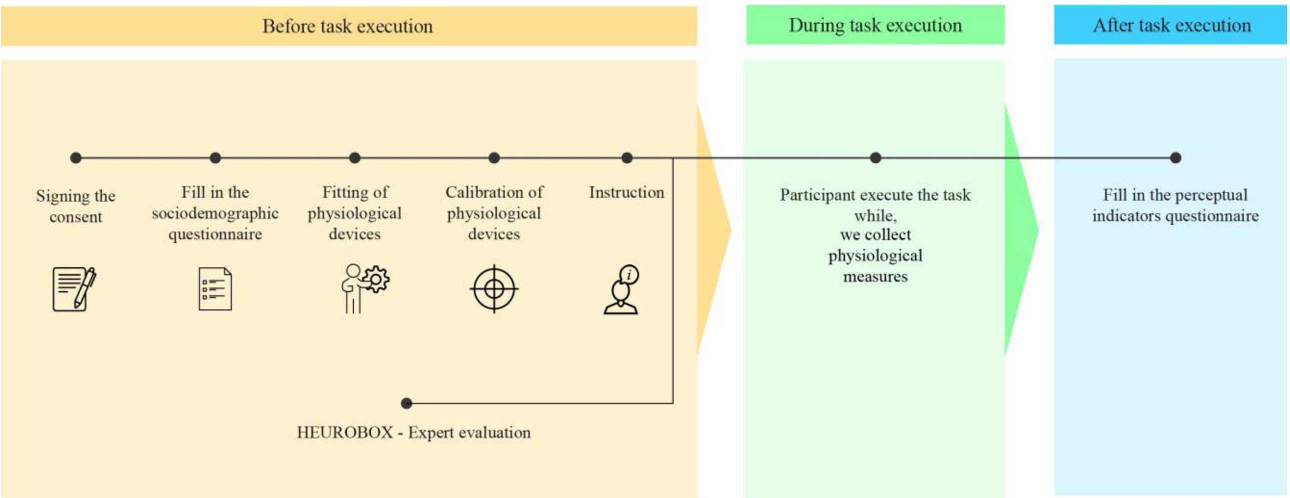

Figure 8: HRC model - application experiments test execution protocol

This protocol aims to ensure a systematic and controlled approach to data collection and analysis, yielding accurate and valuable results. The table shows the factors to be analyzed in each phase and the output obtained from each of the actions (Table 5).

6.1 HEUROBOX

HEUROBOX (Heuristic Robots Experience, see ANNEX 1 for details) is an expert evaluation tool designed to assess the UX in Human-Robot Interaction (HRI) within industrial settings, based on heuristic principles. The tool's primary objective is to offer agile and dependable support for evaluating robot validity through testing human-robot interaction in industrial environments. In essence, it involves assessing the quality of a set of heuristic principles, which are essentially checklist items. This method is both agile and resource-efficient and is known for its effectiveness in detecting usability errors, thereby improving the UX in HRI within industrial contexts. The evaluation process encompasses four main categories: Safety, Ergonomics, Functionality, and Interfaces, each of which further includes sub-categories. There are two types of evaluations available:

- The Basic evaluation is a simpler and faster assessment, consisting of a total of 84 heuristics.
- The Advanced evaluation is a more comprehensive and thorough evaluation, capable of uncovering a wider range of usability issues, and it comprises a total of 228 heuristics.

6.2 PHYSIOLOGICAL DEVICES

In the world of testing and observing users, there are some available physiological devices on the market for further reference. These include eye trackers that visualize the areas of the interface where the user's gaze is focused (6.2.1), EEG devices that measure brain activity (6.2.2), biosensors that track physical reactions (6.2.3), and software to make sense of all this data (6.2.4). These tools measure quantitatively how users interact with a product or system and how they react physiologically. By collecting data from these devices, the insights into user behavior, cognitive processes, emotional responses, and physical reactions, are gained, ultimately allowing for enhancing the Human Robot Collaboration Experience.

Table 5: Protocol in AEs and output metrics

			Output Metrics
PRE	Consent	Form	
	Sociodemographic data	Questionnaire	Gender Age Working years Working expertise
	UX Assessment	Heurobox	Robot validity
DURING	Task	Environment	
		Research variables	
		Task type	
		Duration	Time
	Physiological data	HR and HRV/ ECG	Heart rate Heart rate variability
		GSR/EDA	Activation Impact
		EEG	Memorization Engagement Valence Attention
		EMG	Surface electrodes are placed on the skin. The magnitude of the maximal voluntary isometric contraction.
		Exoskeleton	Force measurement, including normal and shear forces as well as overall interaction force, peak, and average contact force.
		Voice	Participants voice
		Eye tracking	Gaze position: - ch 1: x (mm) - ch 2: y (mm) - ch 3: z (mm) - ch 4: internal timestamp (us)
POST	Perceptual indicators	Questionnaire*	

6.2.1 Eye tracking devices

Eye-tracking devices visualize the areas of the interface where the user's gaze is focused, making it possible to identify the path of the user's gaze while interacting with the digital system through the use of various cameras. The information provided by this device helps to understand which elements on the screen the user is looking at, which indicates where the user expects to find the elements, he/she needs to go to perform the tasks, and therefore where he/she would like to find them. Eye Tracking is a technique for measuring an individual's eye movements, visual attention and focus. This experimental methodology has proven useful for studying the cognitive processes involved in processing visual information, including the visual elements that people look at first and spend the most time on.

TOBII PRO X2-60 EYE TRACKER (2014)

The Tobii Pro X2-60 Eye Tracker (2014) is a device that measures the user's eye activity (Figure 9). Through its different sensors, it is possible to track the user's gaze while interacting with the interface. Therefore, it represents where users fix their gaze so that it is possible to understand what elements they expect to find in order to accomplish tasks. The tool provides a chronological path represented by dots that are drawn on the interface, varying the size of the dot depending on the time of gaze fixation on the elements. The Tobii Pro X2-60 Eye Tracker (2014) enables eye tracking accuracy to be maintained even when users move their head freely with large and fast movements (always positioned at a natural distance from the screen). The device provides very accurate gaze position data within the tracking area, even if the user wears glasses or contact lenses. Accuracy is also maintained during users' head movement and in different ambient light conditions.

The Tobii Pro X2-60 Eye Tracker (2014) offers different possibilities depending on the purpose of the analysis. The Tobii Pro X2-60 Eye-Tracker (2014) is compatible with a wide variety of screens: laptops, PC monitors, tablets, or TVs up to 25" in size. Thanks to various accessories and configurations, it is possible to use this Eye-Tracker for eye-tracking on mobile devices or even on real objects. In the case of industrial HMIs, it is possible to test them by simulating the real use of the machine, on the PC where the device is installed.

For the tracking study, the eye tracker includes a software that analyzes the data in an easy way. It can be run on any computer or tablet running Windows 7 or higher, and Linux Ubuntu. The software allows device configuration, start-stop recording, live data visualization (online), import and playback of recorded data, and data export in CSV format compatible with Matlab, Python, etc.

Figure 9: Tobii Pro X2-60 Eye Tracker (2014)

TOBII PRO GLASSES 2 (2016)

The function of this tool is similar to that offered by the previous one. However, it allows testing interfaces in real contexts since it is a wearable and lightweight eye-tracking system. Its portability allows it to be used both in the laboratory and in real-world contexts.

The Tobii Pro Glasses 2 (2016) is composed of the Eye-Tracker glasses device and the recording unit, which are carried in a carrying case (Figure 10). The tracking glasses capture what the user sees and record their comments. The main unit weighs 45 grams and provides freedom of movement so that the user can display natural human behavior.

The recording unit records the eye-tracking data on an SD card. In addition, it features wireless technology that allows data to be sent via WIFI for real-time monitoring. Thanks to this recording unit, the user can move around without restrictions, ensuring data recording.

The device includes software that allows users to control and run the studies. It can be run on any computer or tablet running Windows 7 or higher, and Linux Ubuntu. The software allows device configuration, start-stop recording, live (online) data viewing, import and playback of recorded data, and data export in CSV format compatible with Matlab, Python, etc.

Figure 10: Tobii Pro Glasses 2

6.2.2 EEG devices

Electroencephalogram (EEG) is a device that measures the brain activity of users in order to determine the positive and negative emotions they feel during the experience.

EMOTIV INSIGHT 5 (2017)

Emotiv Insight 5 (2017) is a 5-channel wireless EEG headset that records brainwaves and translates them into meaningful data that can be easily understood (Figure 11). Thanks to its portable design, it can collect real-time data in industrial settings.

It consists of integrated software for self-quantification and neurofeedback and reports the cognitive and emotional states of the brain, displaying results on the following six key cognitive and emotional metrics: focus, stress, excitement, relaxation, interest, and engagement.

Figure 11: Emotiv Insight 5

DIADEM

Diadem is a dry-sensor EEG designed for real-world applications that require, on the one hand, great comfort for the user, and on the other hand, an agile setup and outstanding signal quality for the researcher. Diadem has been developed with 12 dry sensors located in specific brain areas (pre-frontal, frontal, parietal and occipital) for the estimation of emotional and cognitive states. Its high-performance active shielding and stable mechanical design provide exceptional robustness and signal quality, even under motion or during long recording periods (Figure 12).

Figure 12: Diadem bitbrain 2019

6.2.3 Biosensors

RING

Ring (Figure 13) is a mobile and robust biosignal measurement device for monitoring skin conductance (electrodermal sensor - EDA/galvanic skin response - GSR meter) and cardiovascular activity (BVP sensor).

It has been designed for use in real research contexts that require high user comfort, agile setup and outstanding signal quality for the researcher. The device has an ultralight and comfortable design and features two key biosensors (GSR electrodermal activity and BVP cardiac activity) for the estimation of emotional states, and a three-axis solid-state accelerometer (ACC), for an estimation of the noise that can be generated due to hand movement.

Figure 13: Ring

6.2.4 Data interpretation software

SENNSLAB

Sennslab is a multimodal data recording software. It is an experimental design and data collection software. It integrates the entire project from experimental design to data collection and export for complete analysis.

SENNSMETRICS

SennsMetrics is an extension of the SennsLab software that includes templates of the most common experimental designs, a wide range of cognitive and emotional metrics, and tools to perform data analysis with flexibility and reliability. SennsMetrics allows one step further in the analysis of physiological data.

6.3 QUESTIONNAIRES

In addition to the factors that must be taken into consideration when designing tasks and systems, the success of a product, service, or technology in today's digital landscape heavily relies on its design and user experience.

To ensure the effectiveness of the designs, it is crucial to access various aspects of user experience, usability, and acceptance. By employing questionnaires specifically tailored for this purpose, designers and developers can gather concrete data and gain valuable insights into how users perceive and interact with products, services and/or digital technologies. These insights provide a solid foundation for making informed design decisions and improvements. In this section, we will explore several questionnaires commonly used in the industry to evaluate various aspects of products, services and/or digital technologies.

6.3.1 Common assessment questionnaires on UX and Technology Acceptance

HUROX QUESTIONNAIRE (Human-Robot Experience): The HUROX questionnaire (see ANNEX 2 for details) is designed to evaluate how humans perceive user experience (UX) and technology acceptance in the context of human-robot interaction (HRI) in industrial settings. It assesses aspects such as perceived usefulness, perceived ease of use, perceived safety, controllability, learnability, attitude, and satisfaction. By using HUROX, designers and developers can identify areas for improvement and enhance the overall user experience and acceptance of HRI systems.

HRCAM (Human–Robot Collaboration Acceptance Model): HRCAM is a model, developed by Bröhl et al. (2019), designed to assess and understand the acceptance of robots in collaborative settings involving human-robot interaction. HRCAM takes into account various factors (e.g., perceived usefulness, perceived easy to use, job relevance), also including technology affinity, ethical, legal (occupational safety and data protection), and social implication, as well as cultural context. The model aims to identify factors that influence behavioral intention to use and actual use behavior of robots in collaboration with humans. It provides recommendations to practitioners in the field of human-robot collaboration to enhance the acceptance of robots in such settings.

UEQ QUESTIONNAIRE: The User Experience Questionnaire (UEQ) is a fast and reliable questionnaire used to measure the user experience of interactive products. The questionnaire covers scales that provide a comprehensive impression of the user experience. It measures both classical usability aspects (efficiency, perspicuity, dependability) and user experience aspects (attractiveness, novelty, stimulation).

SUS QUESTIONNAIRE: The System Usability Scale (SUS) provides a "quick and dirty" reliable tool for measuring usability. It consists of a 10-item questionnaire with five response options, ranging from Strongly Agree to Strongly Disagree. Originally created by Brooke (1996), it allows designers and developers to evaluate a wide variety of products and services, including hardware, software, mobile devices, websites, and applications.

USE QUESTIONNAIRE (Usefulness, Satisfaction, and Ease of Use): The Usefulness, Satisfaction, and Ease of Use Questionnaire (USE) measures the subjective usability of a product or service. It is a 30-item survey, designed by Lund (2021), that examines four dimensions of usability: usefulness, ease of use, ease of learning, and satisfaction.

Different questionnaires use different terms and evaluation items. Therefore, it is vital to understand which assessment aspects of UX on technologies, digital products, and services are being evaluated in a specific context. The following section describes the most typical assessment aspects on UX and technology acceptance.

6.3.2 Common assessment aspects on UX and Technology Acceptance

In Table 6 we provide an overview of the assessment aspects that are evaluated by the questionnaires mentioned above. Each aspect is accompanied by its corresponding definition, allowing for a better understanding of what is being assessed.

Table 6: Common assessment aspects on UX and technology acceptance

Construct	Definition
Perceived usefulness	The degree to which a person believes using a particular system would enhance their job performance.
Perceived Ease of Use	The degree to which a person believes using a particular system would be free of effort and easily learned.
Perceived Safety	The degree to which a particular system can acquire new knowledge or skills, as perceived by a person.
Learnability	The degree to which users can successfully perform a task when they encounter an interface for the first time, as well as the degree to which they can become proficient at that task with increasing repetitions of use.
Controllability	The degree to which a person feels in control of a technology and its actions, and the ability to modify its behavior according to their needs or preferences
Attitude	The user's overall positive or negative evaluation of a technology, including affective and cognitive components. It is a predictor of the user's behavioral intention to use.
Satisfaction	The degree to which a person is pleased with the use of a technology, as the result of the overall usefulness, ease of use, and trust.
Novelty	The extent to which the design of the product is creative and catches the interest of users through its innovative features.
ELSI	The extent to which a person's concerns regarding the ethical, legal, and social implications (ELSI) impact the development of human-robot systems

These aspects have been derived from the questionnaires and mapped in Table 7 based on their shared evaluation criteria and focus.

Table 7: Assessment aspects evaluated by mentioned questionnaires.

	HUROX	HRCAM	USE	UEQ	SUS
Perceived usefulness	X	X	X	X	X
Perceived ease of use	X	X	X		X
Perceived safety	X	X			
Controllability	X	X		X	
Learnability	X	X	X	X	X
Attitude	X	X		X	X
Satisfaction	X	X	X	X	
Novelty				X	
ELSI		X			

KEEP IN MIND

When using different questionnaires to measure user experience (UX) and technology acceptance, it's crucial to grasp what each questionnaire assesses. This knowledge helps designers and developers choose the right questionnaire for their specific evaluation needs.

For example, the HUROX questionnaire is designed for assessing UX and technology acceptance in human-robot interaction (HRI) within industrial settings. It covers areas like usefulness, ease of use, safety, control, learnability, attitude, and satisfaction. If you're evaluating HRI systems in an industrial context, the HUROX questionnaire is a proper choice.

By aligning the questionnaire with your evaluation focus, you can gather insights that directly relate to UX and technology acceptance in HRI within industrial settings.

ADDITIONAL INFORMATION

Title: ASSESSMENT QUESTIONNAIRES (HUROX, HRCAM, UEQ, SUS, USE)

Source type: Published questionnaires (.pdf)

Description: For detail assessment items on each questionnaire, please refer to this hyperlink below

Link: (1) HUROX, refer to Annex 2; (2) HRCAM, (3) UEQ; (4) SUS; (5) USE

7. CONCLUSIONS

The concept of a human-centered industry is gaining momentum as a means to foster sustainability and inclusivity within industries. Industry 4.0 and the emerging Industry 5.0 signify significant shifts in manufacturing, with Industry 4.0 focusing on efficiency and automation, while Industry 5.0 envisions a future where technology and humanity collaborate for sustainability and innovation. This transformation brings both advantages, such as new opportunities for value creation and revenue generation, and challenges associated with advanced manufacturing, including humanizing work, increasing automation, and introducing advanced services.

In this context, Section 2 explores the emergence of Operator 4.0, where humans remain central to the success of smart factories, necessitating trust-based relationships between humans and machines. Operator 4.0 possesses new skills to leverage the strengths of smart machines and capitalize on Industry 4.0 technologies. However, to fully harness these technological advancements, optimizing human-machine interaction is essential. This objective requires comprehensive human-centered approaches, encompassing technology acceptance and human factors, human-robot interaction, performance under mental workload, and human factors evaluation. The principles of human factors and human-centered design are invaluable in focusing on the psychological, social, physical, and biological aspects influencing human interactions with socio-technical systems, thereby creating safe, comfortable, and effective work environments that enhance workplace well-being. Nevertheless, integrating Operator 4.0 into work environments presents challenges, including the need to equip individuals with the right skills, design digitally sound solutions, and embrace a holistic view that encompasses experiential aspects for a successful transition to Industry 4.0.

When it comes to technology acceptance and human factors, Section 3 underscores the importance of technology aligning with users' needs and capabilities to enhance job satisfaction and performance. Emphasizing human and ergonomic factors in interaction design ensures that technology complements human abilities, resulting in a "joint cognitive system." Maintaining a people-centered approach in digital system design leads to increased efficiency and improved performance, benefiting both employees and organizations. Additionally, addressing the digital divide, encompassing access, usage, and outcomes, is crucial for achieving digital inclusion and enhancing individuals' quality of life. Bridging this divide requires considering various factors, including demographics, socioeconomic status, personal characteristics, health, and contextual elements, to ensure equitable access and utilization of technology.

Moreover, as Industry 4.0 advances and robots become more prevalent in various industries, Section 4 highlights the key to successful HRI is creating a positive User Experience (UX). Ensuring an optimal UX between humans and robots is crucial. By evaluating the UX, ongoing improvements in the industry's work environments can be fostered. This involves designing robots that fulfil user goals, provide efficiency and safety, and instil confidence and comfort. HRI will continue to grow in importance, necessitating a symbiotic collaboration between human skills and robotic automation. Human factors and ergonomic considerations, alongside emotional factors like trust and satisfaction, play pivotal roles in achieving this. Furthermore, human-machine interfaces serve as communication channels, and a more concerted effort is needed to integrate human-centered design principles into collaborative robotic systems, ensuring a seamless and productive coexistence of humans and robots in the workplace.

Additionally, in technologically advanced systems, mental workload (MWL) is a critical concern across various industries as complex tasks and operating procedures become more prevalent. MWL reflects the mental effort required to complete tasks and is influenced by factors such as cognitive demands, stress, fatigue, and motivation. Maintaining an optimal MWL is essential to reduce human errors, enhance system safety, and improve operator satisfaction. Excessive workload can lead to decreased performance, errors, and long-term health effects on operators. To manage MWL effectively, factors related to job content, technology use, system design, and individual and organizational aspects should be considered. Striking a balance between task complexity, information presentation, and user interaction is key to achieving better usability and a positive user experience (UX) while minimizing cognitive load. Additionally, optimizing performance influencing factors (PIF), including work factors, personal factors, and organizational factors, is essential for reducing the likelihood of human errors and ensuring task efficiency and safety.

To measure how humans interact with technologically advanced systems, Section 6 presents the Human Robot Collaboration Experience (HRCX) model, offering a comprehensive framework for evaluating Human-Robot Interaction (HRI) in industrial contexts. With its three distinct phases - before, during, and after task execution - the model ensures a systematic and controlled approach to data collection and analysis. By employing a combination of expert evaluation using the HEUROBOX tool and physiological devices (e.g., eye tracking devices, EEG devices), it provides a holistic assessment of HRI, enhancing the understanding of user experience and acceptance. Finally, the section delves into the world of questionnaires, which are valuable tools for assessing user experience and technology acceptance. Questionnaires like HUROX, HRCAM, USE, UEQ, and SUS provide insights into usability, satisfaction, safety, and novelty. When using different questionnaires to measure user experience (UX) and technology acceptance, it's crucial to grasp what each questionnaire assesses. For instance, the HRCAM model underscores the significance of considering ethical, legal, and social implications (ELSI) when developing human-robot collaboration, ultimately aiming to optimize the usability and effectiveness of such interactions within industrial settings.

In conclusion, as we move forward into Industry 5.0, it's crucial to keep these insights in mind. We must prioritize human-centric approaches, manage cognitive load, use validated measures, consider safety, and conduct comprehensive assessments. These insights will guide us as we navigate this new era of industry, working towards enhanced productivity, well-being, and the realization of human potential.

8. BIBLIOGRAPHY

Almeida, L., Menezes, P., & Dias, J. (2020). Interface transparency issues in teleoperation. *Applied Sciences*, *10*(18), 6232.

Angeline, M., Luthfia, A., Safitri, Y., Widyakusumastuti, M. A., & Wibowo, D. (2021). Towards Digital Equality: Assessing Youths' Digital Literacy Capabilities. *2021 International Conference on Information Management and Technology (ICIMTech)*, *1*, 282–286.

Aromaa, S., Frangakis, N., Tedone, D., Viitaniemi, J., & Aaltonen, I. (2018). Digital human models in human factors and ergonomics evaluation of gesture interfaces. *Proceedings of the ACM on Human-Computer Interaction*, *2*(EICS), 1–14.

Baines, T., & W. Lightfoot, H. (2013). Servitization of the manufacturing firm: Exploring the operations practices and technologies that deliver advanced services. *International Journal of Operations & Production Management*, *34*(1), 2–35.

Becker, B., & Gerhart, B. (1996). The impact of human resource management on organizational performance: Progress and prospects. *Academy of Management Journal*, *39*(4), 779–801.

Beith, B. H. (1999). First Person: Human factors and the future of telemedicine. *MEDICAL DEVICE AND DIAGNOSTIC INDUSTRY*, *21*, 36–47.

Benyon, D. (2019). *Designing user experience*. Pearson UK.

Beschi, M., Faroni, M., Copot, C., & Pedrocchi, N. (2020). How motion planning affects human factors in human-robot collaboration. *IFAC-PapersOnLine*, *53*(5), 744–749.

Blažič, B. J., & Blažič, A. J. (2020). Overcoming the digital divide with a modern approach to learning digital skills for the elderly adults. *Education and Information Technologies*, *25*, 259–279.

Boden, M. A. (2017). *Inteligencia artificial*. Turner.

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*(5), 709–726.

Brooke, J. (1996). SUS: A "Quick and Dirty" Usability Scale. In P. W. Jordan, B. Thomas, I. L. McClelland, & B. Weerdmeester (Eds.), *Usability Evaluation In Industry* (p. 6). CRC Press.

Breque, M., De Nul, L., & Petridis, A. (2021). Industry 5.0: towards a sustainable, human-centric and resilient European industry. *Luxembourg, LU: European Commission, Directorate-General for Research and Innovation*.

Bueno-Sanchez, L., Martinez-Molina, S., de Almeida, S. M., Garcés-Ferrer, J., Perez, D., & Quilez, M. (2019). Digital inclusion of senior collectives through participatory processes of co-creation of digital tools: design of a mooc. *Edulearn19 Proceedings*, 9295–9298.

Cheah, S. L.-Y., Yang, Y., & Saritas, O. (2019). Reinventing product-service systems: the case of Singapore. *Foresight*, *21*(3), 332–361.

Chen, M., Nikolaidis, S., Soh, H., Hsu, D., & Srinivasa, S. (2020). Trust-aware decision making for human-robot collaboration: Model learning and planning. *ACM Transactions on Human-Robot Interaction (THRI)*, *9*(2), 1–23.

Cho, M., & Kim, K. M. (2021). Exploring the disparity in tangible outcomes of internet use between persons with disabilities and persons without disabilities in South Korea. *Disability and Health Journal*, *14*(3), 101101.

Colim, A., Morgado, R., Carneiro, P., Costa, N., Faria, C., Sousa, N., Rocha, L. A., & Arezes, P. (2021). Lean manufacturing and ergonomics integration: Defining productivity and wellbeing indicators in a human–robot workstation. *Sustainability*, *13*(4), 1931.

Coronado, E., Kiyokawa, T., Ricardez, G. A. G., Ramirez-Alpizar, I. G., Venture, G., & Yamanobe, N. (2022). Evaluating quality in human-robot interaction: A systematic search and classification of performance and human-centered factors, measures and metrics towards an industry 5.0. *Journal of Manufacturing Systems*, *63*, 392–410.

CORREIA MARQUES, J. (2017). *A point-and-command interface for grasping unknown objects with robotic manipulators*.

Dániel, B., Korondi, P., Sziebig, G., & Thomessen, T. (2014). Evaluation of flexible graphical user interface for intuitive human robot interactions. *Acta Polytechnica Hungarica*, *11*(1), 135–151.

Danielsson, O., Syberfeldt, A., Brewster, R., & Wang, L. (2017). Assessing instructions in augmented reality for human-robot collaborative assembly by using demonstrators. *Procedia CIRP*, *63*, 89–94.

Dautenhahn, K. (2013). Human-robot interaction. *The Encyclopedia of Human-Computer Interaction, 2nd Ed.*

Driewer, F., Sauer, M., & Schilling, K. (2007). Discussion of Challenges for User Interfaces in Human-Robot Teams. *EMCR*.

Engwall, K. (2023). Online activities for individuals with intellectual disabilities at a day centre in the wake of COVID-19. *British Journal of Learning Disabilities*, *51*(2), 229–237.

Gao, Q., Wang, Y., Song, F., Li, Z., & Dong, X. (2013). Mental workload measurement for emergency operating procedures in digital nuclear power plants. *Ergonomics*, *56*(7), 1070–1085.

García, O. S., & del Hoyo Delgado, M. Á. (2002). *La carga mental de trabajo*. Instituto Nacional de Seguridad e Higiene en el Trabajo.

Goodhue, D. L. (1995). Understanding user evaluations of information systems. *Management Science*, *41*(12), 1827–1844.

Goodrich, M. A., & Schultz, A. C. (2008). Human–robot interaction: a survey. *Foundations and Trends® in Human–Computer Interaction*, *1*(3), 203–275.

Gopinath, V., Ore, F., & Johansen, K. (2017). Safe assembly cell layout through risk assessment–an application with hand guided industrial robot. *Procedia CIRP*, *63*, 430–435.

Gruzdeva, M. A. (2022). The age factor in the digital divide: The edges of inequality. *Economic and Social Changes: Facts, Trends, Forecast*, *15*(4), 228–241.

Gualtieri, L., Monizza, G. P., Rauch, E., Vidoni, R., & Matt, D. T. (2020). From design for assembly to design for collaborative assembly-product design principles for enhancing safety, ergonomics and efficiency in human-robot collaboration. *Procedia CIRP*, *91*, 546–552.

Hargittai, E. (n.d.). Second-Level Digital Divide: Differences in People's Online Skills, April 2002. *ArXiv Preprint Cs/0109068*, *7*.

Hancock, P. A., & Desmond, P. A. (Ed.). (2001). *Stress, workload, and fatigue*. Lawrence Erlbaum Associates.

Harriott, C. E., Zhang, T., & Adams, J. A. (2013). Assessing physical workload for human–robot peer-based teams. *International Journal of Human-Computer Studies*, *71*(7–8), 821–837.

Helander, M. G. (1997). The human factors profession. *Handbook of Human Factors and Ergonomics*, *3*, 16.

Hentout, A., Aouache, M., Maoudj, A., & Akli, I. (2019). Human–robot interaction in industrial collaborative robotics: a literature review of the decade 2008–2017. *Advanced Robotics*, *33*(15–16), 764–799.

Hietanen, A., Pieters, R., Lanz, M., Latokartano, J., & Kämäräinen, J.-K. (2020). AR-based interaction for human-robot collaborative manufacturing. *Robotics and Computer-Integrated Manufacturing*, *63*, 101891.

Hollender, N., Hofmann, C., Deneke, M., & Schmitz, B. (2010). Integrating cognitive load theory and concepts of human–computer interaction. *Computers in Human Behavior*.

Hollnagel, E., & Woods, D. D. (2005). *Joint cognitive systems: Foundations of cognitive systems engineering*. CRC press.

Joosse, M., Lohse, M., Berkel, N. Van, Sardar, A., & Evers, V. (2021). Making appearances: How robots should approach people. *ACM Transactions on Human-Robot Interaction (THRI)*, *10*(1), 1–24.

Kaasinen, E., Liinasuo, M., Schmalfuß, F., Koskinen, H., Aromaa, S., Heikkilä, P., Honka, A., Mach, S., & Malm, T. (2018). A worker-centric design and evaluation framework for operator 4.0 solutions that support work well-being. *IFIP Working Conference on Human Work Interaction Design*, 263–282.

Kahn Jr, P. H., Ishiguro, H., Friedman, B., Kanda, T., Freier, N. G., Severson, R. L., & Miller, J. (2007). What is a human?: Toward psychological benchmarks in the field of human–robot interaction. *Interaction Studies*, *8*(3), 363–390.

Karabegović, I., Karabegović, E., Mahmić, M., & Husak, E. (2020). Implementation of industry 4.0 and industrial robots in the manufacturing processes. *New Technologies, Development and Application II 5*, 3–14.

Kowalkowski, C., Gebauer, H., & Oliva, R. (2017). Service growth in product firms: Past, present, and future. *Industrial Marketing Management*, *60*, 82–88.

Laschke, M., Uhde, A., & Hassenzahl, M. (2020). Positive work practices. Opportunities and challenges in designing meaningful work-related technology. *ArXiv Preprint ArXiv:2003.05533*.

Lasota, P. A., & Shah, J. A. (2015). Analyzing the effects of human-aware motion planning on close-proximity human–robot collaboration. *Human Factors*, *57*(1), 21–33.

Lindblom, J., Alenljung, B., & Billing, E. (2020). Evaluating the user experience of human–robot interaction. *Human-Robot Interaction: Evaluation Methods and Their Standardization*, 231–256.

Lund, A. M. (2021). Measuring usability with the USE questionnaire. *Usability Interface*, *8*(2), 3–6.

Marvel, J. A., Bagchi, S., Zimmerman, M., & Antonishek, B. (2020). Towards effective interface designs for collaborative HRI in manufacturing: Metrics and measures. *ACM Transactions on Human-Robot Interaction (THRI)*, *9*(4), 1–55.

Mavrou, K., & Hoogerwerf, E.-J. (2016). Towards full digital inclusion: the ENTELIS manifesto against the digital divide. *Journal of Assistive Technologies*, *10*(3), 171–174.

Middle, R., & Welch, L. (2022). Experiences of digital exclusion and the impact on health in people living with severe mental illness. *Frontiers in Digital Health*, *4*, 1004547.

Moray, N. (2013). *Mental workload: Its theory and measurement* (Vol. 8). Springer Science & Business Media.

Morrow, P. B., & Fiore, S. M. (2012). Supporting human-robot teams in social dynamicism: An overview of the metaphoric inference framework. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *56*(1), 1718–1722.

Moulières-Seban, T., Bitonneau, D., Salotti, J.-M., Thibault, J.-F., & Claverie, B. (2017). Human factors issues for the design of a cobotic system. *Advances in Human Factors in Robots and Unmanned Systems: Proceedings of the AHFE 2016 International Conference on Human Factors in Robots and Unmanned Systems, July 27-31, 2016, Walt Disney World®, Florida, USA*, 375–385.

Mubarak, F., & Suomi, R. (2022). Elderly forgotten? Digital exclusion in the information age and the rising grey digital divide. *INQUIRY: The Journal of Health Care Organization, Provision, and Financing*, *59*, 00469580221096272.

Neter, E., Chachashvili-Bolotin, S., Erlich, B., & Ifrah, K. (2021). Benefiting from digital use: prospective association of internet use with knowledge and preventive behaviors related to Alzheimer disease in the Israeli survey of aging. *JMIR Aging*, *4*(2), e25706.

Pantano, M., Regulin, D., Lutz, B., & Lee, D. (2020). A human-cyber-physical system approach to lean automation using an industrie 4.0 reference architecture. *Procedia Manufacturing*, *51*, 1082–1090.

Pacaux-Lemoine, M.-P., & Flemisch, F. (2021). Human-Cyber-Physical System Integration (HSI) in Industry 4.0: design and evaluation methods. *2021 IEEE 30th International Symposium on Industrial Electronics (ISIE)*, 1–6.

Peruzzini, M., Grandi, F., Pellicciari, M., & Campanella, C. E. (2018). A mixed-reality digital set-up to support design for serviceability. *Procedia Manufacturing*, *17*, 499–506.

Park, E.-Y. (2022). Digital competence and internet use/behavior of persons with disabilities in PC and smart device use. *Universal Access in the Information Society*, *21*(2), 477–489.

Prati, E., Peruzzini, M., Pellicciari, M., & Raffaeli, R. (2021). How to include User eXperience in the design of Human-Robot Interaction. *Robotics and Computer-Integrated Manufacturing*, *68*, 102072.

Ragnedda, M., & Muschert, G. W. (2017). *Theorizing digital divides*. Routledge.

Romero, D., Stahre, J., Wuest, T., Noran, O., Bernus, P., Fast-Berglund, Å., & Gorecky, D. (2016). Towards an Operator 4.0 typology: A human-centric perspective on the fourth industrial revolution technologies. *International Conference on Computers & Industrial Engineering (CIE46) Proceedings*, 29–31.

Rikard, R. V, Berkowsky, R. W., & Cotten, S. R. (2018). Discontinued information and communication technology usage among older adults in continuing care retirement communities in the United States. *Gerontology*, *64*(2), 188–200.

Salwin, M., Gladysz, B., & Santarek, K. (2018). Technical product-service systems—a business opportunity for machine industry. *Advances in Manufacturing*, 269–278.

Shakina, E., Parshakov, P., & Alsufiev, A. (2021). Rethinking the corporate digital divide: The complementarity of technologies and the demand for digital skills. *Technological Forecasting and Social Change*, *162*, 120405.

Savela, N., Turja, T., & Oksanen, A. (2018). Social acceptance of robots in different occupational fields: a systematic literature review. *International Journal of Social Robotics*, *10*(4), 493–502.

Schaefer, K. E., Straub, E. R., Chen, J. Y. C., Putney, J., & Evans III, A. W. (2017). Communicating intent to develop shared situation awareness and engender trust in human-agent teams. *Cognitive Systems Research*, *46*, 26–39.

Schillaci, G., Bodiroža, S., & Hafner, V. V. (2013). Evaluating the effect of saliency detection and attention manipulation in human-robot interaction. *International Journal of Social Robotics*, *5*, 139–152.

Schmidtler, J., Knott, V., Hölzel, C., & Bengler, K. (2015). Human centered assistance applications for the working environment of the future. *Occupational Ergonomics*, *12*(3), 83–95.

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.

Smith, D. J. (2013). Power-by-the-hour: the role of technology in reshaping business strategy at Rolls-Royce. *Technology Analysis & Strategic Management*, *25*(8), 987–1007.

Tan, K. S. Y., & Chan, C. M. L. (2018). Unequal access: Applying Bourdieu's practice theory to illuminate the challenges of ICT use among senior citizens in Singapore. *Journal of Aging Studies*, *47*, 123–131.

Tang, G., & Webb, P. (2018). The design and evaluation of an ergonomic contactless gesture control system for industrial robots. *Journal of Robotics*, *2018*.

Tőkés, G. E. (2022). The Third-level Digital Divide among Elderly Hungarians in Romania. *Acta Ethnographica Hungarica*, *66*(1), 241–259.

Tsai, C.-S., Hu, J.-S., & Tomizuka, M. (2014). Ensuring safety in human-robot coexistence environment. *2014 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 4191–4196.

Tsarouchi, P., Makris, S., & Chryssolouris, G. (2016). Human–robot interaction review and challenges on task planning and programming. *International Journal of Computer Integrated Manufacturing*, *29*(8), 916–931.

Valtakoski, A. (2017). Explaining servitization failure and deservitization: A knowledge-based perspective. *Industrial Marketing Management*, *60*, 138–150.

Van Deursen, A. J. A. M., & Van Dijk, J. A. G. M. (2009). Improving digital skills for the use of online public information and services. *Government Information Quarterly*, *26*(2), 333–340.

Van Dijk, J., & Hacker, K. (2003). The digital divide as a complex and dynamic phenomenon. *The Information Society*, *19*(4), 315–326.

Veling, L., & McGinn, C. (2021). Qualitative research in HRI: A review and taxonomy. *International Journal of Social Robotics*, *13*, 1689–1709.

Vicente, M. R., & López, A. J. (2010). A multidimensional analysis of the disability digital divide: Some evidence for Internet use. *The Information Society*, *26*(1), 48–64.

Vygotsky, L. S. (1980). *Mind in society: The development of higher psychological processes*. Harvard university press.

Warta, S. F., Kapalo, K. A., Best, A., & Fiore, S. M. (2016). Similarity, complementarity, and agency in HRI: Theoretical issues in shifting the perception of robots from tools to teammates. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *60*(1), 1230–1234.

Waschull, S., Bokhorst, J. A. C., Molleman, E., & Wortmann, J. C. (2020). Work design in future industrial production: Transforming towards cyber-physical systems. *Computers & Industrial Engineering*, *139*, 105679.

Wilson, J. R., & Sharples, S. (2015). *Evaluation of human work*. CRC press.

Wiltshire, T. J., Barber, D., & Fiore, S. M. (2013). Towards modeling social-cognitive mechanisms in robots to facilitate human-robot teaming. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *57*(1), 1278–1282.

Wiltshire, T. J., Warta, S. F., Barber, D., & Fiore, S. M. (2017). Enabling robotic social intelligence by engineering human social-cognitive mechanisms. *Cognitive Systems Research*, *43*, 190–207.

Wang, X. V., Kemény, Z., Váncza, J., & Wang, L. (2017). Human–robot collaborative assembly in cyber-physical production: Classification framework and implementation. *CIRP Annals*, *66*(1), 5–8.

Wilson, J. R., & Sharples, S. (Eds.). (2015). *Evaluation of Human Work*. CRC Press.

9. ANNEXES

ANNEX 1: HEUROBOX

HEUROBOX

Heuristic Robots Experience

ANNEX 2: HUROX

Please, make your evaluation now.

We value your feedback on your recent interaction with the robot. To help us better understand your experience, please take a few moments to complete the following questionnaire. The questionnaire consists of a series of statements, and we ask that you indicate your level of agreement by selecting a circle that aligns with your opinion. The circles provide a range of gradations from 'Totally disagree' to 'Totally agree,' allowing you to express your thoughts with greater nuance. Your input is crucial in helping us improve, so please be honest and thoughtful in your responses.

Example:

1. Using the robot is easy.

	1	2	3	4	5	6	7	
Totally disagree	O	⊗	O	O	O	O	O	Totally agree

This response would mean that you rate you are not agreeing with the statement above.

Let your instincts take over and make a quick decision. Don't overthink it, just trust your gut and give us your genuine impression. Even if you're not entirely convinced or the robot doesn't seem to fit perfectly into a certain category, simply mark a circle on every line.

Your opinion is what matters most, and there's no such thing as a wrong or right answer. So go ahead, be bold and let your thoughts flow freely!