Towards Inclusive and Accessible Industrial Workstations by Shaping Safe and Adaptive Human-Robot Collaboration*

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***Abstract*— Human-robot collaboration combines the strengths of human workers with the capabilities of robots, creating opportunities to improve inclusion and accessibility in manufacturing environments. This study investigates the integration of adaptive workstations within human-robot systems to close gaps in safety and diversity in industrial settings. The presented design and safety framework incorporates workstations with adjustable heights, flexible tool positioning, and multimodal communication interfaces to accommodate workers with varying physical and cognitive abilities. Through a collaborative assembly use case, the study demonstrates how robots can handle repetitive and physically demanding tasks while human workers focus on skill-dependent activities. This approach improves task efficiency and fosters workforce inclusivity, providing a pathway for integrating individuals with disabilities into the primary labor market. The findings emphasize the need to shift towards adaptive, human-centered design to ensure equitable participation in industrial workplaces.**

***Index Terms*— human-robot collaboration, robotic assistance, people with disabilities, inclusive workstations**

I. INTRODUCTION

In Austria, approximately one in four individuals aged 15 to 89 living in private households — equivalent to around 1.9 million people — suffer from health-related limitations in managing daily activities [29]. The employment rate among people with disabilities is 52.8%, slightly above the EU average of 50.8%. However, only 14.9% of these individuals are employed in the regular labor market, as the majority of them work in specialized environments designed to support their needs [30]. To address this disparity, Austrian legislation mandates that companies with at least 25 employees hire one registered disabled person for every 25 employees. An individual is considered registered disabled if he or she has a degree of disability of at least 50%, as defined in § 2 of the Disability Employment Act [28]. According to § 3 of the BEinstG, disability is defined as a lasting physical, mental, psychological, or sensory impairment that is likely to hinder participation in the labor market for a period of more than six months. Despite these legislative measures, many companies do not meet these requirements. In 2023, only 23.9% of companies nationwide fulfilled this employment obligation. Consequently, 76.1% of enterprises are subject to compensation tax due to not meeting the mandatory employment quote [31].

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Concurrently, demographic change leads to an aging population, decreasing birth rates, and shifts in the population structure. This development has led to an increase in retirement age and a growing shortage of skilled workers [7]. While companies in various sectors, such as industry and tourism, face a severe shortage of skilled workers, there is an untapped potential for individuals who have not yet been integrated into the primary labor market. The current situation underscores the need to find new ways to include people with disabilities in the workforce [15]. One approach to overcome this challenge are so-called sheltered workshops (SWs), which are integrative work organizations designed to meet the specific needs of people with disabilities. In Austria, SWs are structured as non-profit organizations that operate separately from the regular labor market and mainly offer simple repetitive tasks [21]. As a result, they establish a separate employment sector instead of fostering true inclusion. SWs tend to reinforce segregation, limiting opportunities for equal participation in the broader workforce [11].

A. Motivation and Problem Statement

Addressing the interconnected challenges of an aging population, a skilled labor shortage, and the underemployment of individuals with disabilities requires a comprehensive strategy. Promoting the inclusion of individuals with disabilities can help to mitigate the shortage of skilled labor by tapping into an underutilized talent pool [6]. Human-robot collaboration (HRC) not only leads to increased productivity, but also enhances participation. Robot systems can be designed to assist individuals with disabilities, enabling them to perform tasks that might otherwise be challenging. Moreover, robot applications can support older or disabled employees by handling physically demanding tasks, thus improving ergonomics and reducing monotony [11], [8].

In the perspective of robot safety, ISO 10218, as published in 2025, Part 1 describes the safety requirements for industrial robots [16], while Part 2 of this standard defines industrial robot applications and robot cells, including modes for safe HRC [17]. In a collaborative application, the state interaction can be reduced by avoiding collisions between humans and robots or restricting the transferred energy in intended or unintended contact. The second option can be implemented by limiting the application's power and force so that biomechanical limits by ISO/TS 15066:2016 are observed in contact. These thresholds and the associated assessment procedures have now been integrated into ISO 10218-2:2025 [17]. Biomechanical limits are the tolerated pressure and force transmitted to different parts of the human

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body during contact with the robotic system. The values are based on studies that analyze the occurrence of pain onset (pressure) and minor injuries, such as bruises (force) in different anatomical regions [18]. However, these thresholds are predominantly based on average percentile values, which do not fully account for individual variations such as age, physical impairments, or gender-related anatomical and physiological differences. For example, differences in BMI, bone density, and pain tolerance between men and women can affect their sense of force and pressure loads. Similarly, older adults or people with disabilities may require adjusted safety parameters to mitigate risks of injury and ensure safe interaction [4], [3], [20].

Furthermore, the European Regulation (EU) 2023/1230 on machinery requires manufacturers to carry out comprehensive risk assessments, e.g. according to ISO 12100:2010 [1]. A main aspect of this process is the definition of machine limits, including operational and user restrictions based on specific physical requirements [9]. As a result, certain machines may not be approved for being operated by people of different sex, ages, or with physical disabilities.

B. Contribution

This paper investigates the integration of diversity and inclusion in the design of safe HRC. The contribution is provided by a systematic literature review, from which a framework for the design of adaptive and inclusive HRC is presented. The objective is to explore how safety standards and interaction protocols can be improved to accommodate differences such as age, sex, and physical impairments.

The structure of the paper is as follows: First, the state-of-the-art in inclusive HRC is analyzed. Then, our vision of the future of inclusive manufacturing is outlined, covering the concept and the description of an industrial application scenario. Subsequently, the evaluation assesses the inclusivity of the concept, identifies limitations, and suggests next steps. The paper concludes with a summary and directions for future work.

II. State-of-the-Art

A systematic literature review on inclusive and accessible HRC within industrial settings revealed three key thematic areas, which are summarized in the subsequent subsections.

A. Assistive Robotics

Assistive robotics has made considerable progress in recent years, particularly in health care and home care, where robots have demonstrated the potential to improve the autonomy and quality of life of people with disabilities. There are various ways in which physically assistive robots can help people with disabilities. The key research areas include assistance in navigation, feeding, and pick-and-place tasks. Although most studies include participants with disabilities, a significant proportion of summative evaluations involve only able-bodied individuals, highlighting the need for more inclusive and representative research methodologies. Additionally, there is a lack of comprehensive studies exploring the real-world deployment of physically assistive robots, emphasizing the need for more in-context evaluations. Future research shall focus on tailoring these systems to individual user preferences and considering the broader social and regulatory factors that influence their adoption [27].

B. Robot Assistance on the Shopfloor

The literature shows that robot-assisted workplaces can support marginalized individuals in production settings by compensating cognitive and physical deficits. In the case of cognitive disabilities, the research by Kildal et al. demonstrates how collaborative robots can empower assembly workers with cognitive impairments by assisting them with complex tasks, reducing workload, and providing task-specific support [19]. Similarly, for physical limitations, Arboleda et al. highlight how HRC can support people with mobility impairments in the workplace, facilitating tasks that require physical strength or mobility, thus enhancing productivity and inclusion [2].

The AQUIAS project exemplifies how robots can support people with disabilities by helping them participate in modern manufacturing. This is achieved by assigning physically demanding tasks to robots while allowing individuals with disabilities to focus on other aspects, such as quality control. The project focuses on creating scenarios at the intersection of economic efficiency and participation in meaningful work. In the first pilot area, the production assistant ”APAS” is implemented in an integration company where employees with severe disabilities perform assembly tasks. The second pilot area explores different models of HRC within an advanced manufacturing setting. The findings show that although close HRC can improve efficiency, it also presents challenges such as safety concerns, ergonomic load, and limited robot processing speed. The prototype developed addressed these concerns by incorporating height-adjustable tables for accessibility, a laser-based safety system to protect workers, and an integrated learning system to support employees with disabilities [22].

Another related project, IIDEA, focuses on promoting the inclusion and integration of people with severe disabilities into the primary labor market through collaborative robotics. Unlike traditional models that often relegate disabled workers to isolated tasks or sheltered workshops, IIDEA emphasizes human-centered, adaptive work environments at the core of Industry 4.0. The project aims to bridge the gap by offering training, modular robotic workstations, and mobile demonstration units to promote awareness and adoption. By customizing robot assistance to individual capabilities and fostering a broad network of stakeholders, including industry, advocacy groups, and training institutions, IIDEA seeks to establish inclusive employment opportunities [24].

C. Design Aspects of Inclusive Human-Robot Collaboration

Key aspects in designing industrial HRC include safety, efficiency, ergonomics, interaction, and acceptance [14], [23].

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Studies indicate positive acceptance of collaborative industrial robots among people with disabilities, further emphasizing their role in fostering inclusive work environments [11].

The literature highlights capability-based approaches that form the basis for inclusive and collaborative work environments. Several tools and methodologies have emerged to optimize the allocation of tasks between humans and robots in inclusive environments and ensure that people with disabilities receive the necessary support. One such tool is IMBA (Integration of People with Disabilities into the Working Life), developed by the German Ministry of Health and Social Security. It serves as a method for comparing the requirements of workplace tasks with human capabilities and documenting both. However, IMBA has its limitations in modeling dynamic workflows. Specifically, it does not track changes in workload within workflows, which is essential for adaptive task allocation in HRC environments [13]. To address these limitations, RAMB (Robotic Assistance for Manufacturing Including People with Disabilities) was introduced, which analyzes specific process steps where individuals with disabilities may require personalized assistance. This is achieved by combining the decomposition of the process based on MTM (Method-Time Measurement) and IMBA, allowing a uniform evaluation of the process requirements that can be compared with the capability profile [32]. Despite the usefulness of IMBA and RAMB, these tools struggle to adapt to dynamic workflows. Mandischer et al. proposed a two-stage reasoning approach for adaptive task allocation in HRC to overcome these limitations. This system assesses the capabilities of a worker using an ontology-based methodology that distinguishes between factors that change quickly (e.g. fatigue) and others that change slower and have more gradual effects (e.g. worsening of a disease) [26].

Moreover, to ensure appropriate support for people with disabilities, the selection of input and output devices is essential. Weidemann et al. present an approach for selecting suitable devices based on a person's specific disabilities and the demands of the work process. For example, a person experiencing tremors after a stroke, with limited mobility in one hand, may benefit from hand or foot buttons as input devices that require minimal fine motor control [33].

III. The Future of Inclusive Manufacturing

The literature indicates that, while initial approaches have been proposed to address the challenges discussed in previous sections, their potential can be significantly improved by integrating adaptive workplace design concepts [25]. However, a considerable gap persists in the development of diversity-oriented safety strategies within production environments. Research highlights that diversity in robotics is still underdeveloped in workplaces and its implementation is often overlooked or not considered sufficiently [12].

The achievement of inclusive manufacturing requires a concerted effort to develop and integrate diversity-oriented safety strategies. This requires human-centered, safe, and technology-supported environments designed to be adaptive and autonomous. In particular, workspaces should be tailored to the capabilities of the individual workers to enable them to perform tasks efficiently and safely while considering physical and cognitive differences. Our vision is a labor market that maximizes the usage of human potential by moving from a user-driven interaction paradigm to one in which systems and work environments dynamically adapt to human capabilities and enable seamless HRC. This includes designing workstations with appropriate reach and movement areas, performing ergonomic evaluations specific to the individual, and ensuring universal accessibility to safety features, such as the emergency stop button. In addition, integrating auditory, visual, and mechanical warning signals will improve accessibility and provide further support for people with different sensory requirements. Furthermore, a comprehensive risk assessment that accounts for individual variations in risk perception will be crucial to minimizing potential hazards and ensuring a safe and inclusive work environment.

A. Concept

A comprehensive design and safety framework is fundamental to creating inclusive manufacturing environments. Our strategy leverages advanced technologies and robot-assisted systems, focusing on HRC to establish adaptable workspaces. The core principle of this concept prioritizes incorporating diverse user groups to ensure that individual abilities are accommodated rather than relying on generic solutions. This is accomplished through a preliminary assessment of workers' skill profiles to identify competencies rather than limitations. For evaluating the working conditions in human-robot workplaces, the previously described RAMB tool is applied [32]. The evaluation considers factors such as body posture, body movement, sensory capabilities, and complex characteristics to assess the worker's skills. This process also involves analyzing job demands, workflow specifications, and task-specific constraints. Once the comparison is complete, tasks are assigned by distinguishing between those more suitable for human workers and those that robots can perform to assist. This allocation ensures that tasks are assigned in a way that optimizes efficiency and inclusivity as much as possible.

Following task allocation, process planning incorporates our design and safety framework, which extends traditional process optimization by embedding aspects of workplace and process design, risk assessment, and human inclusion.

First, we incorporate flexible workplace configurations that can be adjusted to different physical and cognitive needs, ensuring that workstations are ergonomically optimized for all users. This includes adaptable work surfaces, customizable tool positions, and universally accessible emergency controls.

Second, we aim to extend the risk assessment approach, as scripted in ISO 12100:2010, to have a more human-centered focus. By no means, we intend to replace the normative approach, but we rather add parameters to be able to consider the diversity of potential users already during the process of risk assessment. This is supposed to result in a more sensitive process with respect to the diversity of human

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workers in an industrial workplace. In particular, we want to adapt two steps within the process chain of risk assessment, the identification of hazardous situations and the estimation of related risks. We expect that an additional parameter that considers the skill profiles of various workers leads to a more granular and more expressive risk assessment.

Third, we improve human-robot interaction by implementing intuitive interfaces that support multimodal communication, including voice, gesture, and touch-based input. This ensures that users with varying abilities can interact with robot systems in a way that suits their needs.

In addition, tablet-based guidance can be incorporated to provide accessible work instructions. These instructions could include audio guides and visual aids to ensure that individuals with varying cognitive abilities can easily understand and follow tasks.

Finally, our framework prioritizes barrier-free access and inclusive design principles by universal safety measures such as multi-sensory warning signals and robots with force and speed limitations tailored to individual risk profiles.

B. Use Case

To illustrate our approach, we present an assembly use case from series production that showcases the seamless collaboration between humans and robots. The process begins with a Universal Robots UR5 manipulator, which autonomously retrieves part A from its designated holder and positions it for the worker. The worker's task is to tighten a screw in the opening on the right-hand side of part A. After the worker completes this step, the robot sets part A down and retrieves a new unassembled part A, placing it in front of the worker for the same screwing task. Once the worker has assembled both part A pieces, the robot picks up part B and positions it in front of the worker. The worker's final task is to attach the two finished parts A to the left and right sides of part B, completing the assembly. This workflow illustrates a balanced division of labor, where the robot handles repetitive, precise tasks while the human worker performs the assembly steps that require more dexterity.

Figure 1 shows the robot and the collaborative assembly workstation. The most important adaptive components of the workstation are highlighted in green. Firstly, the autonomous height-adjustable table enables ergonomic adaptation to the physical requirements of the operator. In addition, the positions of the robot within the workstation can be adjusted to suit the operator's reach and ensure optimal interaction. This customization also includes the positioning of the box of screws, which is designed to be accessible to all operators, including left- and right-handed and one-armed operators, ensuring ease of use and involvement. Furthermore, the proposed system incorporates adaptive human-robot interaction by detecting when the operator is fully positioned at the workstation and ready to begin the task. The robot remains in standby mode until the operator arrives and confirms readiness to proceed. Depending on the operator's information processing needs, the system uses various signaling mechanisms, including visual, audible, and haptic signals. Visual indicators are provided by a light tower on the worktable, which uses color-coded signals to display system status and warn of potential hazards. In contrast, audible alerts provide immediate warnings via a loudspeaker in the work area. Haptic signals are transmitted through a smartwatch worn by the operator. This watch warns the user in dangerous situations through vibrations, for instance when a mobile robot is approaching.

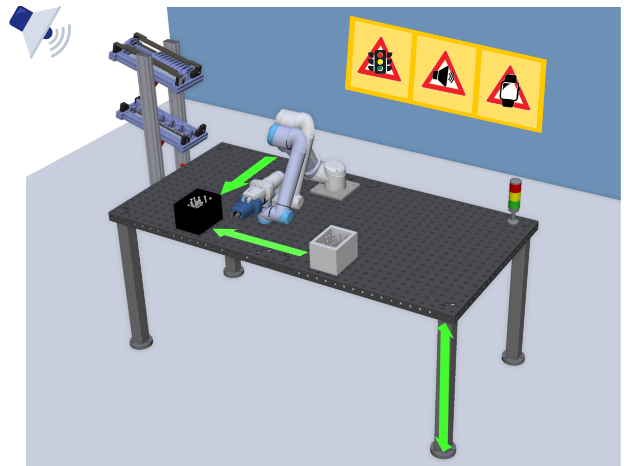

Fig. 1. Human-robot workstation with adaptive components, including ergonomic adjustments, flexible robot positioning, and multimodal signaling

The comparison between a standing human and an individual seated in a wheelchair is presented in Figure 2. In the right image, the table is lowered to accommodate the seated operator, ensuring ergonomic accessibility. In addition, the robot's end effector is positioned closer to the wheelchair user, optimizing reach and interaction. These adjustments demonstrate the adaptability of the workstation in supporting both standing and seated operators.

IV. Discussion

The use case presented illustrates how adaptive workstations can create inclusive environments through HRC. It shows an assembly process in which robots assist in completing repetitive and physically demanding tasks while human workers focus on skill-dependent assembly steps. Several adaptive modifications have been designed, such as adjustable heights, flexible tool positioning, and multimodal communication interfaces. These adjustments ensure better ergonomics, accessibility, and usability for workers with varying physical capabilities. In addition, tablet-based instructions can be incorporated to support physical and cognitive accessibility. These instructions provide clear and tailored guidance to workers, enhancing their ability to perform tasks independently, regardless of mental challenges.

It has to be mentioned that these are relatively small-scale modifications. The illustrated use case does not allow for fundamental changes, such as modifying tools, significantly altering workflows, or introducing fully customized task assignments. These limitations highlight that, although

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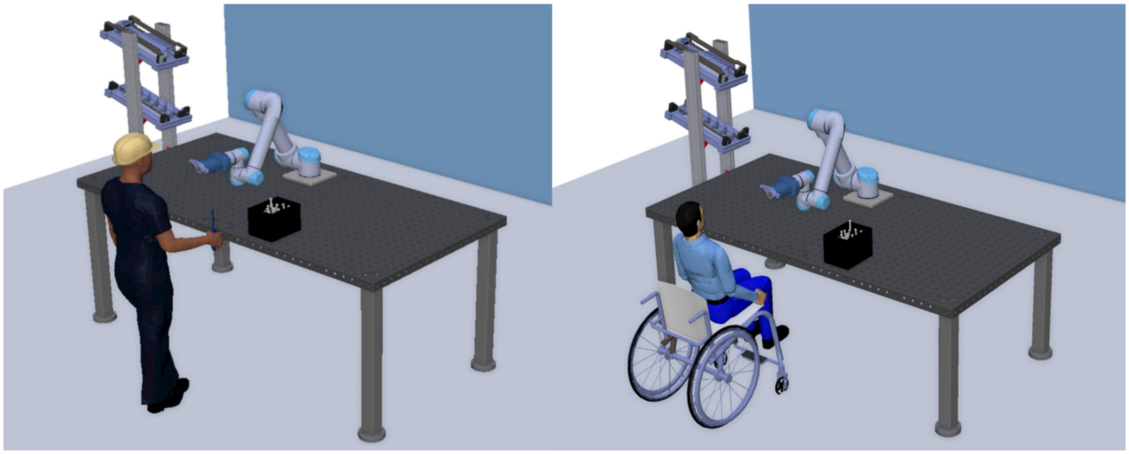

Fig. 2. Comparison of workstation adaptations for standing and wheelchair operators

the approach improves adaptability, it does not yet support comprehensive transformation for highly diverse work environments. Despite these constraints, small adaptations can still have a significant impact. Even minor modifications, such as adjusting the height of the workstation, optimizing component placement, and providing multiple modes of interaction, contribute to greater inclusivity and worker well-being. For instance, an adaptive arrangement of workstation components could improve accessibility for left-handed workers, thereby increasing comfort and overall job satisfaction. These adjustments facilitate a more accessible and efficient workplace without requiring a complete overhaul of existing systems. In manufacturing, where workers are often exposed to cognitive and physical overload, awkward postures, and repetitive tasks, such small adjustments can effectively reduce strain and improve productivity [5], [10].

These considerations underscore the role of adaptive workplaces in fostering inclusion while maintaining economic efficiency. As global labor market competition intensifies, companies are forced to implement flexible, efficient, and sustainable workstations. Organizations must decide whether to implement highly personalized workstations for each employee or develop universally adaptive environments that can accommodate a wide range of needs. A flexible and adaptive system can ensure that workers' abilities align with the demands of their tasks without requiring extensive modifications, thus increasing efficiency and reducing costs.

Another challenge is the broader implementation of adaptive workstations that promote social awareness. Many industries still lack a clear understanding of the benefits of inclusive and adaptable work environments. Public and corporate awareness must be raised through education and advocacy to encourage the adoption and investment in such workplaces. Highlighting long-term advantages, such as improved employee well-being, increased productivity, and the cultivation of a more inclusive culture, can help organizations recognize the value of creating environments that accommodate diverse needs. Thus, a key impact of our presented concept is its ability to drive greater societal awareness and recognition of the importance of inclusive work environments.

To ensure the effectiveness of adaptive work environments, systematic evaluation is necessary. This includes evaluating safety features, worker satisfaction, productivity levels, and economic impacts. In addition, it is crucial to overcome challenges such as organizational resistance, technical limitations, and financial constraints. The current framework would benefit from extensive user testing with a diverse range of participants, particularly individuals with different disabilities. Such an approach would provide deeper insights into usability challenges and enable data-driven improvements to enhance accessibility and functionality. Integrating a wider spectrum of user experiences can optimize the framework to ensure a truly inclusive and effective design.

V. SUMMARY AND OUTLOOK

This paper addresses the gap in manufacturing environments, where safety standards and workplace designs often fail to consider diversity and inclusivity. By integrating adaptive workstations and HRC, this approach aims to create more inclusive and accessible environments. Ergonomic modifications, such as height-adjustable workstations, flexible tool positioning, and multimodal communication interfaces, enhance usability for workers with diverse needs. In addition, tablet-based instructions offer structured, tailored guidance, supporting physical and cognitive accessibility.

To validate and refine such adaptations, the next steps will include user testing on a physical workstation with a diverse group of participants, particularly people with disabilities. This process will involve direct observations and interviews to assess usability, physical and cognitive workload, and trust in the system. The results are used for further improvements, ensuring that future workstations are more inclusive, functional, and adaptable to the diverse needs of employees. Furthermore, by developing a physical demonstrator, this research aims to raise awareness of the potential of adaptive workstations for industrial companies and showcase their

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benefits for inclusive labor market integration.

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