humantech

D1.3 – HT user requirements and ethics approach

Date: 25. Nov. 2022

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement n° 101058236. This document reflects only the author's view and the EU Commission is not responsible for any use that may be made of the information it contains.

Project Title	Human-centred Technologies for a Safer and Greener European Construction Industry
Project Acronym	HumanTech
Grant Agreement No	101058236
Instrument	Research & Innovation Action
Topic	HORIZON-CL4-2021-TWIN-TRANSITION-01-12
Start Date of Project	June 1, 2022
Duration of Project	36 months

Name of the deliverable	HT user requirements and ethics approach
Number of the deliverable	D1.3
Related WP number and name	WP1: Overall Framework Definition
Related task number and name	1.4 Human factors: user requirements analysis and Specification
Deliverable dissemination level	Public
Deliverable due date	30.11.2022
Deliverable submission date	25.11.2022
Task leader/Main author	BAUA / Wischniewski Sascha

Contributing partners	BAUA, SINTEF, ACC, STAM, TEC, LIT, EBC
Reviewer(s)	DFKI / Jason Raphael Rambach; EBC / Fernando Sigchos

Abstract

This deliverable summarizes essential user requirements for interactive robots, exoskeletons and smart glasses. Likewise, an overview of working conditions of the European construction industry is given. Furthermore recommendations for the ethical handling of technologies and data are presented. The work package serves as basis for the application scenarios planned in the HumanTech project.

Keywords

HRI, exoskeletons, smart glasses, GDPR, ethics, user requirements

Revisions

Version	Submission date	Comments	Author
V1.0	25.11.2022		Wischniewski Sascha
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Acronyms and definitions

AGV	Autonomous guided vehicles
AR	Augmented reality
BIM	Building Information Modeling
DSDT	Dynamic Semantic Digital Twin
EU-GDPR	EU general data protection regulation
GDP	Gross domestic product
GVA	Gross Value Added
HRI	Human-robot interaction
ICTs	Information and communication technologies
MMH	Manual material handling
OSH	Occupational safety and health
PPE	Personal protective equipment
WMSD's	Work-related musculoskeletal disorders
XR	Extended Reality

HumanTech project

The **European construction industry** faces three major challenges: increase the safety and wellbeing of its workforce, improve its productivity, and become greener, making efficient use of resources.

To address these challenges, HumanTech proposes to develop **human-centred cutting-edge technologies** such as wearables for workers' safety and support and robots that can harmoniously coexist with human workers while contributing to the ecological transition of the sector.

HumanTech aims to achieve major advances in cutting-edge technologies that will enable a safe, rewarding and digital work environment for a new generation of highly skilled construction workers and engineers.

These advances will include:

- **Robotic devices equipped with vision and intelligence** that allow them to navigate autonomously and safely in highly unstructured environments, collaborate with humans and dynamically update a semantic digital twin of the construction site in which they are.
- **Smart, unobtrusive workers protection and support equipment**. From exoskeletons activated by body sensors for posture and strain to wearable cameras and XR glasses that provide real-time workers' location and guidance for them to perform their tasks efficiently and accurately.
- An entirely new breed of **Dynamic Semantic Digital Twins (DSDTs) of construction sites** that simulate in detail the current state of a construction site at the geometric and semantic level, based on an extended Building Information Modeling (BIM) formulation that contains all relevant structural and semantic dimensions (BIMxD). BIMxDs will act as a common reference for all human workers, engineers and autonomous machines.

Contents

1 Introduction

The HumanTech project combines a wide range of technologies to be used simultaneously in a professional construction environment. When new technologies are introduced into the workplace, a variety of challenges may arise. As an example, exoskeletons may support work tasks, but at the same time restrict the user's movements. Similarly, smart glasses provide valuable information, but on the other hand may lead to information overload. Thus, the use of exoskeletons, smart glasses, wearable sensors or robots change the requirements of the workplace and those of the contractors and their employees. To ensure a safe and human-centred development and use of different technologies, framework conditions must be defined in advanced, notably a baseline level of digital literacy. Against this background, the deliverable summarises existing findings of the technologies to be developed and used in the project. Based on these insights, user requirements are defined to support already in an early stage of the project.

Chapter 2 provides an overview of the working population in the European construction industry. In addition, sociodemographic aspects, information on communication technologies, as well as psychosocial factors and environmental conditions are described in the context of occupational safety and health.

Chapter 3 introduces human-robot interaction, as well as exoskeleton and smart glasses technologies. In detail, the specific characteristics of the technologies, as well as their applications and the existing regulations will be discussed. In addition, user requirements are summarized.

Chapter 4 summarizes the key findings and how they can be taken into account in the further course of the project.

2 Working conditions in the construction industry in Europe

2.1 European construction industry

According to the statistical classification of economic activities in the European Community, NACE, the construction sector consists of three main subsectors: first, the construction of buildings, including non-residential buildings. Second, the subsector of civil engineering, which includes construction of infrastructure like roads and railroad, but also telecommunication and energy infrastructure. Third, specialised construction activities like building site preparation including drilling and demolition, electrical installation and the finishing steps in the building construction process like wall painting [1].

As such, the construction sector is an important pillar of the European economy. One way of measuring the size of its economic role is through the gross value added (GVA) generated by this economic activity as a share of total GVA. This share was between 5 and 6 % in the EU in the period 2010 to 2020. It was highest at 5.8 % in 2010, falling to 5.1 % in 2014 to 2017 and then increasing again to reach 5.6 % in 2020 [2]. The share of the *gross domestic product (GDP) of the EU is even higher with around 9-11 %*. In terms of employment, the sector provides 15-18 million direct jobs in the EU, not counting indirect employment such as production of and logistics for construction material [3].

Similar to the reported data are the findings of the Construction Blueprint report co-founded by the Erasmus+ Programme of the European Union [4]. It provides a detail description of the construction industry in 12 European countries. The key findings are, that the sector is essential for all countries and represents a very important part concerning the GDP and employment. The construction output in the year 2018 was reported at 1,427 billion EUR or 9 % of the total GDP in the European Union. About 14,818,000 people are employed in the construction industry. Interestingly, 95 % of the enterprises in the EU with a total number of 3,332,000 have less than 20 employees. This shows that small enterprises are the overwhelming majority operating in this industry. Accordingly, new technologies should not only consider solutions for large, but also for micro, small and medium-sized enterprises as this is the only way to reach a large number of employees.

According to the report [4], all European countries are focusing on the digitalization of the construction industry, as it is also the interest of HumanTech. However, the national reports outline that the sector is not yet digitized or digitising with the same speed compared to other branches. In Belgium, for example, 30 % of respondents said that they were aware of new digital technologies. Yet they were used in only 5 % of the companies. Consideration should also be given here to improve skills in the use of digital technologies, as it has already been implemented in some European countries.

2.2 Sociodemographic aspects

For sociodemographic information, working technologies and psychosocial working conditions of employees in the construction branch, we draw on our study “digitalisation and change of employment” (DiWaBe). This study includes a sample for the private sector in Germany of more than 6000 employees, with 351 employees in the construction branch. The survey was conducted in 2019.

Figure 1 gives an overview of the age distribution of employees in the construction industry compared to the total population of the workforce. It is important to mention that the DiWaBe data set cannot be considered as a representative dataset for Germany, but provides a good overview. While younger people between the ages of 18 and 34 show similar proportions (12.9 % construction branch vs. 15.9 % overall), the construction industry employs a particularly large number of people between the ages of 50 and 65 (58.4 % vs. 45.4 %), but relatively fewer people between 35 and 49 years than in the overall workforce (28.7 % vs. 38.6 %). Regarding sex, employees in the construction industry are predominantly male with a percentage of 84.5 %, while the percentage of male employees in the total population is 53.5 %.

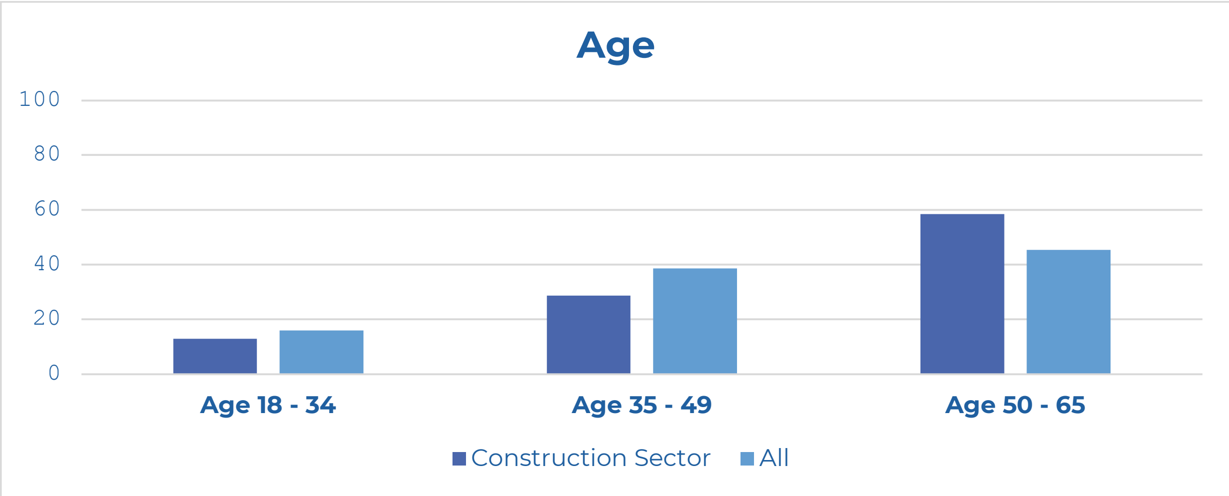

Figure 1: Age of employees in the construction sector compared to others

2.3 Work equipment

When it comes to information and communication technologies (ICTs), employees in the construction industry mainly use smartphones (42.6 % of employees in the construction industry vs. 10.7 % overall). Larger ICTs are used significantly less in the construction sector than in the population as a whole. This is true for laptops (8.9 % vs. 19.0 %) and tablets (0.0 % vs. 2.0 %) as well as stationary desktop PCs (23.7 % vs. 53.4 %). Technologies for physical work however are more prevalent in the construction branch than in the overall workforce. As expected, tools are used much more frequently (27.6 % vs. 10.0 %), as are gauges (25.5 % vs. 14.4 %). Figure 2 illustrates the use of different work equipment.

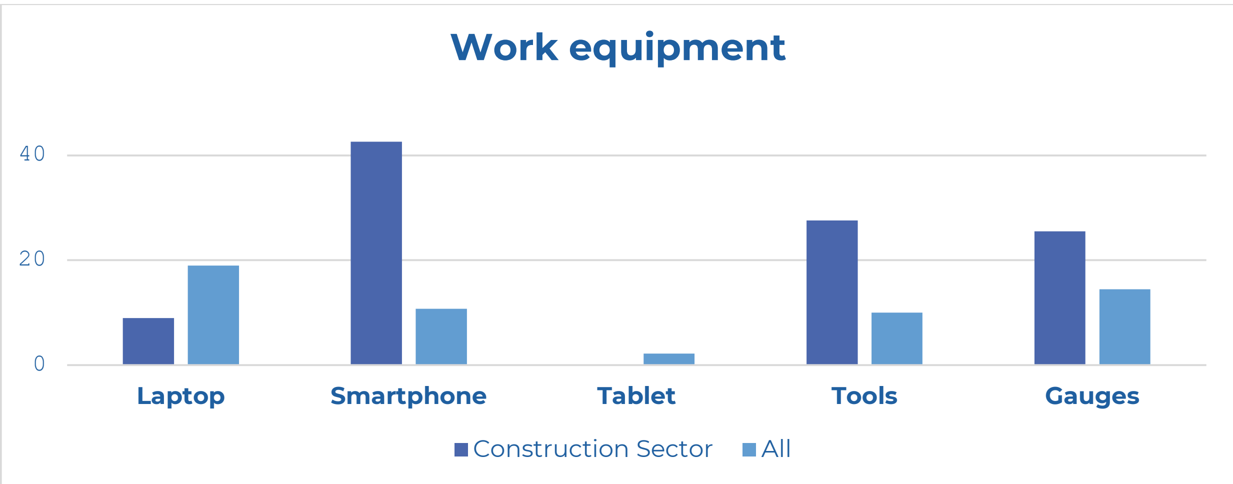

Figure 2: Use of different working technologies.

The comparison for technology interaction (figure 3) shows a greater affinity for employees in the construction sector compared to employees of all other branches (3.20 vs. 3.06).

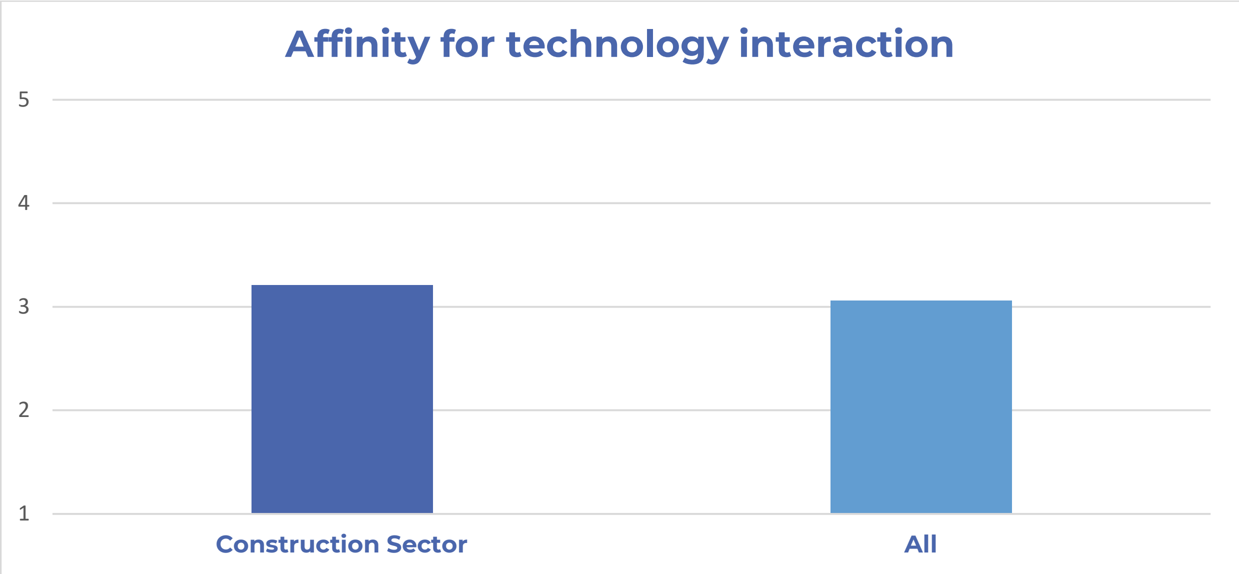

Figure 3: Affinity for technology interaction in the construction sector compared to all others.

2.4 Psychosocial working conditions

With regard to psychosocial working conditions, work in the construction industry is characterised by somewhat increased time pressure (m = 3.56 vs. m = 3.34). On the other hand, the constant repetition of identical work processes is somewhat less prevalent in construction than in the world of work as a whole (m = 3.73 vs. 3.84). The physical stress in the construction industry is significantly higher (m = 2.93 vs. m = 2.41). This includes lifting and carrying loads as well as working in non-ergonomic postures such as working on the knees or overhead. All questions are self-reports on scales from 1 to 5 with higher numbers representing high intensity. Figure 4 summarizes the results.

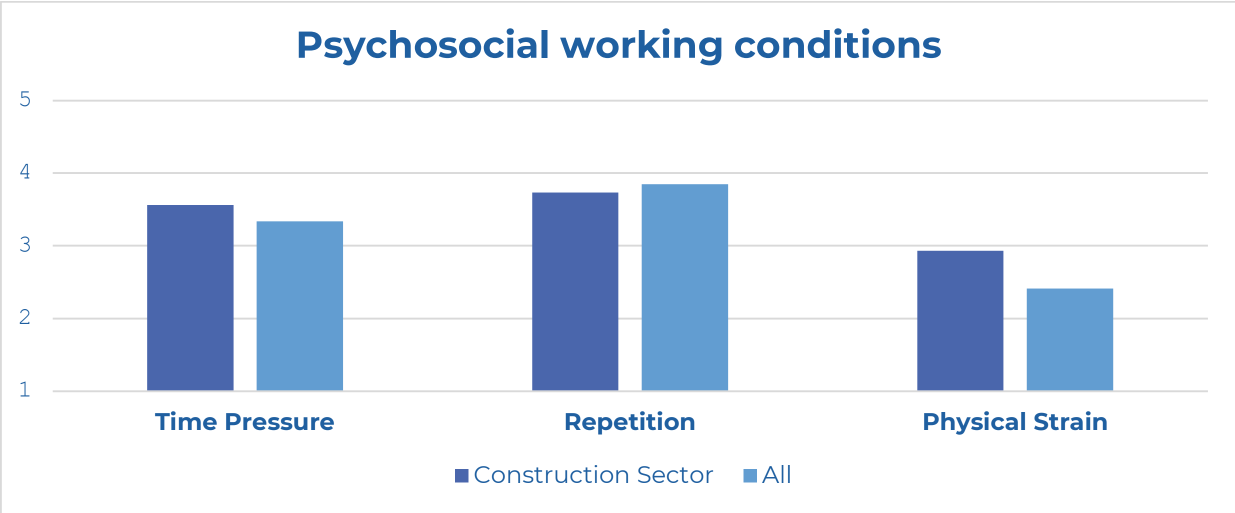

Figure 4: Psychosocial working conditions.

2.5 Environmental hazards and occupational risks

The third European survey of enterprises on new and emerging risks 2019 (ESENER-3) gives an overview on environmental hazards and occupational risks, based on a sample of more than 45.000 employees in the European Union from private and public organisations. The industry breakdown used includes the branch of "construction, waste management, water and electricity supply". Figure 4 shows the self-reporting of interviewed establishments in this branch regarding stressful environmental factors, compared to the average self-reporting of all establishments surveyed. The values refer to the percentage of employees who reported that this factor applies to their workplace. It reveals that employees in the construction industry are substantially more often exposed to loud noises (58.5 % prevalence in construction vs. 30.0 % prevalence overall) as well as heat, cold or draught (67.5 % vs. 36.8 %) during their work than employees in other branches (Figure 5). A similar pattern emerges regarding different occupational hazards (Figure 6). Employees in the construction area report more prevalence for “lifting or moving people or heavy objects” (75.6 % vs. 51.7 %) as well as “risk of accidents with machines or hand tools” (81.2 % vs. 48.1 %) and “increased risk of slips, trips and falls” (60.8 % vs 33.8 %).

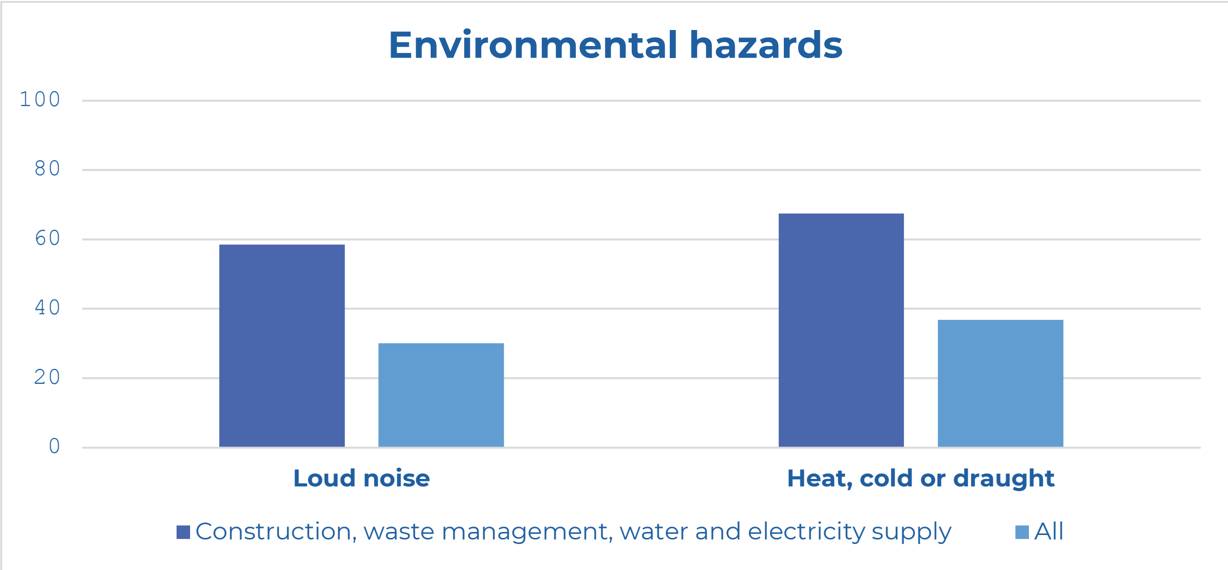

Figure 5: Environmental hazards in the construction industry compared to other branches.

Figure 6: Occupational hazards in the construction industry compared to other branches.

2.6 Summary

In sum, these findings from surveys provide some input for design guidelines for the introduction of new technologies. Employees are generally older and predominantly male, both in absolute numbers as well as compared to the average working population. They show an average to high level of affinity for technology. In principle, this is a favourable factor for the introduction of new technologies, as employees are open towards technology. Furthermore, this factor can facilitate the further development of overall digital literacy in the workforce. In addition, the fact that smartphones are already widely used is a favourable starting point for technologies that are controlled by or linked to an app. At the same time, the special working conditions in the construction sector result in a number of additional demands for potential assistance systems that go beyond the general requirements of usability. Firstly, because of the rough environmental working conditions, any technology used in the construction sector should be resistant to external influences in the form of heat, cold, humidity, dust and dirt in order to be reliable. Secondly, work in the construction industry is characterised by an increased risk of accidents and physical stress, which is why assistance systems should not impair the ability to move or the perception of the employees, to not increase the already high risk even further.

3 Design Recommendations for cobots, exoskeletons and smart glasses

3.1 Interactive robots

In the continuous automation of workplaces, advanced robotic systems have been playing an increasingly important role. Technological innovations in the field of sensors and actuators produce new types of robotic systems. These new generation of robots can perform a wider variety and more complex tasks than previous ones. Furthermore, there are now a number of robotic systems available that can safely interact with humans, without any physical separation. This in turn enables novel forms of interaction between humans and robots [5]. Within this document they are referred to as interactive robotic systems. This term includes the quite often used term of collaborative robots (cobots).

3.1.1 Definition of interactive robotic systems

To better understand, implement and study human-robot interaction (HRI) it is categorised based on interaction design. The types of interaction are commonly divided into co-existence, cooperation and collaboration. The three differ in both the degree of closeness the robotic system has to the employee, as well as the degree of a shared goal. In a co-existing HRI the two do not share a common goal, they only physically share a workspace. In cooperation there is a shared goal to a degree, but steps to reach that goal are taken independently. In collaborative HRI both the physical workspace and the goal is shared to a significant degree. Both robot and human might even be working on the same work piece at the same time. Significant for human-robot interaction with these advanced robotic systems is the lack of physical separation between human and robot. The removal of physical barriers and the new variety of interaction possibilities with robotic systems opens new avenues to develop robots with an increased focus on ergonomic system design.

3.1.2 Application of interactive robotic systems

While the breadth of robotic application is increasing, some sectors already use them more frequently than others. A recent report by EU-OSHA found that when it comes to automating physical tasks industrial robots are still the most commonly found ones in today's workplaces [6]. The second noticeable group they identified were medical robots, like surgical robots, lifting assistance for nurses and transportation robots. A third noticeable group were mobile robots or autonomous guided vehicles (AGV). They can be integrated in a wide variety of workplaces. They especially benefit from the shared physical space with employees, as they now can deliver parts directly to an employee or medication to a patients bed. Especially, logistics companies and warehouses are pioneering the use of AGVs, but they can also be found in the agriculture industry, and the medical sector.

These findings are largely supported by the Third European Survey of Enterprises on New and Emerging Risks (ESENER-3) data, gathered on HRI in different sectors in 2020 (see figure 7). Here, the manufacturing and automotive industry lead the field in human-robot interaction. ESENER-3 categorises participating businesses based on the NACE (v. 2) code of enterprises. Much like the results of EU-OSHA the health and social work sector and agricultural sector are displayed as significant groups, however the ESENER-3 findings also highlight the construction sector as dominant when it comes to HRI.

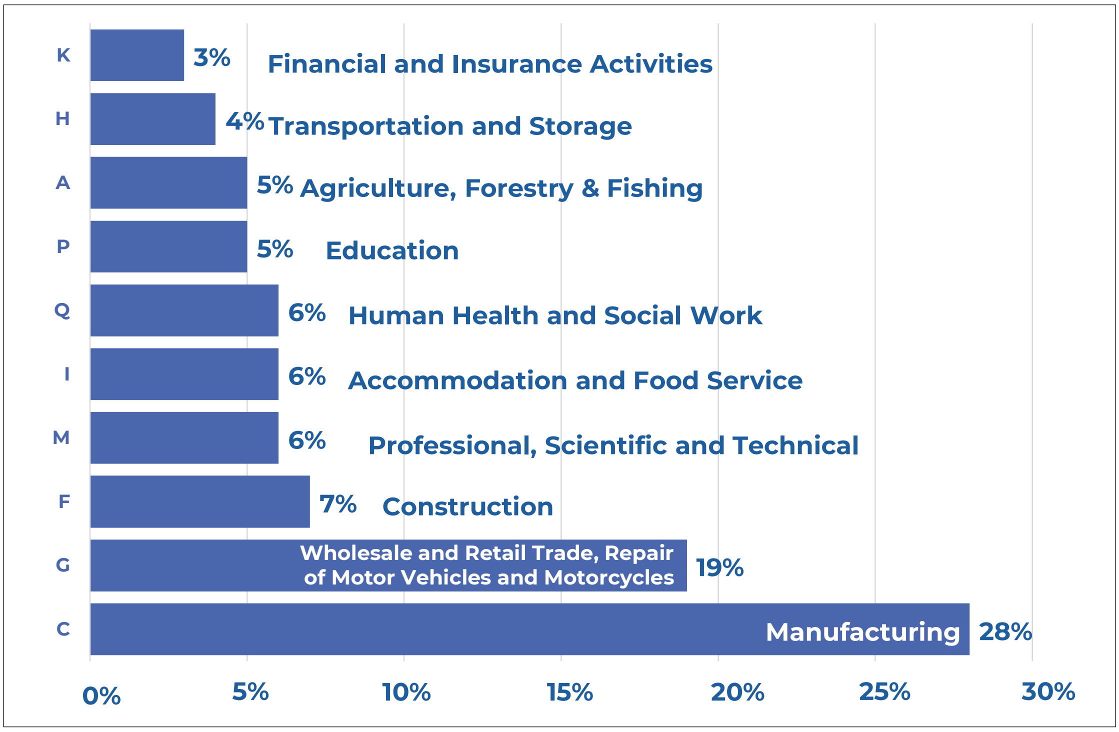

Figure 7: NACE (v. 2) code of enterprises with HRI according to ESENER-3 [7].

Stepping away from the sector perspective on human-robot interaction into a task-based approach can also provide valuable insight. The majority of advanced robotic systems are currently performing physical tasks. Especially tasks like lifting heavy loads, supporting strenuous movement, and transporting items are commonly found [6]. These tasks share that they are predominantly repetitive, as well as part of a set routine. Hence, they are considered easily codifiable. More complex tasks that are outside of a set routine are currently very rare and predominantly found in test runs in the educational and healthcare sector, automating tasks like teaching vocabulary or conversing with patients. More commonly robotic systems are employed in what is called 3D (dull, dangerous, dirty) jobs. This often aligns with manual material handling (MMH) tasks or being exposed to forced postures. Distancing humans from or supporting them during these types of tasks, reduces their risk of long or short-term injury.

3.1.3 Regulations

To create a work environment that is both safe and efficient numerous stakeholders have created directives, standards and guidelines, when it comes to human-robot interaction. Europe currently presents three main legislations or norms relevant for human-robot interaction. Two of them apply to technology use in the workplace and therefore contribute to the legislative basis for advanced robotics. The first is the Machinery Directive 2006/42/EC [8]. When the directive was evaluated in 2018 it was declared as a relevant fit for digital revision, while a new revision is ongoing. The second directive is the OSH Framework Directive 89/391/EEC [9]. It contains general principles for harm prevention in the workplace (e.g. avoiding risks, evaluation risks) and states employees and employers obligations in these matters.

For interactive robots specifically, both companies and researchers can look towards the ISO/TS 15066 [10]. This norm was specifically developed for interactive robotic devices. It supplements the industrial robot safety standards EN ISO 10218-1 [11] and EN ISO 10218-2 [12], while providing guidance on the operational functions for advanced robotic systems. While these three can form a basis to integrate advanced robotic systems into a workplace, it is vital that any company taking these steps is additionally adhering to any national guidelines and legislation, as these differ throughout Europe.

3.1.4 Recommendations for practice

However, next to all legislative requirements there are a number of design principles as well as introduction factors companies should consider when implementing advanced robotic systems to their workplace. These are both in the interest of occupational safety and health, as well as the foundation of a human-centred, effective and efficient collaboration, between human and robot.

When assessing these criteria, one must be aware that the increasing possibility to develop robotic systems for a specific task or need results in less unifiable applicable recommendation. Hence, it is important to consider the end-user, the specific task the workplace and surrounding constraints when looking at these recommendations. One source for guidance on how to design human-robot interaction can be the standard EN

ISO 9214-110 on the Ergonomics of human-system interaction. The standard contains seven relevant interaction principles: suitability for the task, self-descriptiveness, conformity with user expectations, learnability, controllability, use error robustness, user engagement. Among these seven there are several that seem to be of specific importance to users, when it comes to human-robot interaction. Research found that potential future users of these systems perceive the individual interaction principles to be of differing importance. Conformity with user expectations; Suitability for the task; Controllability are especially important to the interaction [13]. Level of expertise can also influence which interaction principles are prioritised by the users. Nonetheless, all principles should be considered when designing the interaction.

- *For creating human-machine interaction, i.e. human-robot interaction, as smooth as possible companies, integrators and researchers should consider* design *guidelines according to the standard on Ergonomics of human-system interaction (EN ISO 9241-110) [14]. The interaction principles are suitability for the task, Self-descriptiveness, conformity with user expectations, learnability, controllability, user error robustness, user engagement.*

Robotic systems are becoming increasingly more autonomous. While it is understandable to initially focus on the physical changes this will bring to workplaces, the mental impact of them should not be forgotten. Experts mentioned the risk that an advanced robotic system could become autonomous to a point, where the system dictates a course of action to the employee [6]. This might impact the employees' psychological well-being, as they can experience a loss of control. Hence:

- *When designing or implementing advanced robotic systems it is important to create an interaction that follows the „human-in-control" principle.*

To create a feeling of control in a heavily standardised work environment, like the manufacturing sector timing and method control are especially influential factors. They can impact the employees mental health, motivation and satisfaction [15]. The loss of job control can be exacerbated by a non-flexible coupling between human tasks and robotic performance. This is potentially associated with adverse psychosocial effects including an overall poorer mental health and less intrinsic job satisfaction [16, 17]. Hence:

- *When designing human-robot interaction tasks, the work rate should be determined by the employee and not by the machine. Including the option to increase* *or decrease the speed as needed by the employee, to further increase feeling of control.*

Integrating an interactive robotic system to support the employee in a task might change the nature of that specific task. This can potentially result in new health and safety risks. Hence:

- *Prior to introducing an interactive robotic system into a workplace thorough risk assessment must take place.*

In HRI the need for communication arises. Research has compared effects of different communications channels in HRI. For example combining modalities like gesture and speech [18] or solely verbal scenarios [19]. Good interaction design attempts to include attributes and characteristics in the way an interactive robotic system expresses itself to enable a smooth and natural interaction. This can be important when the robotic system needs to communicate a limitation or need (e.g. an AGV asking for an obstacle to be removed from its path). The modalities of communication that result in the smoothest interaction are highly dependent on the implementation context. For example: verbal communication can be well suited for a relatively quiet work environment like a hospital, while being ineffective in a loud surrounding like a factory floor. Gestures might communicate more effectively here, while not being suited in workplaces with low visibility. Hence:

- *When creating the communication channels for human-robot interaction it is important for the chosen channels to fit both the task, as well as the work environment.*

Trust is another vital factor in HRI. Research shows that both, trust and acceptance are likely to increase by prolonged exposure to a system. Nomura et al. [20] found that the negative attitudes towards robotic systems decreased as experiences of interacting with them increased. This results in two relevant guidelines:

- *When planning to introduce an interactive robotic system into workplaces, employees should be involved in the introduction process as early as possible to increase trust and acceptance towards it.*
- *When introducing a new interactive robotic system into a workplace a specified in-depth training should be provided for the operators.*

Another central issue to consider when creating or implementing interactive robotic systems is data privacy and surveillance. Many advanced robotic systems use sensors or cameras to be aware of or navigate their surroundings safely. Next to a possible actual loss of privacy, employees might also feel like they are being surveyed. Hence:

- *Employee's right to privacy must be preserved. Employees must be made aware if and what type of data is collected by the robotic system and for what purpose.*

3.2 Design recommendations for exoskeletons

Work-related musculoskeletal disorders (WMSD's) are a major problem in the European Union. Affected individuals usually suffer from significant shoulder and or lower back pain. The main cause is attributed to manual material handling tasks (MMH), which include lifting and carrying heavy loads. Since the demographic change additionally enlarge the problem of these diseases, the technology of exoskeletons has gained increasing attention in recent years. However, the technology is still in its infancy and should only be used at workplaces if various factors relating to occupational safety and health are considered. Up to this date, exoskeletons are not widespread in the industry.

3.2.1 Definition

Exoskeletons are body-worn mechanical systems designed to support the user during physical work. Therefore, they aim to facilitate work processes and reducing work-related musculoskeletal disorders (WRMSDs). An important differentiation can be made between active and passive exoskeletons. The former describes a device that is equipped with sensors and actuators. The actuators can be hydraulic as well as in form of electric motors or pneumatic muscles [21]. The latter works entirely without electrical power but rather uses springs and attenuators. With this, humans can be supported through energy capture of previous movements. Furthermore, they can be classified into full-body, upper-body or lower-body exoskeletons. Depending on the specific design and intended use, different body regions can be supported. In recent years, exoskeletons are slowly moving out of the lab into the industrial market [22, 23]. Here, not only factors like safety, comfort, usefulness and usability become important but also the acceptance of these devices by employees working in in industrial settings [21, 24].

3.2.2 Application of exoskeletons

With exoskeletons slowly being introduced into workplaces, their proper application becomes an important issue. In cases of MMH tasks exoskeletons provide an opportunity to improve working conditions. Also, in cases where full automation is not possible and the human ability to decide and quickly adapt to changes within the working environment is still required, the use of exoskeletons is a feasible solution. As stated in the paragraphs above, interactive robots provide another way of relieving physical stress from employees while retaining the flexibility and creativity that are inherent in humans. Nevertheless, in dynamic environments the implementation of exoskeletons might be simpler than programming a robot or teach humans to interact with it in a correct way [25].

Although exoskeletons are built to relieve strain on specific parts of the body, complete support during heavy lifting tasks is still not feasible. Besides technical challenges, the justification to establish exoskeletons at a workplace needs to be scrutinized. Using exoskeletons for assistance because of an otherwise poorly ergonomic workplace design, goes against occupational health and safety principles and should therefore only be implemented when technical or organizational measures fail [26]. The hierarchy of control describes an important principle for the design of ergonomic workplaces. Thus, potential hazards must first be removed by technical measures e.g. by redesigning the workplace or by the use of technical aids. If technical measures cannot be implemented, organizational measures bust be considered. This includes, for example, the rearrangement of work processes to reduce the workload of employees. Only if none of these steps improve the ergonomic design personal measures should be considered. Depending on the intended use, an exoskeleton can be a technical or a personal measure. Accordingly, the priority can be very different.

3.2.3 Regulations

Further specifications e.g. user requirements can be found in the European regulation on personal protective equipment [27]. Although this regulation presupposes that the exoskeleton is a personal measure, which up until now has not been conclusively decided on, guidelines can be derived for practical use. The basic recommendation is that the personal protective equipment (PPE) can be used without harm. This regulation states among other things, that any impediment caused by e.g. an exoskeleton must be reduced to a minimum. Furthermore, exoskeletons must be adaptable to the anthropometric measures (body dimensions) of the employees. It should also be considered that exoskeletons can be used together with other PPE which is not unusual on constructions sites. The above aspects only summarise some of the many requirements of the regulation, yet they are essential particularly in view of the fact that HumanTech combines several technologies simultaneously.

In Germany, an occupational health guideline on the use of exoskeleton in the context for primary, secondary and tertiary prevention has also been elaborated [28]. This guideline summarizes key findings and provides recommendations for the use of exoskeletons at a workplace. The main statements of the guideline are that the hierarchy of control for occupational safety and health must be taken into consideration when using exoskeletons. It should first be examined whether technical or organisational measures can be applied before a personal measure, such as the exoskeleton in this case[1], is considered. A preventive effect of exoskeletons on musculoskeletal disorders cannot be substantiated on the basis of the current state of scientific knowledge and experience from practice. Currently, there is no evidence for the use of exoskeletons with regard to symptom relief or prevention of symptom aggravation (e.g. lower back pain). Three main recommendations for practice are also given. For workplaces where an exoskeleton is used, a specific risk assessment should be carried out in relation to the used exoskeleton. Furthermore, the use of exoskeletons should be voluntary as long as there is no proven evidence regarding their health benefits. A physician/health professional should supervise the use of exoskeletons and the interests and concerns of employees should be taken into account.

3.2.4 Recommendations for practice

Besides challenges and requirements put forward through the described regulations, researchers have put together numerous design principles as well as facilitating factors to introduce exoskeletons within a workplace [22, 24, 29]. Fox et al. [29] state that introducing exoskeletons within workplaces will only prevent new sources from WRMSDs and accidents when one sticks to “careful health and safety planning”. This includes an

[1] Note: An exoskeleton can be a technical measure as well. However, if it is used for prevention or to reduce muscular skeletal complaints in general, it should be considered as a personal measure.

ideally iterative human-centered design with initial screening, (re)development and evaluation phase.

Based on an extensive literature review, Elprama et al. [24] propose that the acceptability of potential users is dependent on multiple factors such as physiological, psycho-social factors, implementation related factors, work related and policy related factors. These include, for example, the ease of use, reliability, compatibility with tasks, controllability in accordance to the international standard ISO 9241-110 [14] and safety (figure 8). In addition, factors like cleanness, financial cost for implementation, existing knowledge and cultural beliefs are considered to determine the acceptance of exoskeletons. The aforementioned author created a list of 38 requirements for potential end users that can be used as a checklist for designers in all stages of development. The following recommendations are essential findings based on the literature review of Elprama et al. [24].

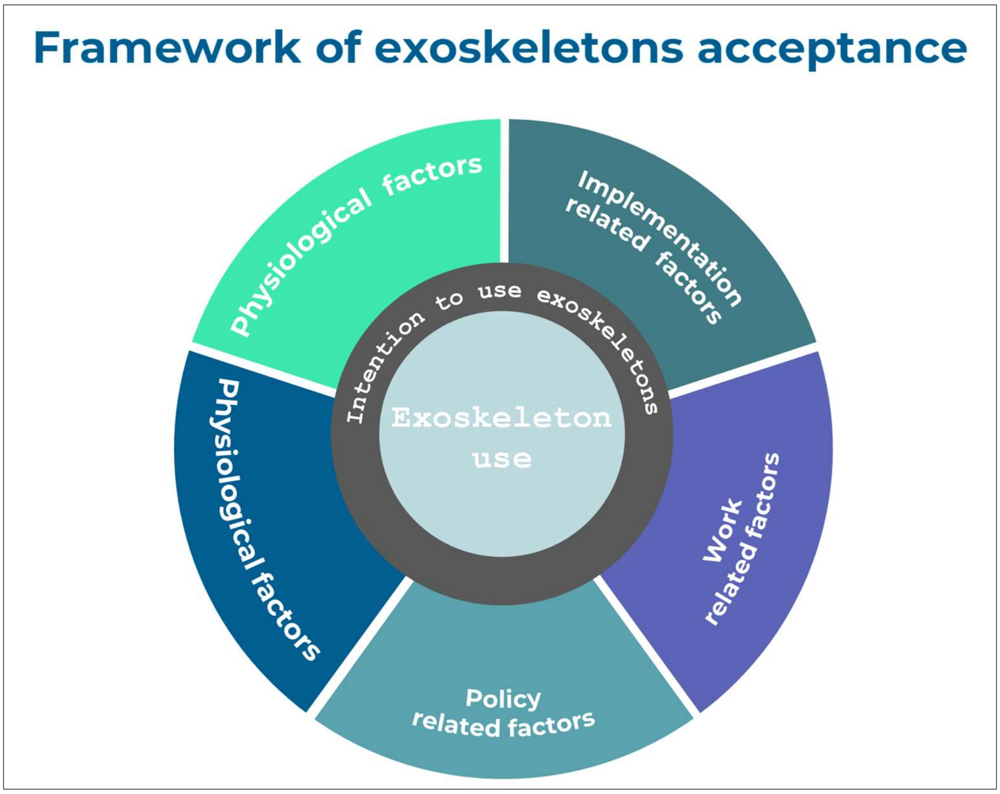

Figure 8: Framework of exoskeleton acceptance modified form [24]

- *Exoskeletons should be easy to clean. This includes the possibility for sterilization*

Since exoskeletons might be worn from multiple people throughout the day, especially in environments that require this (food processing, operating theatre). Passing on an exoskeleton to the next employee can also occur when the device is only used for one specific task.

- *The compatibility of the exoskeletons with the task needs to be investigated extensively.*

Ideally, a variety of tasks needs to be studied to allow the support of a wide range of different movements and tasks. Within this section, designers need to pay attention to the compatibility.

- *Compatibility with different clothing (e.g. surgical masks) or PPE, the limitation of movements as well as the impact of wearing an exoskeleton on productivity.*
- *Exoskeletons need to be as compact as possible so that they can be stored easily.*

This is especially important for exoskeletons that are used at construction sites since there often is not a lot of storage room. Additionally, devices that are used in these environments must be robust.

- *Exoskeletons must be durable so they can be used in different weather and environmental conditions such as dirt, water, rain or extreme temperature.*

They also should be robust enough to withstand bumping into objects at the workplace without breaking. This plays also an important role in the perceived safe use of an exoskeleton.

- *Exoskeleton should be designed in a way that the risk of getting caught by objects in the work environment is as small as possible to decrease the risk of injury and falling.*

Currently, there is no evidence that exoskeletons protect against WMSD's. Likewise, it is possible that regular use of exoskeletons may result in new muscular skeletal diseases.

- *Wearing an exoskeleton should not lead to the development of new musculoskeletal disorders or muscle atrophy.*
- *The design of an exoskeleton should be attractive.*

This is relevant to prevent stigmatization. Here, another important issue is seeing the use of exoskeletons as a weakness which might cause negative social feedback and lead to disuse of the device.

- *The perceived usefulness of an exoskeletons is tangible by employees through direct alleviation of the task.*

According to Elprama [22], this could be achieved by perceived physical support or the ability to work for a longer time when wearing an exoskeleton as well as higher efficiency and less pain.

- *Exoskeletons should be as light and as unobtrusive as possible.*

This includes not only the weight itself but also the setup of the exoskeleton, which can lead to pressure points and movement restriction. This is also linked to the comfort of the exoskeleton which is considered as very important. Most often, the ease of use and compatibility with the task are mentioned as equally important.

The variety of recommendations put designers in the balancing act of developing exoskeletons that are, on the one hand, easy to use and cost efficient and robust but on the other hand also adapted to the human anthropomorphism, unobtrusive and easily adaptable while being capable for heavy lifting.

3.3 Design recommendations for smart glasses

Modern cognitive assistance systems can offer advantages in coping with large amounts of information by adapting to the respective workplace in a context-sensitive way. In doing so, they independently identify the needs of employees when performing tasks. This can help to reduce the complexity of information and thus the mental load. In addition to context-sensitive information provision, augmented reality (AR) is becoming increasingly important in research and practice. AR is intended to make it easier for employees to access information in a needs-oriented way. Digital information is integrated directly into the real environment at the workplace. For this purpose, external data about the environment is collected, analyzed and converted using integrated sensor technology and corresponding algorithms. Especially smart glasses offer high potential for the implementation of AR. They make it possible to be mobile when retrieving information and at the same time to have both hands free while working. Another advantage is that additional, context-sensitive information can be displayed directly in the user's field of view while the user still can see the real environment.

3.3.1 Definition of smart glasses

Smart glasses are display devices that are worn directly in front of the eye, similar to a pair of glasses, and provide information on displays. They consist of the actual display unit with one or two displays and an optical module in front of it. This is used to transfer the digital information displayed directly in front of the eye to a user-friendly viewing distance. This image layer is usually between one and two meters in front of the user.

A basic classification is made between two types of smart glasses. Monocular smart glasses work with a display in front of only one eye, leaving the second eye free. Binocular smart glasses, on the other hand, contain a display in front of each eye, with the same information being shown on each display, overlaid in the direction of gaze. In comparison to monocular models, this also enables plastic 3D representations. Monocular and binocular smart glasses are further divided into see-through, non-see-through and look-around technologies. With see-through technologies, the information is displayed on a semi-transparent mirror so that the user can still perceive the information of the real environment behind it. Non see-through and look-around smart glasses, on the other hand, are closed behind the display and thus create a visual barrier where the display is located. However, mostly the user is still able to see the real world around the display [30].

Especially binocular see-through smart glasses are seen as a potential technology for the implementation of augmented reality. The idea is to enable context-sensitive information to be displayed in the user's field of view directly on the real-world objects being viewed. Models of smart glasses currently available on the market offer a smaller field of view than humans can perceive with their eyes. The usable, horizontal field of view is approximately between 20 and 45 degrees, depending on the model. It can occur that displayed information partially hides important elements of the real environment. These properties must be adapted to the performed tasks, the existing conditions and possible hazards. For practical applications, the luminance and contrast of the displays also is important. The information presented on the display may only be recognizable to a limited extent in bright daylight or light reflections. When used in closed rooms with defined lighting conditions, there are usually no problems [31].

3.3.2 Application of smart glasses

Smart glasses are currently only used practically as work assistance in real use cases. One prominent application is in order picking, where the principle of pick-by-vision is applied. Here, the employee gets all the information required to perform the task (e.g., storage location, item number, picking quantity, etc.) displayed directly in his field of view.

In addition, the results of scientific research projects underline the basic potential of smart glasses as work assistance. Most of the use cases investigated are in the industrial sector. A high potential is currently seen in the area of maintenance and repair. The advantage here is that employees can share their field of vision with a remotely connected expert during fault diagnosis. The implementation of augmented reality by means of binocular data glasses is especially pursued in (automotive) production and in the related industrial training and education [32, 33].

3.3.3 Regulations und standards

For a purposeful model selection, implementation and use with regard to smart glasses as work assistance, the usability in terms of effectiveness, efficiency and satisfaction [34] is essential. In this context, particular attention should be paid to the requirements of software and hardware ergonomics. In the area of software ergonomics, again the EN ISO 9241 series of standards on the ergonomics of human-system interaction should be mentioned. In detail, the principles for the presentation of information [35] as well as the interaction principles [14] must be taken into account in order to ensure a user-friendly design of the software. In the case of the interaction principles, particular focus should be placed on the aspects of controllability and an easy, intuitive learnability of the technical assistance system.

In the direct context of smart glasses or augmented reality, standardization is still in its initial stages. However, there are several working groups at the International Organization for Standardization (ISO) dealing with this topic area. As an example, the ISO/IEC JTC 1/SC 24/WG 11 works on the standardization to health, safety, security and usability of augmented and virtual reality.

3.3.4 Recommendations for practice

The decision whether it makes sense to use smart glasses depends on the working task. A careful analysis of the fit between the working task and the technology is essential for optimal use. A high degree of task-technology-fit not only increases the probability that the technology will actually be used. As a result, the individual's work performance usually increases as well, as the requirements of the task can be fulfilled more effectively. The preconditions for these positive effects are a high level of acceptance of the technology and its best possible adaptation to the requirements of the task [36, 37].

On the basis of various research activities and expert workshops held by the German Federal Institute for Occupational Safety and Health (BAuA), indicators were identified that argue for and against the use of smart glasses as work assistance. According to these indicators, the use of smart glasses makes the most sense when both hands are needed to fulfill the working task and the employees have to be mobile when performing it. Furthermore, the use of smart glasses is essentially recommended for working tasks that can be subdivided into subtasks with a low information requirement for individual work steps [30].

In principle, graphically prepared information - images, videos, diagrams, etc. - can be better displayed on smart glasses than text. If a lot of individual information is needed to perform the tasks, it should be presented in a structured and clear manner for the respective work step.

The use of smart glasses is not recommended if the task requires a complete field of view and if the work environment must not be obscured for safety reasons. Another reason for exclusion is a large amount or high complexity of the required information. In addition, the environmental conditions must fit the technology. For example, some floor surfaces have the characteristic of reflecting light. This can lead to problems with the visual perception of information on the display. The same applies to outdoor applications in bright daylight [31].

Furthermore, some factors can be found that increase the acceptance for the use of smart glasses [36, 38]. These were also confirmed in field studies in the industrial sector. For example, the objective characteristics and features of the smart glasses themselves are significant for the user acceptance. They place a high value on both wearing comfort and aesthetic design. Both factors have an influence on whether employees use smart glasses or not. On the other hand, interest and initial enthusiasm fade in the case of less wearing comfort, disturbing head mounting and an unbalanced weight. If easy adjustment options are available, the user can fit the smart glass to their individual needs. If the holder fits, it should not cause a feeling of pressure on the head even when worn for a long time and should prevent or reduce sweating. The most important factor is that even people who wear glasses can use the technology without restrictions.

Several laboratory studies have also investigated the mental load and physical strain associated with using smart glasses as work assistants. The following recommendations result for the consideration of mental load [39]:

- *When working with smart glasses for several hours, frequent short breaks are recommended during which employees can take off the device. Breaks in use prevent both subjective stress and objectively existing visual fatigue.*
- *Individual acclimatization phases are appropriate for older employees. They are more affected by visual fatigue than younger ones. Therefore, the time to get used to the device should be adjusted accordingly.*
- *Smart glasses should offer the possibility of easily adjusting contrast, sharpness and luminance to the individual needs of the user.*
- *Employees should be introduced to the technology in detail by means of instruction before their first contact with smart glasses. In particular, a person experienced with smart glasses should demonstrate all the setting options, because incorrectly set smart glasses lead to higher stress in the long term.*

The following recommendations result for the consideration of physical strain [40]:

- *The weight of smart glasses should not only be as low as possible, but also evenly balanced. Older employees in particular react to uneven weight distribution with compensatory muscle activity. This can cause faster fatigue.*
- *Smart glasses with a head mount cause additional strain on employees due to the weight and possible pressure points of the mount. In this respect, regular glasses frames offer considerable advantages. If a helmet is worn at work, the smart glasses should be attached to it.*
- *Smart glasses do not promote movement. Rather, they lead to a fixed head posture with the risk of muscular tension. If users are already working in forced postures at times, the use of smart glasses is less recommended.*

- *Wired smart glasses restrict freedom of movement. Wireless devices are the optimal option. If this option is not available, the cable routing should guarantee such a degree of freedom of movement that the work can be performed without hindrance or risk of accident.*

3.4 Privacy and ethics recommendations

Assistance systems that adapt to the workplace and respond adaptively to the individual needs of employees can reduce complexity and cushion the impact of informational stress. Adaptive, context-sensitive assistance systems, however, require a comprehensive data structure and diverse information about the status of the work system and the employee himself. The combination of these various data can support the employee and increase productivity.

The assistance system aimed in the project enables the collection and evaluation of many personal data through sensors worn on the body. The resulting possibility of monitoring work, performance and behavior must be viewed critically. Ethical questions go hand in hand with data protection aspects. For this reason, risks and recommendations for dealing with possible monitoring effects are presented below against the background of the EU General Data Protection Regulation (EU-GDPR).

3.4.1 Risk of employee monitoring

Frequently, accumulating data streams allow for complete profiles in the sense of a transparent employee through aggregation and linkage. Even if the data is not collected for this purpose, it is a side product of such work assistance systems and can be perceived by employees as a monitoring tool. In a representative employee survey in Germany [41], respondents reported a perceived increase in monitoring and control of their work performance through digitalization. A systematic review was done to derive fundamental effects of context-sensitive assistance systems with respect to a monitoring effect [42, 43].

The results indicate that electronic monitoring is mostly associated with negative effects on subjective perceptions (e.g. stress, strain, control and satisfaction). In the case of employee performance and motivation, on the other hand, incoherent results appear. Here, monitoring has different effects, depending on the motivational situation and performance requirements. In the case of simple tasks, monitoring increases performance, whereas in the case of difficult tasks, performance was reduced. Often, monitoring leads to a more quantitative focus on performance aspects than on work quality. Monitoring can be particularly performance-enhancing and motivating if it is seen as valuable feedback rather than as a threat or punishment tool. On the other hand, monitoring has a frustrating effect if it is perceived as unfair or faulty. Crucial to this are different incentives of intrinsic and extrinsic motivation among employees.

The employees' perception of monitoring as well as their attitudes and expectations are therefore influencing factors that should not be underestimated. Strict monitoring is generally associated with stress. With electronic monitoring, supervisors no longer have to be physically present. This can create a feeling of permanent control, as it is often impossible to determine whether a context-sensitive system is currently monitoring or not. This uncertainty can trigger additional stress. Furthermore, monitoring reduces the autonomy of employees and the perception of control over technology and work task.

3.4.2 Data protection

Since 2018, the EU-GDPR established a new legal standard for data protection law in Europe, which sets a new framework for the application of adaptive work assistance systems.

Two central requirements of the EU-GDPR are the principles of transparency and purpose limitation. To create transparency, employers have information obligations that require employees to be informed about the type, purpose and duration of the storage of personal data before it is collected. Furthermore, employees have the right to know the data collected about themselves. In the context of purpose limitation, personal data may only be collected for a clearly defined, legitimate purpose and only stored for the duration of the purpose. A change of purpose with regard to data already collected is only possible under strict conditions and with proven compatibility. In general, the requirement for data minimization applies. Only data that is indispensable for the assistive function of the assistance system should be collected. Data retention is not possible according to this principle. The EU-GDPR also focuses on technical data protection. Accordingly, anonymization or pseudonymization concepts should be taken into account as early as possible in the design of the technology [44].

3.4.3 Recommendation for practice

Taking into account the data protection principles can help reduce uncertainty and fear of being monitored by the work system. Monitoring at the individual level must be avoided, and data to be collected must be anonymized or aggregated at the level of multiple individuals so that traceability to individuals is not possible. Employees should be involved before the new systems are introduced. They should be provided with comprehensive information about the reasons for and the capabilities of the new technology. When the system is in use, employees should also have access to the data and be able to use correction and comment functions. If necessary, a shutdown or delay function should be considered to give employees more control. In the context of wearables, it must be examined which data can be processed directly on the device and which must be forwarded to centralized systems, especially in the case of systems that record sensitive and body-related data (e.g., health data).

4 Summary of specifications and user requirements

In this document, the main user requirements and the specifications of the overall technologies to be used in the HumanTech project have been elaborated. In addition, aspects of data protection and the associated ethical conditions were explained. The research conducted shows there is already a large number of regulations and specific user requirements that must be considered. The detailed findings should be used to specify practical application scenarios in the later course of the project.

The findings from the analysis of the European construction industry summarize the socio-demographic aspects of the employees, as well as the technologies already used and the working conditions. Table 1 shows the five essential aspects of the analyses.

Table 1: Key findings for the European construction industry

Findings from survey data		Implication for technology design
1.	Employees older and predominantly male	
2.	Smartphones established	Smartphone usable as a possible platform for applications
3.	Rough working environment	Technology should be resilient against heat, cold, draught, dirt etc. and shock resistant

4.	High level of physical demands and risk of accidents	Technology should not hinder movement or perception
5.	High pressure and unstandardized working tasks	Technology should be fast and easy to use, applicable in different subtasks and body postures (e.g. standing on a ladder or crouching)

The design recommendations summarized the requirements of robots, exoskeletons, and smart glasses. The specific technologies were explained, their possible areas of application described and the existing regulations described. Although the technologies presented are still relatively new and in some cases standards for safer application still need to be developed, there is already a great deal of knowledge available. On the one hand, findings from pilot project can be used to specify the requirements, and on the other hand, general regulations can be applied. The interaction principles as described in EN ISO 9214-110 are applicable for human-technology interaction. While they can be applied to a wide spectrum of interactions they have to be applied with the specific characteristics of the technology and workplace in mind. Furthermore, the importance of individual interaction principles can differ between technologies. Table 2-4 summarizes the key findings of robots, exoskeletons, and smart glasses and how they might be considered in the HumanTech project. It should be noted that not all aspects of the technologies have been listed. Detailed recommendations can be found in the individual chapters of the respective technology.

Table 2: Key findings for design recommendations for HRI

Findings from research		Implication for technology design
1.	Robotic autonomy is increasing	Human-robot interaction should follow the „human-in-control“ principle
2.	Non-flexible coupling between human and robotic performance can have adverse effects on employees.	A cobots utilisation and pace should be adjusted to fit the operator, not the other way around.
3.	Advanced robotic systems allow for novel forms of human-robot interaction.	To create human centred interaction with robotic systems guidelines like the ISO 9241-110 “Interaction principles”, and the user’s level of expertise with robotic systems should be taken into account.
4.	Advanced robotic systems can be used in a variety of environments and tasks that can affect how they can receive input.	Communication channels in human-robot collaboration must fit both the task and the work environment

5.	Advanced robotic systems come with new sensors and abilities to perceive their environment	Employee's right to privacy must be preserved.

Although there is currently little evidence on the effectiveness of exoskeletons, there are recommendations that can be considered based on existing regulations, guidelines, reports and preliminary findings from research. Table 3 summarizes key aspects of exoskeletons and what should be considered when using them.

Table 3: Key findings for design recommendations of exoskeletons

Findings from research		Implication for technology design
1.	Exoskeletons are barely used in industrial workplaces	Iterative screening of expectations and acceptance by employees as well as careful integration planning
2.	Dynamic working environment and large variety of applicable tasks	Exoskeletons should be easy to store and use, time for donning and doffing as well adjustment needs should be minimized
3.	Rough working conditions	Exoskeletons should be durable when facing rain, dirt and extreme temperatures
4.	High risk for rejection because of movements restriction, pressure points and decreased productivity	Exoskeletons should be as light and unobtrusive as possible
5.	Decreased usability and reliability through immoderate battery support	Exoskeletons should be provided with lasting batteries or easy replacements

Table 4: Key findings for design recommendations of smart glasses

Findings from research		Implication for technology design
1.	Visual fatigue can occur in long-term use	Frequent short breaks are recommended during which employees can take off the technology
2.	The technology is more accepted if it can be adapted to individual needs.	Smart glasses should offer the possibility of easily adjusting (e.g. contrast, sharpness and luminance)
3.	Incorrectly used smart glasses lead to higher stress in the long term.	Employees should be introduced to the technology in detail. Especially older employees should be demonstrated all the setting options.

4.	The weight and balance of smart glasses has an impact on strain and acceptance.	Smart glasses should be as light as possible, but also evenly balanced. Older employees in particular react to uneven weight distribution with compensatory muscle activity.
5.	Smart glasses do not promote movement. Rather, especially wired models lead to a fixed head posture with the risk of muscular tension.	Smart glasses should be avoided in workplaces with forced postures. If not otherwise possible, models with maximum possible freedom of movement should be used.

With regard to data protection, it should be determined at an early stage which data will be collected, by whom and in what form. Particularly in the HumanTech project, where many technologies are used simultaneously, a clear data processing is important. Transparent handling of the data is essential. Employees should never have the feeling that they are being monitored by technology. The feeling of surveillance can be a negative influencing factor. Accordingly, employees should be involved as early as possible. Data collection should always be critically evaluated against the background of the EU General Data Protection Regulation (EU-GDPR).

This all leads to our ethical approach:

When integrating new technologies into the workplace, it is particularly important to involve employees at an early stage of the planning process. Here, concerns can be addressed and misunderstandings clarified. An iterative evaluation process can be used to document the changes. Furthermore, a proper Task-Technology-Fit is essential. For this, the work task should closely examined before a specific technology can be selected. Current findings in the field of human factors must be taken into account. Moreover data transparency and the consideration of the EU-GDPR substantial. Accordingly, the collected data should only be recorded to the extent needed for the evaluation.

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