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Review

Innovative Technologies for Occupational Health and Safety: A Scoping Review

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Abstract: Technological advancements have allowed for the design and development of multiple intelligent devices that monitor the health and safety status of workers in the industry in general. This paper reviews and describes the alternative technologies and their potential for monitoring risk situations, vital signs, physical variables, worker positions, and behavioral trends of workers in their work activities in the workplace. A scoping review was conducted using PRISMA ScR in which information was extracted from 99 scientific articles related to these technological advances. The operational characteristics and utilities of devices whose primary function is to control better and monitor worker safety and health were identified. It was concluded that technology strongly improves the acquisition and sending of information. This information can be used to provide alerts and feedback to workers so that they act more safely and protect their health. In addition, technological developments have resulted in devices that eliminate operational risks by replacing manual activities with automated and autonomous tasks.

Keywords: technology; scoping review; portable device; safety; health; risk

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1. Introduction

Currently, workers in many industries are exposed to diverse risks that can be avoided by implementing new technologies that contribute to their health and safety. Despite the implementation of workplace safety measures, the level of mortality remains considerable. According to the International Labour Organization (ILO), approximately 2.3 million people, both men, and women, die each year due to work-related accidents or diseases worldwide. This translates into more than 6000 deaths every day. About 340 million occupational accidents and 160 million cases of work-related diseases are reported annually worldwide [1]. According to several systematic reviews (SR) there are many technologies available to monitor people's health. Some of these technologies include wearable sensors, fitness tracking devices, heart rate monitors, sleep monitors, and mobile apps that allow users to track their health and well-being, allowing medical professionals to monitor and diagnose diseases more accurately and effectively [2]. Despite the advances in portable devices for occupational health and safety, there is no comprehensive review of the use of these technologies in industry and their benefits [3].

This article describes the possible technological applications for better control and monitoring of occupational health and safety in the form of a systematic review in accordance with the PRISMA methodology guidelines.

The developments described in the scientific literature include contributions from fields of knowledge such as nanotechnology, robotics, data analysis, video, and telecommunications. These technological solutions provide more data that are obtained with greater accuracy and speed. The information provided by these technologies allows us observe aspects such as physical stress levels, physiological variables, and levels of exposure of workers to risks during their work activities [4].

In the last decade, technological developments to promote occupational health and safety have led to the use of systems such as building information modeling (BIM), radio frequency identification (RFID), and augmented reality (AR) technologies to improve occupational safety in the real estate and construction industries [5]. The present paper shows some of the alternatives and developments in the last ten years that contribute specifically to the field of safety in terms of health monitoring and situations that involve risks for workers, as well as health solutions that allow control of the actions of workers and contribute to stable health situations while performing routine work tasks.

In addition to the portable and wireless devices presented in this review, multiple robotic systems have been demonstrated that assist or supplant workers in performing tasks that generally involve risks, as in the case of work at height.

2. Materials and Methods

A systematic review of scientific articles was carried out following the guidelines of PRISMA-ScR [6]. Appendix A presents a list proposed by PRISMA-ScR that indicates the number of pages that meet or do not meet the 22 criteria described in the seven sections of the SR, including the title, abstract, introduction, methods, results, discussion, and financing. The review can be visualized in an Excel format within the document [7]. For this review, we used the following search keywords: Technologies, Safety, Health, and Work. The IEEE, PUBMED, Web of Science, SCOPUS, and Science Direct repositories have been considered. We considered journal articles and conference papers of the last ten years related to engineering and health. In addition, a manual search of the scientific literature was carried out in other search engines, such as Scilit, and scientific dissemination pages, such as the scientific research repository of several universities and institutes in which occupational health and safety issues are developed.

Although the PICO [8] criteria and the PRISMA [6] checklist have different purposes, they are related to systematic research. The PICO criteria are used to define and structure research questions, while PRISMA guides how to report the results of a systematic review or meta-analysis appropriately. Using both approaches facilitate the conduct and communication of evidence-based research.

The reference information for the development of this work considered the answers to the following questions: RQ1. What occupational health and safety areas benefit from using and developing new technologies? RQ2. What new technologies have been developed in the last five years to support occupational health and safety? RQ3. What advantages and/or benefits does the use of these new technologies provide in occupational health and safety? RQ4. What limitations, drawbacks, and problems can be found in using and implementing new occupational health and safety technologies?

The quality and relevance of the articles considered as a reference for the development of this article were evaluated. Five Question Assessments (QA) based on the PICO [8] criteria were used for the evaluation (Table 1).

Figure 1 presents the workflow of the systematic review, from which 99 documents were obtained and reference information was extracted to realize this article.

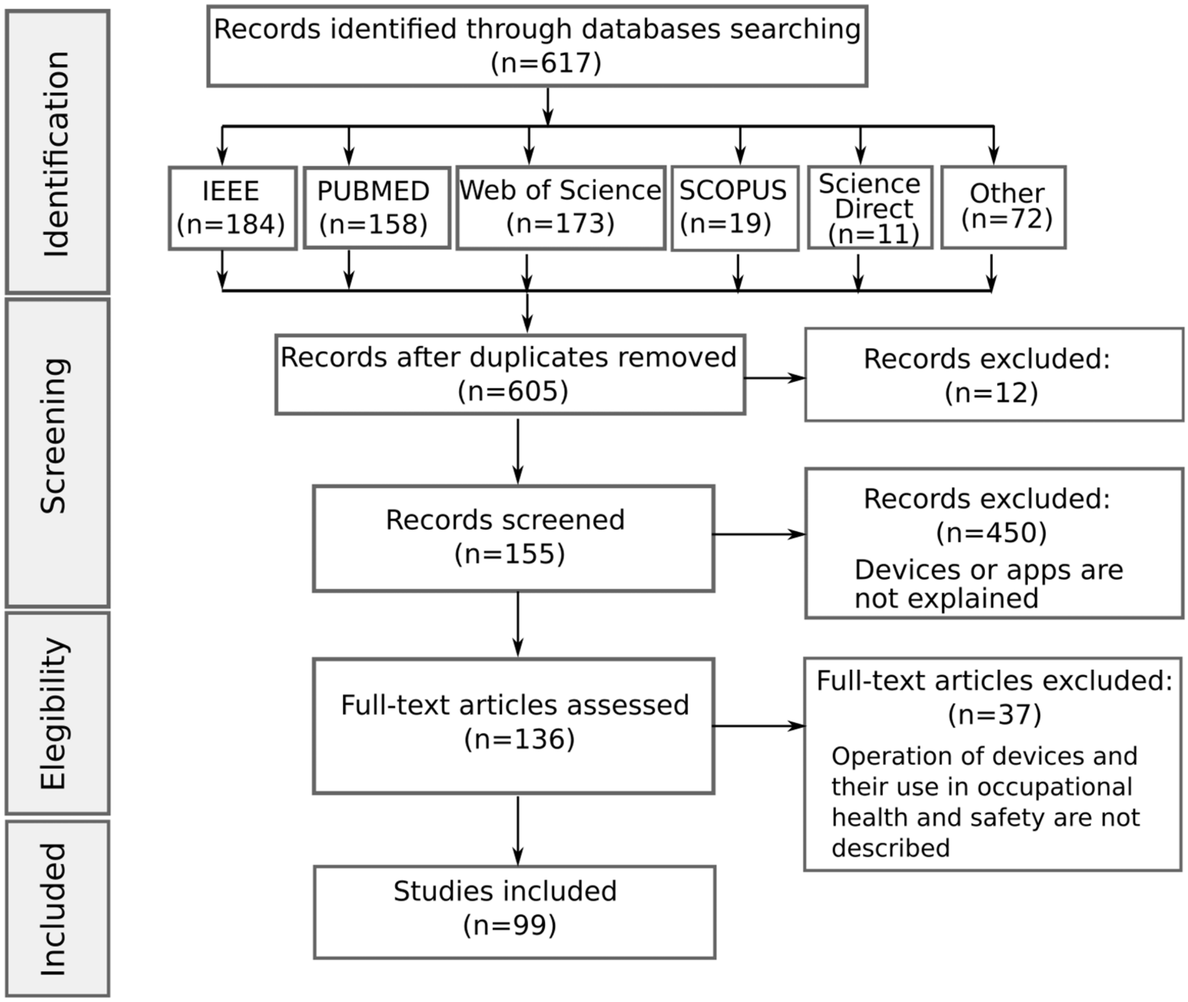

Figure 1. PRISMA flow diagram.

Table 1. Document quality assessment checklist.

N°	Quality Assessment Questions	Answer
QA1	Does the paper describe devices or technologies for safety and occupational health?	(+1) Yes/(+0) No
QA2	Does the document specify how technology improves working conditions?	(+1) Yes/(+0) No
QA3	Does the paper describe the principles and technical characteristics of the operation of these technologies?	(+1) Yes/(+0) No
QA4	Are the limitations of using these technologies described in the paper?	(+1) Yes/(+0) No
QA5	Is the journal or conference in which the paper was published indexed in SCImago Journal Rank (SJR)?	(+1) if it is ranked Q1, (+0.75) if it is ranked Q2, (+0.50) if it is ranked Q3, (+0.25) if it is ranked Q4, (+0.0) if it is not ranked.

The search of the databases which resulted in the reference articles for this work was carried out using the search terms shown in Table 2. The number of articles identified is indicated.

Table 2. Selected scientific articles and quality assessment outcomes.

Database	String Search	Studies Number
IEEE	[title: technolog *] AND [title: "occupational safety"] AND [title: "occupational health"]	184
PubMed	(("technolog *"[All Fields] AND "occupational safety"[All Fields]) AND "occupational health"[All Fields]) AND ((y_5[Filter]) AND (ffrft[Filter]))	158
Web of Science	search: technolog * "occupational safety" "occupational health"	173
Scopus	TITLE (technolog* AND "occupational safety" AND health)	19
Science Direct	Title, abstract, keywords:technology technologies "occupational safety" "occupational health"	11

The outcome of the quality control review of the selected articles following the procedure outlined in Figure 1 was assessed and normalized based on the criteria presented in Table 2 and calculated according to Equation (1):

$$Normalization = \frac{Score - minimum(score)}{(maximum(score) - minimum(score))} \quad (1)$$

3. Results

Multiple technological devices aimed at improving industrial safety have been designed and manufactured for placement in specific areas of the human body and workwear clothing. For example, monitoring systems of physiological variables obtain information from the human body and communicate it to peripheral devices for processing and statistical use. Other technological developments use robotic systems such as drones to perform tasks, thereby avoiding risks to operators in places with some risk indices. Exoskeletons contribute to the performance of tasks in a way that increases human strength by seeking lower-risk positions in the workplace. Systems with vision and artificial intelligence are used to identify objects, track them and understand the environmental conditions in which workers interact. These technological developments for both occupational safety and health are addressed below.

3.1. Occupational Safety Technologies

Figure 2 presents a classification of new technologies and applications that have been evidenced in scientific articles in the last ten years; their applications are briefly described by referring to the work activities of the industry. Portable devices provide a means to access required information, apply functions, process data, and transmit information to other devices, commonly by wireless communication [9]. Robotic and drone-based applications have been developed for occupational safety and both comprise systems with a base structure, sensors, actuators, microprocessors, and power supplies [10].

Safety applications are mobile applications designed to run on smart devices with touch screens that allow the entry of information and provide other helpful information for the user [11]. The use of immersive technologies such as augmented reality (AR), mixed (RM), and virtual reality (VR) allows the worker greater precision and efficiency in the identification of hazards, assisting them in the prevention of accidents and injuries at work. These technologies based on eye tracking provide an experience that increases user perception by incorporating computer-created scenarios [12].

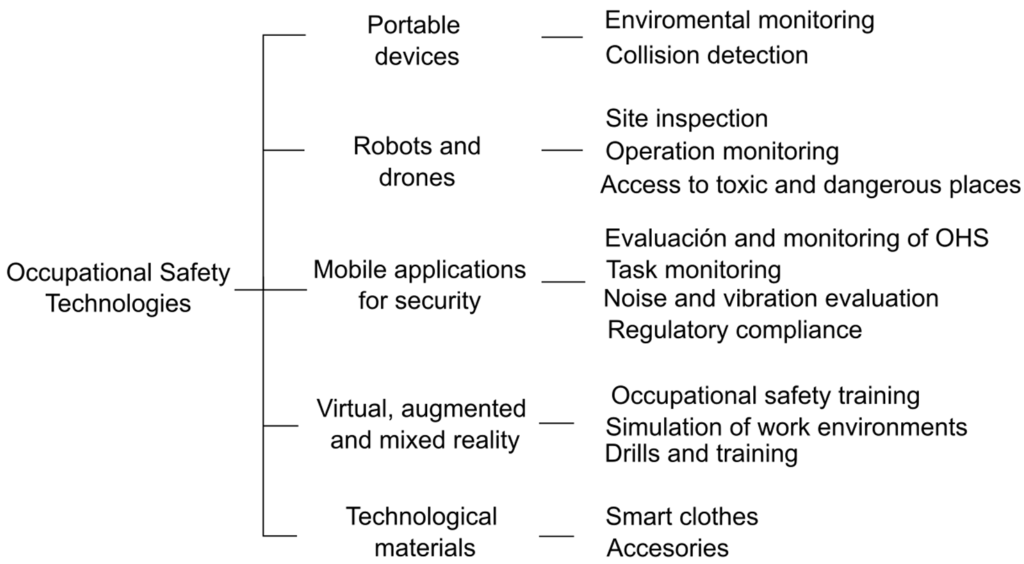

Figure 2. Occupational safety technologies.

The technologies presented in Figure 2 provide workers with tools to reduce the risks they are exposed to in performing their tasks.

Portable devices are well-suited for monitoring occupational safety due to their flexibility, speed, and accuracy in collecting information. Robots and drones can reduce risk and improve efficiency by enabling remote monitoring. Mobile applications for worker safety offer quick access to workplace information, education, training, constant communication, and real-time data logging. Technological materials that support worker safety provide personalized protection, enhance task performance efficiency, and decrease the risk of injury.

Technological devices for worker safety aim to reduce limitations and increase the ease with which tasks are performed. For example, autonomous mobile robots can facilitate driving vehicles through specific areas. When performed routinely by operators, these tasks are prone to frequent incidents as the operators are susceptible to fatigue and fatigue from repetitive tasks [13].

3.1.1. Portable Devices for Occupational Safety

With the technological advancement and growth of Industry 4.0, devices that monitor safety in the workplace have been adopted in various industries [14]. Multiple developments in wearable technologies have been employed to reduce worker mortality in today's industries [15]. Physical activity trackers monitor the real-time drowsiness of drivers and operators remotely using a smart device [16]. Vital parameters, such as heart rate, blood pressure, body temperature, and brain activity, have been transformed into information enabling the employer to understand the worker's performance from the physical point of view and make decisions to avoid risks for the worker.

Bright clothing has been developed with a technology that allows the automatic regulation of body temperature through a network of intelligent sensors attached to the fabric. The sensors measure the temperature of multiple areas of the body, and when they cool, the fabric is heated, providing heat in certain areas and thus keeping the worker's temperature stable when they perform operations in an environment with extreme cold [17].

Devices have been developed that monitor a worker's movements. These devices send a wireless alert in case of falls or sudden movements in case the worker requires immediate medical attention. These devices are intended to provide timely and critical medical attention to those in need and thereby enhance the overall safety and well-being of the workforce. This type of implementation is based on accelerometers sensitive to rapid changes in movement [18].

Smart bracelets allow the measurement of the exposure of a worker to the harmful factors that may exist in their work environment. In addition to monitoring the vital signs of the worker, such bracelets can detect a wide range of chemical materials whose presence can have health consequences due to risk of poisoning [19]. In addition, detection of environmental variables assists with understanding the type of protective equipment the worker should use.

Waterproof, shockproof, and dustproof intercoms that can be easily attached to clothing and a headset can be plugged into the worker's ear, facilitating communication between workers and eliminating the distraction factor of hand-held intercoms [20].

Intelligent helmets have been developed that use sensors to monitor a worker's movements and in the case of falls, provide medical attention with shorter response times. These devices measure the worker's linear acceleration and physical conditions by sending notifications to those responsible for industrial safety [21].

Figure 3 illustrates technologies developed to monitor variables contributing to industrial safety. Several devices have been designed to be incorporated into work clothes; in other cases, they are fastened with bands on the legs or arms, which are the parts of the human body that show more movement and, therefore, contribute to monitoring the movements made by the worker.

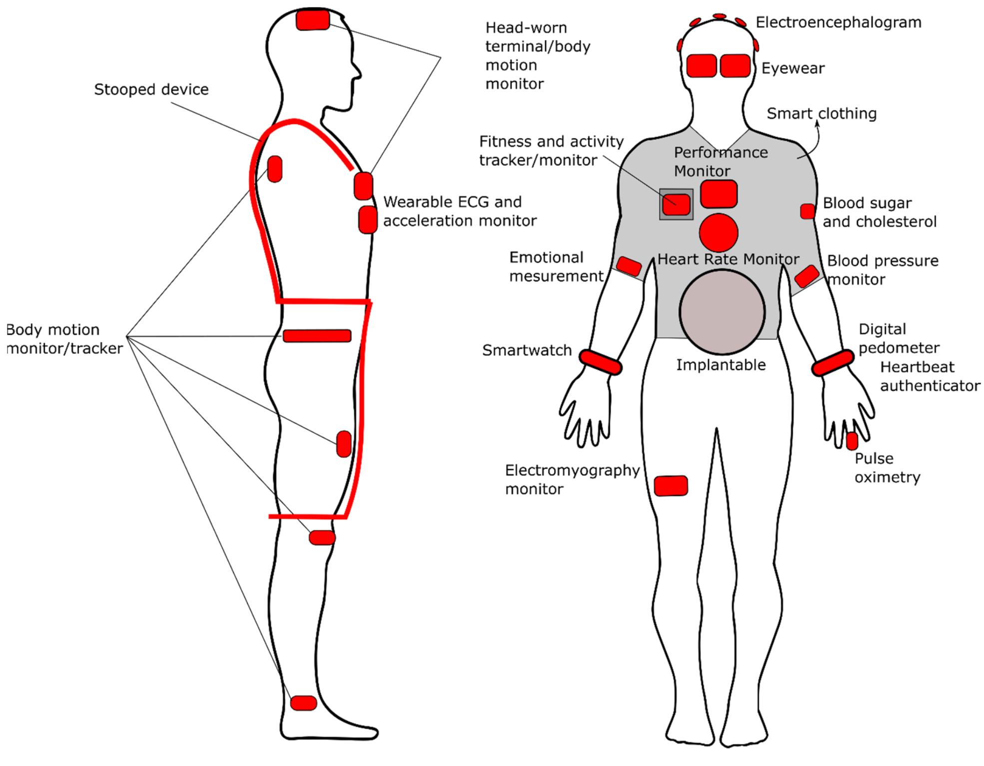

Figure 3. Portable devices for monitoring physiological variables and worker movement.

3.1.2. Robots and Drones for Occupational Safety

The use of drones in the industry is regulated in Articles 14 and 15 of the Law on Occupational Risk Prevention [22], which states that industry managers can consider using drones to monitor preventive activities to ensure the safety and health of workers. The objective of using drones is to exclude all human factors in the performance of tasks that may affect the risk to the safety and health of workers [23].

The construction industry is one of the most dangerous for its workers [24], and therefore, the incorporation of drones in the this industry has increased as they provide advantages in accessibility to remote places, lower costs, and greater efficiency in the tasks performed. Companies have benefited from replacing manual work with aerial technology to carry out activities in topography assessment, monitoring, progress tracking, surveillance, and inspection, which also allows visualizing risks that were previously unobserved, such as collisions between humans and the distraction of workers. Drones are also actively used for security planning and site monitoring, offering high-quality photographic and video surveillance [25].

In open field work, drones are used for operations at high altitudes, over water in rivers or oceans; they can even be introduced and operate underwater [26]. This technological alternative makes it possible to reduce and eliminate hazardous operations for humans. Using drones increases the quality of the data retrieved and contributes to the monitoring process in the oil and gas industry, as is the case in Norway [27].

For tasks such as monitoring pollution and its environmental impact, some systems use drones to transport sensors that measure different air components at regular intervals [28]. In addition, some solutions utilize drones to detect toxic gases, facilitating the task of delimiting safe areas or perimeters [29].

In their production activities, some companies use structures of a considerable size such as oil storage tanks, large transmission towers, photovoltaic energy systems, and oil pipelines and related infrastructure. Drones can be used for the inspection and evaluation of such infrastructure, avoiding the need for workers to carry out these activities in places that involve risks of falling. Measurements using thermography techniques to find cracks in tanks or structures are currently carried out by drones [30]. Additionally, since 2014, drones have also performed inspections of electrical infrastructure, buildings, and urban planning [31]; in addition, they can be used to visit toxic, contaminated, or radioactive environments. Figure 4 presents some of the most common drone operations used in some countries for visual inspection of structures.

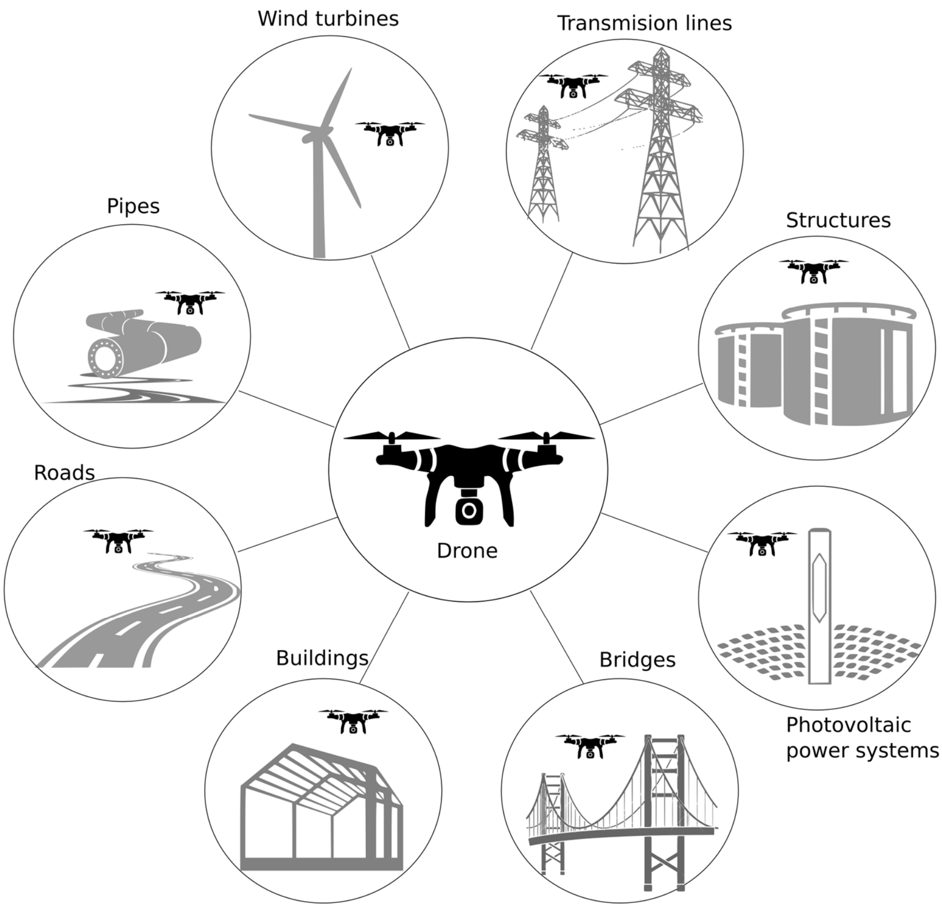

Figure 4. Inspection operations in places of risky access for humans.

Figure 4 describes some situations where drones are already employed for routine tasks in some industries [32]. The most common tasks performed by drones include the visual inspection of the state of the parts of the structures, measurement of the quality of materials through infrared spectrum vision, inspection of the state of pipe networks, and the operation of wind and solar systems. In addition, some systems facilitate monitoring forest areas and generate alerts in cases of fire or any abnormal events that could put inhabitants and workers at risk [33].

3.1.3. Occupational Security Applications

For workers to complete their tasks more efficiently and safely, some glasses allow viewing of live information, documents, work procedures, and health and safety information. In addition to this, they facilitate evacuation and rapid emergency activities by locating workers in the plant and dynamically guiding them to a safe point through geolocation technology [34]. In such systems, assistance is provided to people who require attention by sending their location to specialists and automatically requesting the support of the emergency team.

Some applications run on the IOS and Android platforms and have been designed for mobile devices or smartphones. One of these applications is First Aid, which cooperates with the American Red Cross and directly connects with the 911 emergency service [35]. These applications provide expert information and step-by-step instructions so that workers and managers can quickly and efficiently address setbacks, accidents, and serious injuries that may occur [36–40].

Heat can be a significant risk in some countries and at certain times of the year, so there is an application that allows workers and supervisors to calculate, according to weather conditions, the levels of risk to the health of workers. The application generates alerts about the use of protective equipment, taking breaks, and drinking water. This application is based on the Occupational Safety and Health Administration (OSHA) criteria proposed for heat safety tools [41].

One of the most frequent workplace risks occurs due to the misuse of ladders; therefore, an application has been developed that provides information to the worker on how to position the ladder safely using visual and sound signals [42,43].

To mitigate fatigue among employees who engage in prolonged periods of sitting, an application specifically designed for iPhone mobile devices has been developed to provide information and alerts. This application reminds its users to take regular breaks and provides stretching exercises tailored to their job's demands. [44,45].

Another application allows workers and managers to determine daily the condition of machines. The operator uses a checklist that also avoids sanctions and infractions [46], making it possible to reduce the risks resulting from operating machines in poor condition.

The lifting of loads of considerable weight can be made safer by using an application designed to calculate slings and lifting elements according to their resistances. The application also requires the approval and confirmation of those responsible for these loading operations [47,48].

Some applications measure noise levels in decibels to reduce the risk posed by noise levels above the established limit of 60 dB [49]. There are also informative pocket guides adapted for intelligent devices that provide information on risks resulting from the proximity of chemical agents. First responders use applications of this type to identify and protect personnel [50].

The physical fatigue that workers can suffer is scored with the help of mobile phone applications. This score helps identify the type of risk to which they are exposed and allows managers to assign tasks more efficiently or stop the work of certain operators if the risks are considered high. Such applications greatly assist when there are many remote workers [51].

3.1.4. Virtual, Augmented, and Mixed Reality for Occupational Safety

The development of technologies in virtual reality (VR), augmented reality (AR), and mixed reality (MR) has opened many possibilities in the field of occupational safety. In addition, given the current regular use of mobile and smart devices with accessible costs, VR, AR, and MR applications are widely available and easily accessible [52].

According to experts, three leading causes influence the injuries of machinery operators: inadequate training, insufficient work experience, and the monotony of repetitive tasks. Solutions have, therefore, been developed to reduce error rates and prevent injuries [53].

AR systems have been demonstrated which allow the simulation of multiple situations related to occupational safety to recreate certain risks and understand the operator's decision-making speed. In addition, AR systems have also been developed to facilitate the training tasks of workers. AR applications that support the performance of equipment maintenance provide technical information to eliminate the risks that may occur during these activities. The application guides the operator in the steps to be taken to provide suitable maintenance to specific machinery [54]. Such systems replace manuals and facilitate the realization of activities reserved for experts while ensuring safe conditions in performing these activities.

Training using AR applications provides virtual guidance for processes within the industry environment. The applications can also place information in the worker's vision so that they do not easily omit instructions that may cause situations of risk to their physical and emotional integrity [15]. The worker can simulate the performance of activities, which can be analyzed, and thereby learn and avoid future accidents [55].

Applications have been developed to facilitate access to information on security processes, risk identification, and safety information in utilities, manufacturing, and construction industries. These applications support frontline workers by alerting them to risk areas using augmented reality [56].

There are developments aimed at supporting evacuation processes. In an emergency, maps with dynamic indicators are projected in the visor worn by workers to guide them to most appropriate path and evacuate people from the danger zone.

Table 3 shows the developments that have been applied in industry with good results. The table includes the field of application, a description, and the benefits reported in its use according to the respective bibliographic sources.

Table 3. Several advances in VR that are employed to improve worker safety.

Application	Field	Description	VR Benefits Reported	Year
Immersive virtual reality for training and decision making [57]	Chemical	Creation of an accident scenario to test VR-based training for decision making	Improve operator responses time and accuracy of actions	2014
Virtual reality simulation technology for military and industry skill improvement and training programs [58]	Energy	VR-based training for machinery in oil and gas rigs.	VR was shown to be an effective method of training due to the enhanced sense of scene realism.	2014
Virtual reality-based pilot training for underground coal miners [59]	Mining	Evaluation of virtual reality training for underground coal mining	Users considered the VR training a helpful program. Miners reported positive effects of the VR training as long as three months after the training session	2015

Table 3. *Cont.*

Application	Field	Description	VR Benefits Reported	Year
Virtual reality simulation for construction safety promotion [60]	Construction	Testing the use of VR to increase construction safety	Demonstrates the development and utilization of a training program based on VR. The training program can offer a safe working environment where users can effectively rehearse tasks with electrical equipment common in the construction industry.	2015
A social virtual reality-based construction safety education system for experiential learning [61]	Construction	A VR environment was used as an educational way to train in safety in construction work	VR platforms showing social/collaborative situations can improve construction safety as well as health education.	2015
Operator training simulator for biodiesel synthesis from waste cooking oil [62]	Chemical	Testing a training scenario for the process of homogeneously catalyzed biodiesel production. Various malfunctions were included in the scenario.	A complex scenario where realistic malfunctions are included. It can be beneficial for training operators, enhancing the learning curve.	2016
Virtual reality-based application for safety training at shipyards [63]	Nautic	This development simulates immersive training using portable fire extinguishers, fire drills, and confined space hazard observation.	The result showed that safety training used in virtual reality could improve knowledge of occupational safety theory by 14.05%.	2022
An evaluation of virtual reality for fear arousal safety training in the construction industry [64]	Construction	Provision of safety training focusing on job site simulation for hazard identification, demonstration of safety practices, and knowledge-based safety testing.	It was demonstrated empirically that training in safety and situations with the excitement of fear in VR improve the safety attitudes of construction workers, subcontractors, and employees.	2021
Incorporating virtual reality technology in safety training solutions for construction sites of urban cities [65]	Construction	Immersive and interactive training platforms based on multiplayer mode and incorporating virtual reality (VR) technology to improve workers' safety awareness. The developed simulation platform is a training solution providing repeatable and flexible procedures within a secure environment.	Results indicate that workers were better trained under the developed immersive environment and could memorize critical points more effectively because VR technology can allow people to experience dangerous situations without being physically injured, thus creating a safer and more efficient training environment.	2020

3.1.5. New Materials for Occupational Safety

Multiple nanomaterials have been developed that are currently used in various forms and compositions in industrial protective clothing fabrics to contribute to the prevention of occupational risks [66].

Smart textiles address challenges such as the need for sensitive permeability, which can be developed using shape-memory polymers, polymer gels, superabsorbent polymers, grafted polymer brushes, and polymeric ionic liquids [67]. Advances in nanomaterials enabled the development of new properties and applications in the textile area. Some industries research and develop new alternatives in finishes for textile materials, providing them with hydrophobic, antimicrobial, self-cleaning properties, as well as a multifunctional character, by using a sol-gel and manufacturing them with advanced inorganic material processes [68].

Some newly developed materials employ particle retention mechanisms such as those shown in Figure 5 [69]. Smart textiles can use a variety of particle retention mechanisms, such as filters, electrostatic charges, hydrophobic surfaces, and chemical treatments, to improve worker protection against suspended particles in the workplace environment.

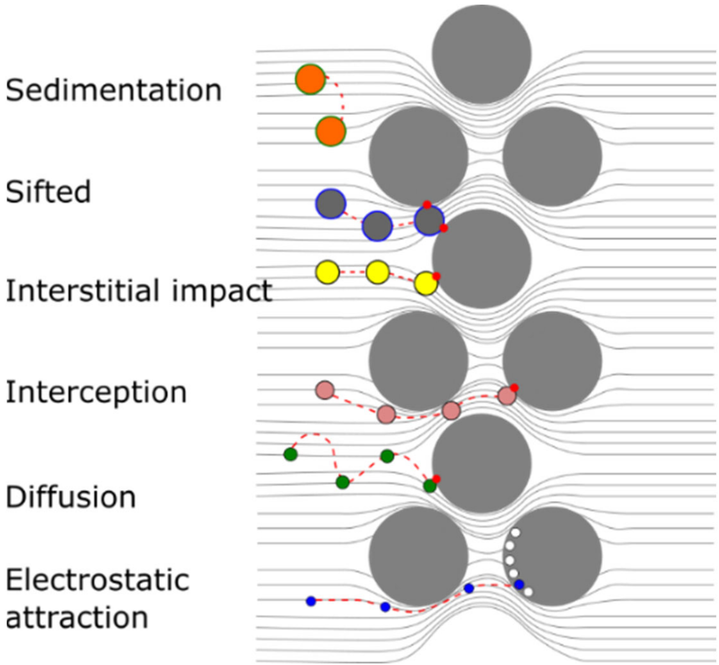

Figure 5. Particle retention mechanisms.

Figure 5 shows several mechanisms of particle retention. Depending on the characteristics of the particles to be retained, one or more mechanisms must be employed. Thermal comfort can be improved by generating materials that provide thermal comfort by manipulating the material phase change.

The effectiveness of a worker's protective helmet depends on the type of material from which it is manufactured; the use of materials such as hybrid fibers that offer better performance and mechanical properties has been proposed [70].

3.2. Occupational Health Technologies

Considering the development of health technologies, Figure 6 shows a classification of the most evident advances. Similar technologies proposed in the classification in Figure 1 have been adapted to support preserving worker health. It is highlighted that the technologies addressed in this section monitor, affect, and ensure health and well-being during the workers' activities in the industry.

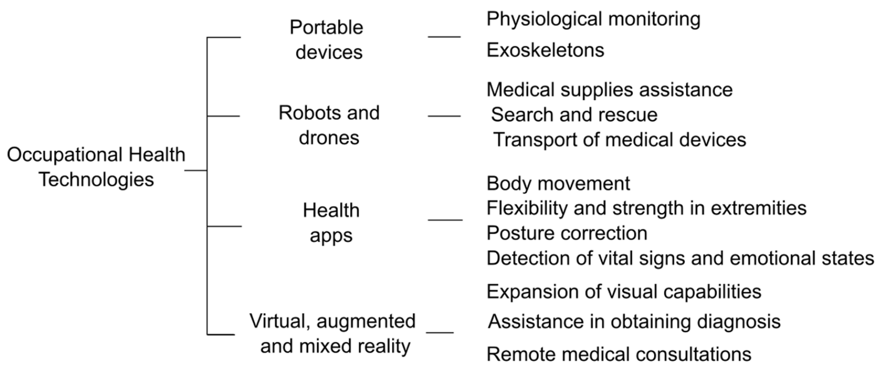

Figure 6. Occupational health technologies.

Regarding Figure 6, portable devices can measure physiological variables and act to regulate or maintain health without significant alterations. Exoskeletons assist by ensuring that the physical force performed is not excessive and that the postures are corrected, resulting in less fatigue and wear on joints. Robots perform assistance tasks with supplies, devices, and rescue actions. Health applications provide information and alerts. Finally, VR, AR, and MR technologies help in diagnostic processes and medical consultations.

3.2.1. Portable Devices for Occupational Health

The use of portable devices to promote health in the workplace has become more frequent, even though they have been considered toy-type technologies in some cases [71]. Considering health monitoring, one of the developed technologies incorporates sensors in watches to monitor the heart, sleep habits, and stress levels so that in unusual situations, an alarm can be launched to ask for help [72]. Solutions exist to monitor the position of the back when stooping outside of set limits [73]. Stress is also considered in these portable devices which are worn next to the clothes used. Such devices can measure breathing and heart rate to estimate the stress level and are in the form of washable labels adaptable to underwear and sleepwear [74].

The metabolism of a person or worker can be estimated by devices using information about the human body's processing of fats, carbohydrates, and proteins. Devices of this type analyze the breath exhaled after inhaling and holding the air for 10 seconds, and these devices have connectivity with smartphones [75].

3.2.2. Robots and Drones

In occupational health, there is a so-called "emergency drone," designed to support the tasks of saving lives in cases of medical emergency due to accidents; these devices are used for rescue tasks. This type of drone can reach the site of an accident in a few minutes and connect the injured person with a paramedic through a video camera connected to a control room with a live stream camera. The operator is able to speak, observe and give instructions to the victim of a work accident [23].

Technologies for safety and health are becoming more widely used in companies every day, constituting a strategy to improve occupational safety and health conditions. This benefits the workers, enabling them to work more flexibly with reduced stress [76]. In addition to increasing a worker's ability to adapt to the new demands of work systems, the stress level is managed by eliminating routine and tiring jobs [77].

When it comes to health care, drones perform tasks such as delivering life-saving products, vaccines, and blood packets [78,79], providing better access to rural and remote regions. Drones can also reach their target by alternative routes with less impediment than ground vehicles, thereby improving response times in providing help to people requiring it.

Drones allow survivors to be found after natural disasters and even provide care in emergencies [80]; in addition, drones have been used to support situations such as of out-of-hospital cardiac arrest by transporting defibrillator equipment promptly [81]. For rescue tasks in the case of missing people in deserts and snow, drones are an efficient alternative aid response [82].

Contributions in the fields of robotics, biomechanics, and informatics have allowed the development of exoskeletons, whose use in industry has been growing in recent years. Exoskeletons facilitate a comfortable interaction between the human and the robot, thus assisting the worker by allowing them to perform activities with reduced mechanical demands on the human body [83]. Some developments are considered essential to support workers in handling heavy loads, even though the efficiency of exoskeletons still has much scope for study and much more objective and operational information is required [84].

Advances in exoskeletons [85] have been designed to reduce the risk of low back injury, although their effectiveness has not been evaluated. However, the developed technology has been shown to reduce chest and back tension when workers lift loads of considerable weight and when performing other load movements that affect the tension in the lumbar area [86]. The increase in physical skills provided using exoskeletons eliminates the risks of musculoskeletal injuries in the performance of physically forced operations.

Figure 7 shows the categories of exoskeletons according to their kinematic structure and depending on the actuators they possess. Within the first category, rigid exoskeletons consist of articulated structures of mobile links. In contrast, the second category includes sets of flexible elements that provide a certain degree of elasticity in some moving parts of the body to redistribute efforts and improve the mobility of the operator's limbs. Non-anthropomorphic exoskeletons possess structures that do not align with human anthropology [85], while anthropomorphic exoskeletons better fit the human form.

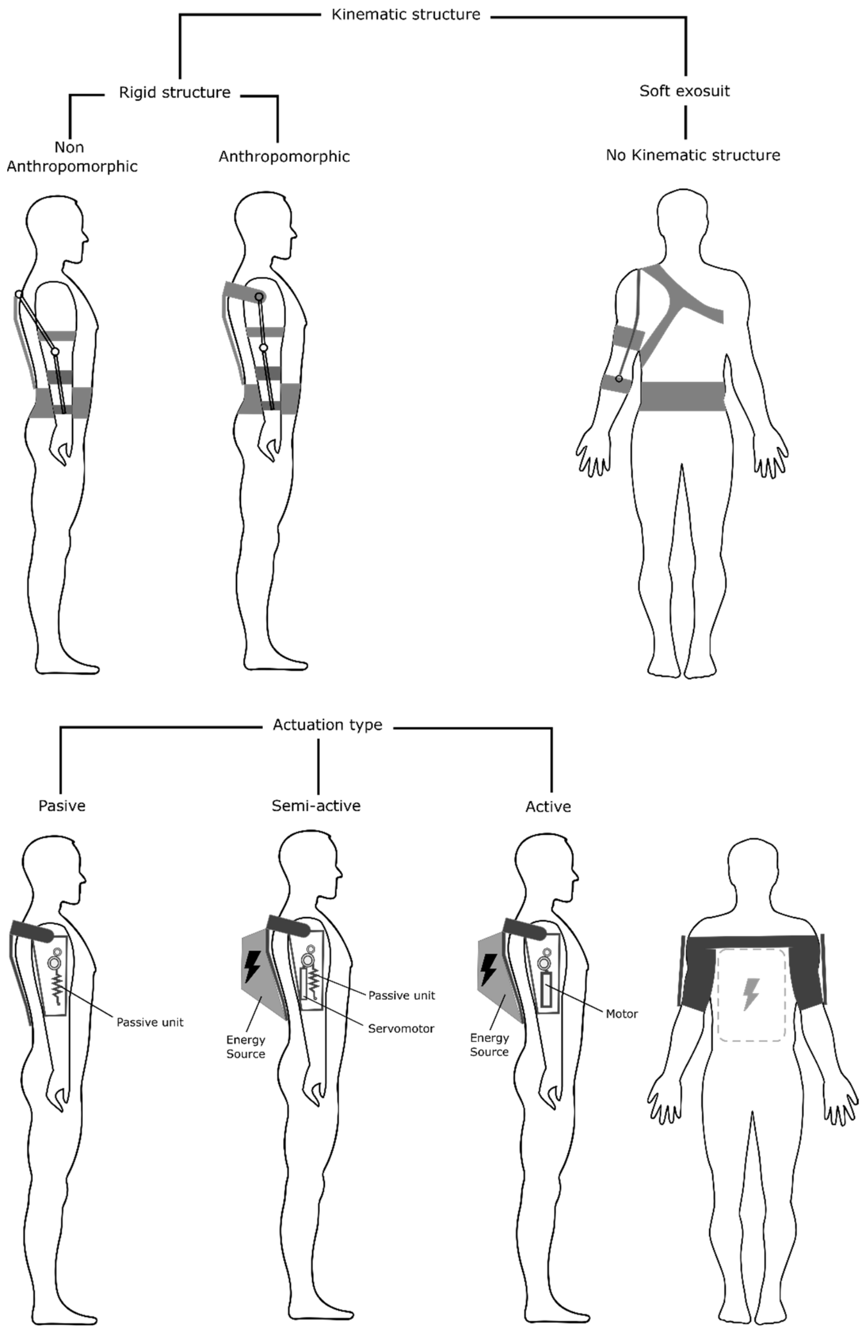

Figure 7. Types of exoskeletons depending on the actuators and the type of kinematic structure.

Concerning the type of actuator, in the case of passive actuators, mechanical springs allow elastic recovery of the limbs, avoiding the realization of significant efforts in the sense of preferential movement. In the case of semi-active exoskeletons [87] that use servo motors and passive actuators, the first performs a force in one direction while the passive actuator recovers the original position. An active exoskeleton [88] uses a motor that allows movement in both directions, which, despite adding a more significant advantage, also provides a greater weight in the structure that must be more rigid to withstand the efforts. The active and semi-active exoskeletons include an energy source to power the motors or servo motors.

3.2.3. Health Applications

Some technological alternatives, most of which have been designed for use with cellular devices, aim to improve worker health [89]. These applications allow the user to receive information or a series of instructions, alerts, and signals related to their health care when they experience situations that affect their ergonomics [90] and stress [91] or perform repetitive actions that lead to a deterioration in their health. Some devices use artificial vision systems to detect an increase in body temperature, a symptom directly related to infection by the SARS-CoV-2 virus [92]. On the other hand, some applications create flexible work routines [93], automatically reducing the worker's stress levels and improving their mental and physical health.

For structured environments in which there are fixed positions in the activities of workers, technologies based on the use of artificial vision manage to identify basic emotions such as joy, sadness, fear, disgust, surprise, and null emotion or contentment. These emotions and combinations of these stress levels can be determined as proposed by [94].

The work of [95] presents an application to support workers' mental health, ensure good performance and improve their work environment. An application called "Blue Dot" was designed to provide training and considers the opinion of workers anonymously, allowing them to be heard and establishing actual data on the mental health situation of workers [11].

A vast array of applications has been developed to support the health of workers; one of these promoted by Google is "Workers Health," which is an application that facilitates the management of workers' occupational health in a responsible way. It collects information about whether the worker is on vacation, sick, or presenting with any symptoms. This application allows employees to complete a digital questionnaire as a self-certification so that the company administrator can finally identify those cases representing a risk of contagion and implement preventive isolation within the workplace. This application allows the employer to gather workers' information confidentially and coordinate with the occupational doctor [96].

3.2.4. Virtual, Augmented, and Mixed Reality

Stress is also an area of interest for the development of solutions employing augmented reality viewers, such as the work presented in [97]. This study evaluated a virtual reality application and the use of VR glasses aiming to provide peace of mind for workers who provide medical care, and the technology was observed to provide short-term benefits. These immersive experiences were also evaluated during the pandemic, with changes in feelings of anxiety, emotional distress, cognitive function, and self-efficacy being observed [98].

Some applications use augmented reality (AR) glasses to project three-dimensional representations of a patient's anatomy, the images of which help improve the surgeon's accuracy and surgical outcomes [99]. Some developments, such as that proposed by [100], study the implementation of virtual reality technologies to assist people in rehabilitation processes in which caregivers and rehabilitation doctors are active participants in the development of the user-centered design.

The field of health has been and will be strongly influenced by developments in AR which allow doctors to considerably improve their capabilities in performing diagnoses, treatments and surgeries. In addition, AR can greatly assist in training processes in medical areas [101].

4. Discussion

Technologies strongly influence all aspects of the workplace. Based on this review, there is a tendency to generate new technologies linked to wireless communication and some devices, such as drones, provide much more information than conventional safety and health systems [23,24,29,30]. Variables not previously considered in safety assessment processes for industries include worker interference and collisions [27] and the tendency for workers to transit through specific preferential sectors according to their criteria.

There is a strong dependence on mobile devices to execute applications that have sometimes been perceived as toy devices [71]. Despite this, they fulfill relevant tasks according to their industrial applications and work type. With time, applications tend to be more accepted because they allow the more rapid completion of tasks and the possibility of automating specific tasks quickly and with little programming knowledge.

An extensive literature exists on numerous developments, both commercial and experimental in nature. These include prototypes generated in academic settings by engineering students. Because the existing technology is adapted in low-cost developments, the results expose limitations and ranges of operation that sometimes result in these developments being perceived as unhelpful when applied in occupational safety.

Regarding research question RQ1, manufacturing is one of the areas most reliant on technology to improve its work environment and conditions. However, many identified developments correspond to tasks performed under extreme conditions such as low and high temperatures.

Considering RQ2, mainly articles describing the development of wireless devices that monitor worker posture with feedback to contribute to their safety conditions were found. In Figure 8, the variety of technological developments can be seen in the word cloud generated from the keywords of the reviewed works. Artificial intelligence, virtual reality, real-time systems, big data, approach to using and incorporating human factors, training, and occupational safety management are highlighted. In addition, computer science, robotics, automation, and machine learning have found applications in areas such as construction.

Figure 8. Word cloud of keywords in reference articles (made with StartLapes v3.5).

Addressing RQ3, the wide variety of devices considered in this review provide several benefits, including improved safety conditions at work, more effective training of new workers using virtual media and simulators, better real-time monitoring of worker health status, increased worker efficiency, cost savings on accidents for the company, greater hands-free operational freedom (as several wireless devices can be easily adapted to the worker's garments), improved communication quality, and enhanced data collection capacity for analysis.

Regarding the contributions of these technologies to occupational safety, they include solutions which involve monitoring the work environment and physical working conditions [14–19,28–31,49–51], communication support [20,21,34–40,56,57,61], workplace inspection [25–27,42,43], task monitoring [23,33,44–46,58], occupational training [15,53–57,59,62–64,66], and protective clothing [67–70].

The most frequent occupational health and safety benefits are facilitated by physiological and vital signs monitoring [72–74,76,77,93,95,96]. Additionally, benefits are obtained through devices such as exoskeletons and robots [23,83,84,87,89]. Other devices support medical assistance and rescue [80,82,98], transport of medical implements [78,79,81], and medical diagnoses and consultations [90–92]

Responding to RQ4, limitations in the use of these technologies include worker resistance to the use of such technology, the uncertainty generated by its use, safety and privacy of data, the implementation cost of new technology, compatibility of devices with flexible worker tasks, cybersecurity risks, and the difficulty of integrating new technology with existing systems and processes. These technologies have been considered toy-type technologies in some cases [71], which has made their implementation by workers difficult. A negative aspect of using these technologies is that dependence on technology may cause workers to neglect their safety when they place all their trust in devices, thereby reducing their care.

Implementing electronic monitoring devices in the workplace can have several benefits for improving worker safety. These devices can automatically detect when workers are not wearing proper safety equipment or are performing dangerous tasks. When a dangerous situation is detected, the devices can alert workers and supervisors, which can help prevent injuries. They can also provide valuable data to improve workplace safety in the long term.

Regarding cost challenges, it is essential to consider the economic impact of implementing electronic monitoring devices in the workplace. In particular, the costs of the devices, the necessary training for workers and supervisors, and maintenance and upgrade expenses must be carefully considered. Costs can vary depending on the device type and the monitoring system's complexity.

One way to address these challenges is to explore funding options and grant programs available to companies and organizations interested in implementing electronic monitoring devices. In addition, the long-term cost-effectiveness of these devices should be considered as they could help prevent costly injuries and improve workplace efficiency and productivity.

5. Conclusions

Technological solutions to prevent risks to workers have led to the development of numerous specialized applications in various industries, as illustrated in Figure 3. However, future developments should strive to reduce the number of devices needed and increase their multifunctionality to improve user comfort and usability.

In several examples, the contribution the technology to health is limited to monitoring and the presentation of helpful information so that the worker knows how to act and avoid risks or improve work practices to protect and maintain their health.

In terms of safety, technological solutions allow rapid communication of events and situations that involve risks for the worker. Their employment and implementation in industries provide better response times for medical assistance to those affected by accidents or even people at considerable risk. In several developments, alerts and communication possibilities with those responsible for occupational safety have been incorporated, in some cases with connectivity to public services such as 911 or other social support entities. In future literature reviews, we will focus on the effectiveness of the solutions described. This review provides a helpful overview of existing technological solutions for improving safety and health in the workplace.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMAScR) Checklist [102].

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE
			TITLE
Title	1	Identify the report as a scoping review.	1
		ABSTRACT	
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	2
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	2
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	2–4
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	4
Information sources	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	4
Search	8	Present the full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	4
Selection of sources of evidence	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	4
Data charting process	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	4

Table A1. *Cont.*

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	4
Critical appraisal of individual sources of evidence	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	4
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	4
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	4–14
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	4–14
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	4–14
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	4–14
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	4–14
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	14
Limitations	20	Discuss the limitations of the scoping review process.	15
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	15
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	16

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