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Systematic Review

The Impact of Wearable Devices on the Construction Safety of Building Workers: A Systematic Review

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Abstract: Worker safety is a key concern in the construction industry. Making construction safer by reducing safety hazards is critical to sustainably developing the construction industry. Big data, the Internet of Things, artificial intelligence, and other emerging information technologies are deeply integrated within the construction industry. The real-time monitoring of important physiological indicators of the physical state of construction workers is possible with the use of wearable sensing equipment and can pre-emptively give warning of safety hazards. Data mining and analysis of the monitoring data enable an assessment of the safety status of construction workers and can thus reduce potential hazards faced by construction workers on site. This study firstly reviewed the applications of common wearable devices in various industries, focusing on their use in construction safety. Then, CiteSpace 6.1 R4 software was used to visually analyze the literature data related to wearable devices in construction safety. Thirdly, a comprehensive review was conducted on the psychological state and safety evaluation methods of construction workers. Finally, several challenges and future research trends of wearable devices in the construction safety field were discussed. This paper has important theoretical value in advancing the field of construction safety risk management and improving risk control strategies.

Keywords: wearable devices; building workers; construction safety; risk control; sustainable development

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1. Introduction

Building construction is characterized by sustainability, mobility, complexity, dependence, and coordination, which is the reason for the difficulty of safety management and the low input–output ratio [1]. Safety in building construction has always been of major scientific and technical concern to the research and engineering communities. The flourishing economy of China is inseparable from the development of the construction industry. However, accidents often occur during construction, resulting in casualties and property loss. The most frequent and direct cause of accidents is the unsafe behavior of construction workers [2]. Construction workers are essential to building construction, and they are inevitably exposed to danger on the construction site. However, as construction workers adapt to their dangerous environment, they become less sensitive to the risk of accidents. The difference between actual work environment accident risk and worker perceived accident risk leads to unsafe behavior [3]. Researchers have typically focused on environmental and technical factors in construction accidents because major accidents cause economic and property loss, injuries, and death, but physiological and psychological factors that affect construction workers have been largely ignored. Construction workers endure long working hours and high outdoor temperatures and perform single repetitive operations that cause physical and psychological fatigue [4]. Foreseeable mistakes hide other dangers for the safety of construction workers and eventually lead to construction accidents. It is necessary to dynamically monitor and assess the safety of construction workers in a complex construction environment in order to prevent safety violations and ultimately reduce the risk of accidents or even eliminate them.

The transforming development of digital technologies such as cloud computing, big data, the Internet of Things, 5G, and artificial intelligence has become an important driving force for innovation and development in the construction industry [5]. The creation of a smart construction site that incorporates the Internet of Things, artificial intelligence, and sensing technology provides a new model for construction safety and risk management. In order to reveal the application of wearable devices in the construction industry, some studies have reviewed past developments and proposed new research trends in this field. For example, Awolusi et al. [6] conducted a systematic review of the application of wearable devices in construction safety monitoring and analyzed relevant safety performance indicators. Ahn et al. [7] reviewed the application of wearable devices in the construction safety field and summarized the current main problems. However, most of these reviews have focused on specific subfields or may have relied on qualitative analyses, potentially overlooking important research.

This study firstly reviewed the applications of wearable devices such as wristbands, headsets, and smart garments in various industries, focusing on their use in construction safety. Then, CiteSpace software was used to visually analyze the literature data related to wearable devices in construction safety from 2015 to 2023. The structure, rules, and distribution of scientific knowledge were presented using visual analysis. This study not only analyzed the application and research progress of wearable devices in various industries but also provided a quantitative summary of the research status of wearable sensing technology in construction safety. Building upon this, a comprehensive analysis was conducted on the psychological state and safety evaluation methods. Finally, some challenges of wearable devices in the construction safety field were discussed, and future research trends were proposed. This study expands the traditional literature review method and the use of wearable devices by increasing their application range in construction. The results of this research are of significant importance in enhancing the existing construction risk analysis methods and further improving the management of construction risks.

2. Background and Research Questions

With the advancement of new urbanization construction, the construction industry is thriving. The number of high-rise buildings and super-high-rise buildings is constantly increasing. To complete the complex and dangerous construction tasks, higher requirements are placed on the construction safety of construction personnel. At present, the construction industry still mainly uses human monitoring to monitor the safety status of construction personnel, and there is still a lack of efficient safety monitoring methods for construction personnel under special working conditions. Faced with the special task requirements of high-rise and super-high-rise operations, traditional safety monitoring methods have obvious limitations. In addition, at the management level, in addition to being responsible for the efficiency and quality of the construction project, the project leader also needs to be more responsible for the health level of workers. However, due to various factors and potential situations, the safety of on-site construction personnel is often overlooked. If the safety of construction personnel cannot be guaranteed, the quality and efficiency of the construction project will inevitably be greatly affected. Therefore, our work could provide an overview of various wearable devices, monitoring technologies, and safety evaluation methods, aiming to explore an objective, dynamic, and quantitative method for evaluating the safety status of construction personnel. This work has important theoretical value for enriching the theory of construction safety risk management, innovating risk analysis methods, and improving risk control levels.

3. Research Method

Wearable device technology has developed to such a degree that wearable devices are widely used in various industries because they offer the benefits of real-time measurement, convenience, and speed. In construction, wearable devices are used for physiological monitoring, environmental sensing, proximity detection, and location tracking. The main purpose of using wearable devices is to ensure construction safety and to promote a safe working environment, which is supported by monitoring various psychological and physiological factors of wearers, leading to an improved worker health and increased work efficiency [8–11]. Common wearable devices are wristbands, head-mounted sensors, and smart garments. Figure 1 illustrates these three types of wearable device.

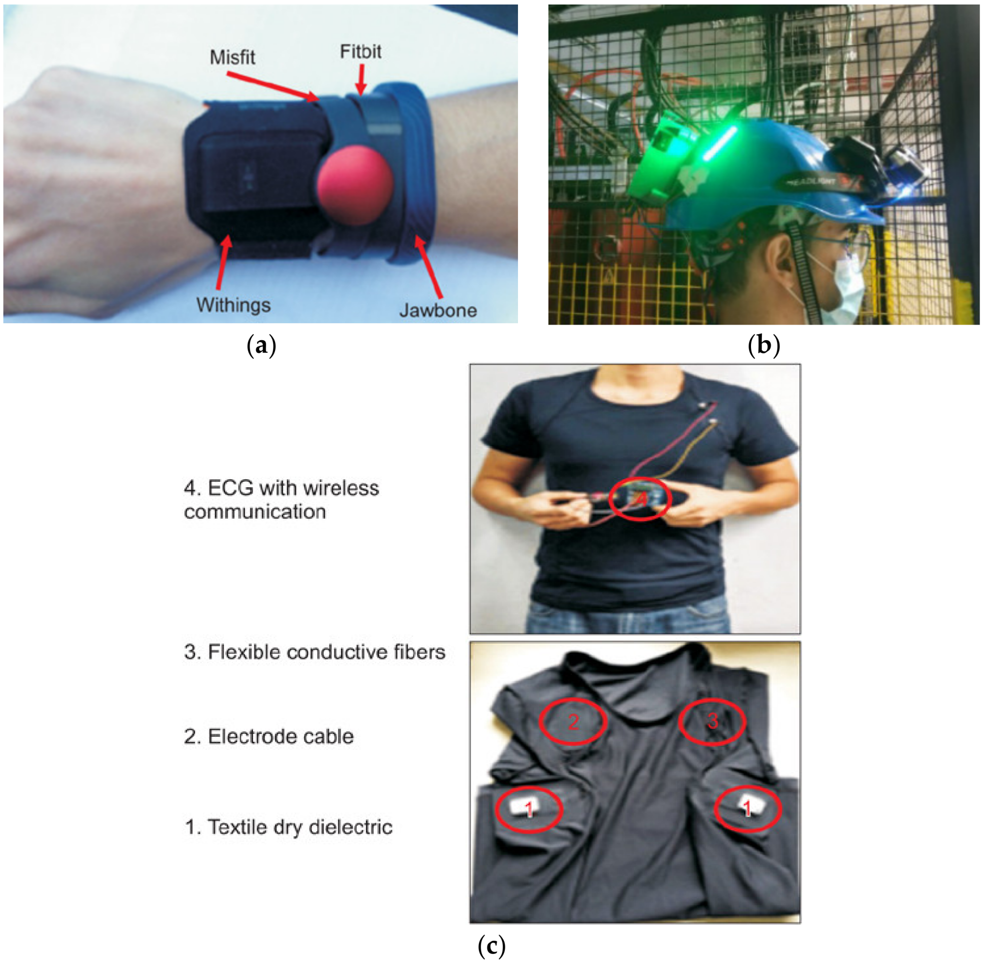

Figure 1. Three common types of wearable device. (**a**) Wristband [12]. (**b**) Head-mounted sensors [13]. (**c**) Smart garments [12].

In this study, firstly, the applications of common wearable devices were summarized in various industries, such as the mining and construction industries. Secondly, CiteSpace software was used to visually analyze the literature data, and the structure, rules, and distribution of scientific knowledge were presented by means of visual analysis. The literature used in the analysis of this paper is from the Scopus database, and a total of 70 pieces of literature from 2015 to 2023 were retrieved. The Scopus database fully includes all journals published by mainstream publishers such as Elsevier, Springer, Nature, Science, and American Chemical Society. Compared to other index databases, the Scopus database has a more comprehensive content and a wider range of disciplines. In addition, the citation indicators in the Scopus database consider more influencing factors, which are more comprehensive and objective, and could eliminate the impact of different disciplines and research types on the evaluation indicators. The visualization analysis was mainly based on keyword co-occurrence analysis, keyword cluster analysis, and country publication analysis, and the visualization knowledge map of the field was plotted to describe the research content and frontier trend of the field. In our study, the top 10 most frequently occurring keywords were presented in keyword co-occurrence analysis, such as: construction safety, wearable technology, occupational risks, construction workers, wearable sensors, and so on. Finally, a comprehensive review was conducted on the psychological state and safety evaluation methods of construction workers. This review was performed in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [14] (see supplementary materials).

4. Results and Discussion

Figure 2 shows the data sources of this work. The literature used in the analysis of this study is from the Scopus database, and a total of 70 pieces of literature were retrieved. A total of 13 pieces of literature were excluded. Finally, 57 pieces of literature were used for analysis.

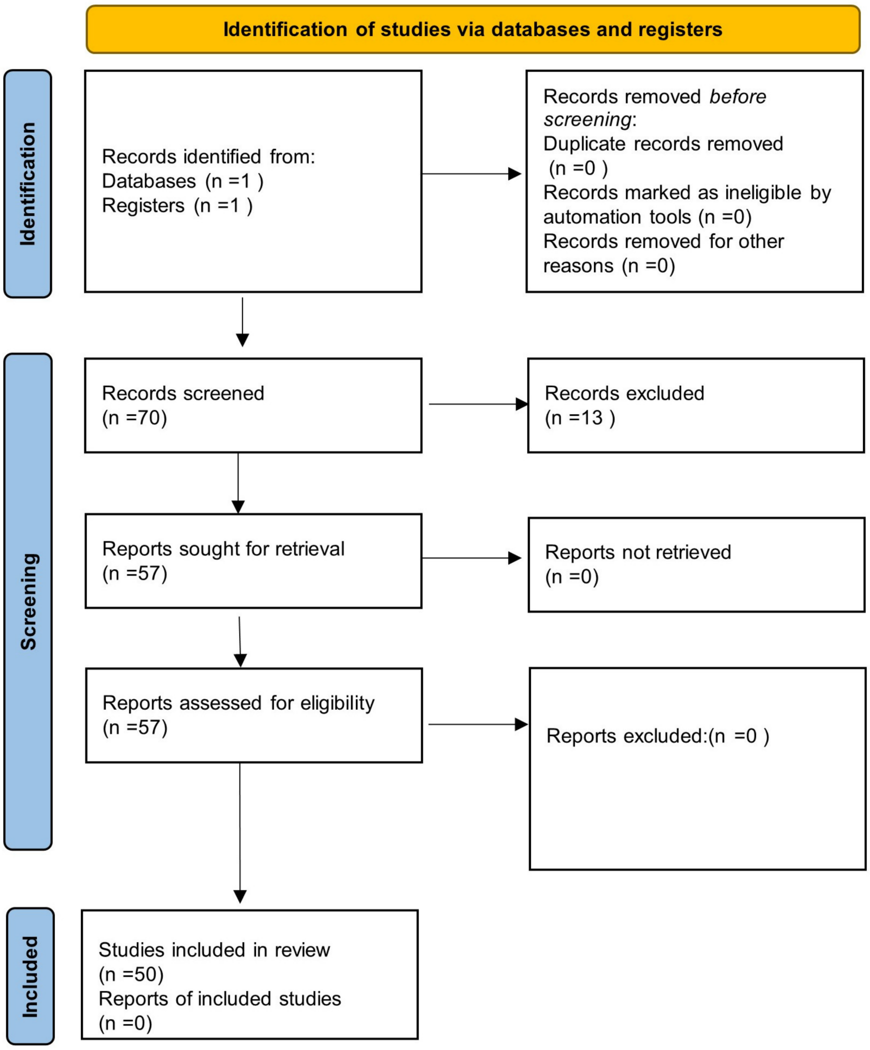

Figure 2. PRISMA flow diagram.

4.1. The Application of Common Wearable Devices in Various Industries

4.1.1. Wristband Devices

Wristband wearable devices are used by researchers to monitor the physiological activity of construction workers and to assess their physical status. Relevant literature that we reviewed is shown in Table 1.

Table 1. Literature on the monitoring of physiological indicators of construction workers by wristband wearable devices.

References	Sensor Type	Physiological Indicator(s) Obtained
Hwang and Lee [15]	Heart rate (HR) sensor	Heart rate
Guo et al. [16]	Basis–peak smart watch	Heart rate, skin temperature, calories, steps
Jebelli et al. [17,18]	Photoplethysmography (PPG) sensor, electrodermal activity (EDA) sensor, and infrared heat sensor	PPG, EDA, skin temperature
Shakerian et al. [19]	PPG sensor, EDA sensor, and infrared heat sensor	PPG, EDA, skin temperature
Lee et al. [20]	E4 wristband biosensor	PPG, EDA, skin temperature
Moohialdin et al. [21]	HR sensor	Heart rate
Chen et al. [22]	HR sensor	Heart rate

Hwang and Lee [15] first investigated the feasibility of using wristband devices to monitor various physiological indicators of construction workers and an analysis of the HR data measured by wristbands to evaluate the physical status of construction workers. Guo et al. [16] analyzed the physiological factors to infer psychological states; they correlated the psychological state of a worker with their physical state by analyzing the measured physiological data and concluded that the physiological data can be used to indirectly measure a worker's mental state. Jebelli et al. [17,18] analyzed wristband biosensor data to create a stress recognition application and a physical demand recognition application. Shakerian et al. [19] created a model to predict safety risks, and Lee et al. [20] developed a model for evaluating risks perceived by workers. Both studies provided valuable bases for increasing construction safety.

The preceding studies also found that different types of work, worker age, and the working environment all had different effects that were indicated by physiological changes in workers. The current research has examined and assessed physiological demand [21] and monitored workers [22] in specific environments (such as extremely hot and humid environments or a tunnel) or engaged in specific types of work. Such research improves the validity and increases the accuracy of the models developed. Currently, limited research has been conducted on using wristband devices for the stress assessment of construction workers. Jebelli et al. [17], in research into the stress assessment of construction workers using wristband devices, used a supervised learning algorithm to predict worker stress from data recorded by a wristband device that showed a stress prediction accuracy of approximately 80%.

Based on the above analysis, it can be concluded that wristband devices are widely used in safety status monitoring in the construction industry due to their convenience, affordability, and non-disruptive nature. However, they are mostly used to collect basic physiological indicators. The investigation of mental stress among construction workers is still in its initial stage, and there is still room for improvement. Furthermore, it is important to note that wristband devices have limitations in terms of the number of physiological indicators that they can monitor, and their accuracy may not be very high. Additionally, not many evaluation models are developed based on data acquisition from wristband devices.

4.1.2. Head-Mounted Wearable Devices

Head-mounted wearable devices that monitor body activity have been developed rapidly, and industries and workers are more widely using this technology. The relevant literature that we reviewed is shown in Table 2.

Table 2. Literature on the monitoring of physiological indicators of construction workers by head-mounted wearable devices.

References	Sensor Type	Monitoring Indicators
Constant et al. [23]	PPG sensor	Heart rate
Agashe et al. [24]	Head-mounted blood-oxygen-monitoring sensor	Blood oxygen
Ko et al. [25]	Head-mounted wireless electroencephalography (EEG) sensor	EEG
Lin et al. [26]	Scan NuAmps Express system EEG sensor	EEG
Rohit et al. [27]	The MUSE brain sensing headband	EEG
Sharma and Maity [28]	Safety monitoring smart helmet	The concentration of methane and CO, Temperature
Wang et al. [29]	NuAmps EEG test module	EEG
Li et al. [30]	Inertial measurement unit (IMU) and EEG sensors	IMU and EEG
Colombo et al. [31]	Acoustic sensors and gas sensors	Noise and harmful gases
Zhang et al. [32]	aNIRS, electrocardiogram (ECG), and accelerometry/actigraphy	Brain function, systemic hemodynamics, ECG, actigraphy

Pulse-sensing smart glasses containing a photoplethysmography (PPG) sensor monitoring the heart rate continuously were developed by Constant et al. [23]. Agashe et al. [24] improved a head-mounted blood-oxygen-monitoring device that operated in real-time using elastic tension headwear by significantly reducing the reading errors. Ko et al. [25] designed a head-mounted device to monitor classroom student attention by recording brainwaves in order to make teaching more effective. Lin et al. [26] developed a driver attention system that monitored EEG signals, which provided driver feedback when it detected driver distraction. Rohit et al. [27] developed an effective head-mounted EEG monitoring device to objectively determine driver fatigue from EEG signals. Sharma and Maity [28] investigated signal acquisition technology for smart helmets that provided miners with safety protection by monitoring the concentration and temperature of harmful gases in their working environment. Wang et al. [29] recorded EEG signals from miners to monitor their anxiety level, which prevented the miner from operating improperly; thus, the operation safety can be improved. Li et al. [30] monitored head movement and EEG signals to indicate drowsiness in workers; if drowsiness was detected, the worker was alerted through a vibration motor. Colombo et al. [31] designed a head-mounted device to monitor harmful gases and noise in a work environment that provided visual and audible warnings when workers were in a dangerous environment. Zhang et al. [32] developed a head-mounted multimodality neuromonitoring detector that recorded brain function (via cerebral hemodynamics), systemic hemodynamics, electrocardiography, and actigraphy simultaneously and continuously for up to 24 h.

Based on the above research, it can be found that, compared to wristband devices, head-mounted monitoring devices have a wider range of applications. They have been developed and used in various situations to monitor physiological indicators in research subjects. Moreover, the analysis shows that head-mounted monitoring devices could collect more types of data, and that these data have higher accuracy. However, due to the high cost of head-mounted monitoring devices and the potential to disrupt the work of construction workers, there are few studies in the construction field. In addition, the data collected by head-mounted monitoring devices is more complex than those collected by wristband devices, and they require professional analysis equipment.

4.1.3. Smart Garments

In recent years, with the exploration and development of bendable, ductile, and biocompatible organic materials, smart garments have become a topic of intense research. A smart garment integrates sensors and garment through materials technology, textile technology, and electronics technology. It is therefore a conventional garment for keeping the wearer warm that is capable of information acquisition, analysis, storage, and transmission. A smart garment must be comfortable to wear, so each sensor must be a flexible device to ensure integration with the garment and maintaining wearability. However, in the current state of research, some key sensing devices cannot be made flexible. The development of a smart garment is more challenging than the development of more common wristband and head-mounted sensors. There are fewer physiological indicators to monitor, the garment is relatively expensive, and the market for the devices is small. Research into smart garments lags behind research into the other two categories of wearable smart devices. Current research into smart garments is primarily concerned with monitoring common physiological indicators, such as heart rate and body temperature, and there are few smart garments that monitor stress and mood.

Paradiso et al. [33] used fabric sensing equipment to monitor ECG, respiration, and activity. The information contained in the signal obtained by the health monitoring system based on this can be equivalent to the information obtained by standard sensors. Song et al. [34] compared fabric electrodes, dry microneedle electrodes, and noncontact dry electrodes and found that fabric electrodes were ideal physiological sensors. However, more research is needed into the stability of fabric electrodes and their fitting to the wearers as well as the wire and lead technology for connection with fabric electrodes used in physiological monitoring. Researchers have suggested that incorporating pH sensors in the fabric of military combat clothing will ensure the detection and warning of biochemical agents, toxic and harmful particles, and nerve gases on the battlefield, thus increasing combat preparedness and the survivability of soldiers. Flexible fabric sensors can also be tailored into protective garments for firefighters, workers in high-risk work environments, and workers exposed to toxic environments. The underlying principle of sensor fabrics is to incorporate active fluorescent dyes into optical fibers to form inductive sensors that detect temperature and pH and can trigger a real-time alarm [35].

The preceding research shows that most research into smart garments is still at the stage of laboratory research, although research into smart garments has recently become more intensive and has produced new biosensors. However, more research is needed into factors that affect the function and comfort of wearable equipment, such as high external temperatures and individual sweating, to ensure the effectiveness of smart garments in practical applications, especially in construction safety monitoring and other applications of smart garments in special working conditions.

4.2. Visualization Analysis of Wearable Devices in Construction Safety

4.2.1. Keyword Co-Occurrence Analysis

Keyword co-occurrence network analysis involves examining the keywords provided by authors in the literature. Keywords serve as a refinement of the article's topic and represent the direction and core of the research. High-frequency keywords can reveal the current popular issues and concerns among scholars in the field.

Figure 3 provides an overview of the keyword co-occurrence network, which consists of 227 nodes derived from the dataset. Each node represents a keyword term specified in the articles.

Table 3 presents the top 10 most frequently occurring terms with a total of 642 co-occurrence frequencies, representing 38% of all keyword frequencies in the dataset.

According to the analysis presented in Figure 3 and Table 3, construction safety was identified as the most frequently used keyword, appearing 54 times, indicating that most studies are focused on addressing the risks and hazards prevalent in the construction industry. Wearable technology was the second most frequently used keyword, appearing 37 times, highlighting its centrality to research in this area. Other keywords, such as occupational risks, hazards, risk assessment, and safety engineering, are related to the problems to be addressed and the objectives to be achieved, thereby reflecting the primary research direction of wearable devices in construction safety.

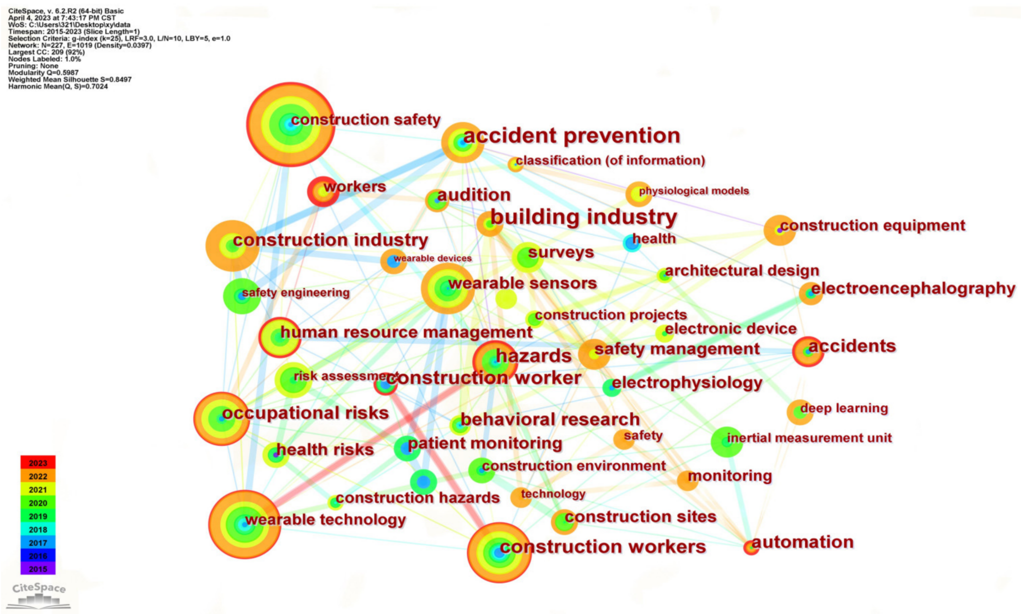

Figure 3. Keyword co-occurrence network of wearable devices in construction safety.

Table 3. Co-occurrence frequencies of specified keywords in the literature of wearable devices in construction safety.

Keywords	Frequency	Keywords	Frequency
Construction safety	54	Hazards	17
Wearable technology	37	Human resource manage	14
Occupational risks	28	Accident prevention	14
Construction workers	24	Risk assessment	10
Wearable sensors	20	Safety engineering	9

4.2.2. Keyword Cluster Analysis

Keyword clustering involves extracting words with distinct characteristics as clustering objects in complex networks within the research field. Subsequently, complex data are mined to classify and aggregate words. Keyword clustering can reflect the research hotspot in this field. The map showed overlapping clusters, indicating close relationships between clusters and concentrated research topics. An inverse relationship exists between the number of clusters and cluster size. The fewer the clusters, the more closely related keywords that they contain. The figure illustrates the cluster analysis diagram of the application of wearable devices in the construction safety field.

Figure 4 presents a cluster view of the knowledge domains related to wearable devices in construction safety.

In Figure 4, the nine clustering words can be roughly divided into the following four categories: the first category is the problems to be solved in this field (#5 hazards); the second category is the cause of the hazards (#1 labor intensity, #6 mental fatigue); the third category is data collection methods (#0 technology, #3 wearable sensors, #7 surveys); and the fourth category is the functions of wearable devices (#2 accident prevent, #4 hazard classification, #8 fall detection). These four cluster labels describe the research content of wearable devices in construction safety in a more comprehensive way.

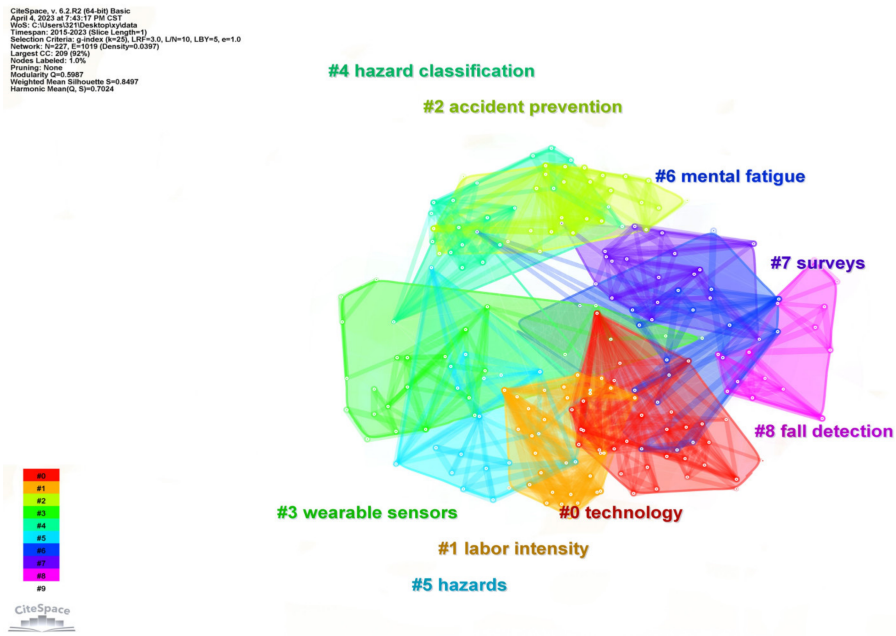

Figure 4. Cluster view of knowledge domains related to wearable devices in construction safety.

4.2.3. Country Publication Analysis

Figure 5 displays the country publication analysis of wearable devices in construction safety.

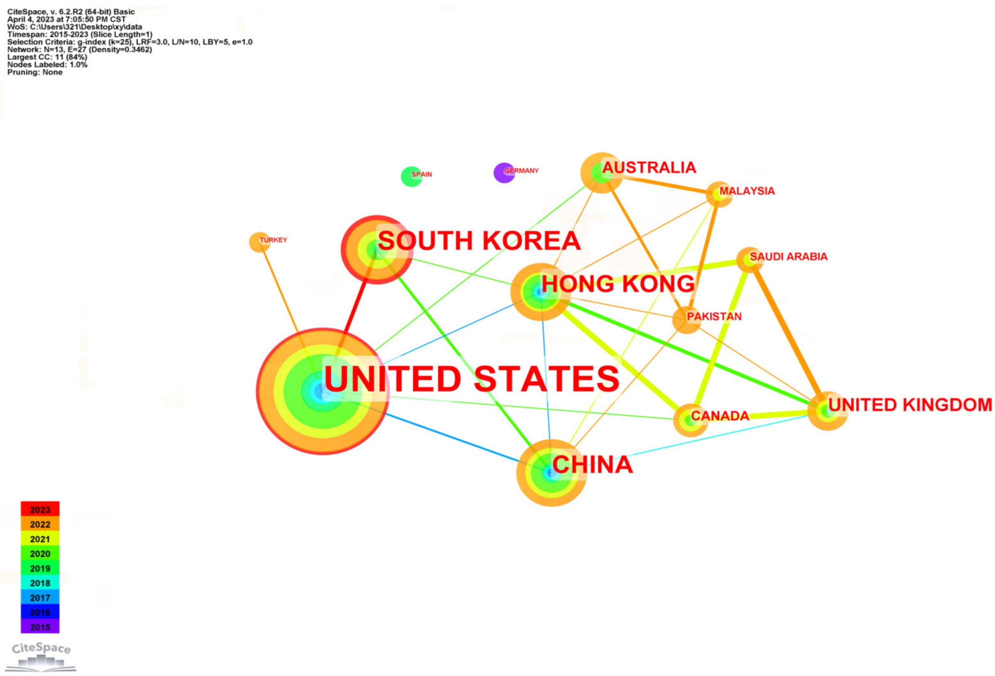

Figure 5. The country publication analysis of wearable devices in construction safety.

The size of the concentric circles indicates the number of publications in a country over the years, the color of the concentric circles represents the year of publication, and the lines between nodes represent cooperation between countries. The United States, China, and South Korea are the top three countries in terms of the number of publications, reflecting their academic development and industry leadership in this field. Hong Kong, China has close cooperative relationships with many countries and plays a significant role in promoting globalization and accelerating development in this field. The number of articles published by countries worldwide has increased since 2020, indicating that research on wearable devices in construction safety has become a popular topic in recent years.

4.3. Effects of Attention Level Change on Construction Safety

The rate of fatal accidents in the construction industry is much greater than in other industries [36]. Studies have shown that 88% of accidents in construction projects are caused by the unsafe actions of construction workers [37]. Construction workers are often employed in high-temperature, high-intensity, and high-paced work environments, which leads to worker fatigue and distraction that affect the quality of work and cause cost overruns [38] and, more seriously, major accidents [39,40]. Seevaparsaid-Mansingh [41] analyzed a sample accident using accident causation theory and found that distraction was a causal factor of the accident. Research into worker attention can therefore help to prevent accidents and establish good safety, health, and environmental management systems. Nnaji and Gambatese [38] investigated the effects of worker attention on safety and on work quality by reviewing an extensive literature survey and found that distraction reduces work quality and increases the likelihood of improper equipment operation, accidents caused by carelessness, and accidents involving falls, which can affect both project cost and schedule. However, there are also studies [42] that use the Pearson correlation coefficient between computational attention networks and safety perception to show that no significant link exists between worker attention and safety, but that such results may be due to a small experimental sample size. To date, research into worker attention forms a small corpus, and additional research into this aspect of worker safety is urgently needed.

Researchers have recently begun to use wearable EEG devices to monitor worker attention objectively and quantitatively during construction. Wang et al. [43] first used EEG to monitor worker attention and used time frequency analysis and event-related potential (ERP) analysis to extract various features from EEG data for modeling. They concluded that the frequency, power spectrum density, and spatial distribution of EEG signals quantified and indicated the level of risk perceived by construction workers. The study demonstrates the effectiveness of using EEG sensors to study worker attention levels. Ke et al. [44] used a sustained attention response task (SART) to introduce distraction in a simulated construction safety inspection task. They hypothesized that the distraction promoted certain cognitive responses, which made it possible to discover and therefore control inherent distractions that lead to unsafe behavior or otherwise diminish the task performance. Hasanzade et al. [45] used multivariate analysis of variance (ANOVA) on worker eye-tracking data to assess the effects of hazard recognition on visual attention and found that hazard recognition significantly affected a worker's visual search strategies. Another study also found, from monitoring visual attention, that knowledge gained from work experience and injury exposure significantly improved construction workers' hazard detection and visual search strategies.

The above analysis could provide two major insights for improving construction safety. (1) Measuring the risk perception of construction workers is important in construction site safety management. (2) Quantifying the degree of cognitive load by analyzing the strength of different EEG signal channels is necessary to identify vulnerable individuals on the construction site. However, EEG equipment cannot be used in its present state in complex environments; considering the complexity and multiple characteristics of brain waves, further research is required to improve the future sensor performance.

4.4. Construction Safety Assessment Methods

Questionnaire surveys are widely used in construction safety management research [46] to study the unsafe behavior of construction workers. Li et al. [47] analyzed the influencing factors during the construction workers' cognitive process from the perspective of safety cognition, and constructed the interaction and cognition of the agent under the bidirectional effect of formal rule awareness and a conformity mentality model. They showed that the higher the level of conformity intention of construction workers, the easier it is to increase the unsafe behavior of the group, and that formal rule awareness can play a greater role only when the management standard is at a high level. Choudhry and Fang [48] used behaviorism theory to identify the external characteristics of habitual unsafe behavior by construction workers. They identified psychological and behavioral changes and factors that influenced them through behavioral investigation and case analysis. Chen et al. [49] investigated causal paths between various influencing factors and unsafe behaviors in subway construction workers according to expert interviews, accident case analysis, and references in the FCE method. Czarnocka et al. [50] developed a scaffold by using a risk assessment model (SURAM) to assess risk levels in construction and other types of work. Alomari et al. [51] identified and quantified worker perspectives of the key factors affecting worker safety using the Delphi method. Liang et al. [52] used exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) to build a structural equation model (SEM) of safety capability.

Some researchers have used gradually maturing vision technology to determine the state of individual safety. Han et al. [53] used eye-tracking safety monitoring technology to identify the cognitive load of a subject when detecting dangers. They suggested a novel technique for evaluating the ability of construction workers to detect dangers and thereby improve safety education. Ding et al. [54] developed a novel hybrid deep learning model that combined a convolutional neural network (CNN) with long short-term memory (LSTM) to automatically identify unsafe worker behavior. The model accurately detected safe–unsafe worker acts on site. Seo et al. [55] reviewed the application of computer vision technology in construction from both a technical and a practical perspective and identified directions for future research in computer vision in health and safety monitoring. Teizer and Vela [56] investigated the possibility of using cameras to track workers on construction sites. Guo et al. [57] developed a framework for the real-time recognition of unsafe behavior that combined image technology, construction safety knowledge, and ergonomics.

The rapid development of wearable sensor devices has led researchers to investigate their potential applications in civil engineering and construction safety, as well as in other fields. Lee et al. [58] investigated the usability and reliability of wearable sensors for monitoring the on- and off-duty activities of roof workers. Hwang et al. [59] used wearable EEG sensors to determine the influence of a construction worker's emotional state on their behavior. Guo et al. [16] determined the correlation between a worker's mental state and the physiological data recorded by wearable devices. They used a positive and negative affect schedule (PANAS) and a day reconstruction method (DRM) to collect psychological data. Hinze et al. [60] used a wearable EEG device to assess the degree of recklessness of construction workers during work. Yang et al. [61] developed a method of smartphone sensor data acquisition and used a labor intensity framework to assess the workload of construction workers. Choi et al. [62] used the physiological responses recorded by wearable sensors for a continuous and quantitative assessment of worker perception of risk.

The preceding research shows that questionnaire design tends to produce subjective results, so the survey results may not accurately represent the actual situation. Safety situations as captured by computer vision provide researchers with data from only a single viewpoint. However, current research into wearable devices focuses on the relationship between physiological characteristics and safety, and there is little available research into the mechanisms that relate several physiological indicators to an individual's state of safety.

5. Conclusions and Outlook

This study firstly reviewed the applications of common wearable devices in various industries, with a focus on their use in construction safety. Secondly, CiteSpace software was applied to visually analyze the literature data related to wearable devices in construction safety. Finally, a comprehensive review was conducted on the psychological state and safety evaluation methods of construction workers. The results indicate that wearable devices are rapidly gaining popularity among researchers and practitioners as an emerging technology for collecting safety data on construction sites. Notably, wristband devices have emerged as the most widely used wearable technology for safety monitoring in the construction industry when compared to other wearable devices. Moreover, the above analysis reveals a significant gap in research and experimental work on using wearable devices to monitor distraction in construction workers. At present, there lacks reliable and comprehensive indicators for monitoring worker distraction on construction sites. Furthermore, while neurophysiological monitoring techniques such as EEG and ECG have been developed to provide an objective real-time detection of mental fatigue, their dependence on recording the electrical activity of the human body can be very invasive for workers. Moreover, the electrical signals can be easily affected by the harsh environment of the construction site, which raises concerns about the accuracy of the measurements.

Based on the above analysis, several existing challenges are summarized. The first challenge is that wearable devices are rarely used in the construction industry. The second challenge is the low accuracy of data collected by wearable devices. The third challenge is the issue of data privacy. The other two challenges are the selectivity of physiological indicators characterizing attention changes and the limitations of the construction safety evaluation method, respectively.

According to the above challenges, future research can focus on the following aspects.

(1) In future research, it is recommended to combine the characteristics of the three types of wearable devices and to develop smart wearable devices that are portable, comfortable, and unintrusive.

(2) Future research needs to increase the number of sampling workers and various construction workers with different characteristics as much as possible to improve the reliability and universality of the data.

(3) Future research needs to focus on the impact of changes in construction environmental factors on construction workers, especially the construction status of workers under special working conditions.

(4) For future research, advanced transfer learning algorithms should be used to reduce the impact of individual differences so as to improve the universality of the model.

(5) There is a need to focus on the research of the labor intensity and mental fatigue of construction workers. Additionally, a more accurate safety assessment model for quantitatively assessing the construction safety of construction workers needs to be further studied.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su151411165/s1, PRISMA 2020 Checklist. Reference [14] is cited in the supplementary materials.

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Informed Consent Statement: This study is a review paper and does not involve ethical issues.

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