ICCEPM 2024 https://dx.doi.org/10.6106/ICCEPM.2024.0879
The 10th International Conference on Construction Engineering and Project Management
Jul. 29-Aug.1, 2024, Sapporo

Enhancing Construction Safety through Wearable Technology – A Study of Employee Acceptance and Adoption in the USACE

Karen E. CARNAGO[1], Junshan LIU[1]*, Scott KRAMER[1]

[1] *McWhorter School of Building Science, Auburn University, USA,* E-mail addresses: kec0153@auburn.edu, liujuns@auburn.edu, kramesw@auburn.edu

Abstract: In the dynamic construction industry, particularly within the United States Army Corps of Engineers (USACE), ensuring worker safety in high-risk environments is a critical challenge. This study explores the integration of wearable technology in construction safety, focusing on its potential to enhance personal protective equipment (PPE). The primary goal of this study is to understand the factors influencing USACE employees' acceptance and adoption of wearable technology. Additionally, the research aims to assess the experiences of employees who have already used such technology to identify its practical benefits and levels of user satisfaction. A mixed-method approach was employed to gather qualitative insights from interviews with USACE safety experts and quantitative data from an online survey of USACE personnel. The findings indicate a general reluctance among workers to adopt wearable technology for monitoring work activities, mainly due to privacy concerns, usability issues, and perceived additional workload. However, there is interest in technologies that provide direct safety benefits, such as hazard alerts. This study illuminates the gap between the potential benefits of wearable technology and its current level of acceptance in the construction industry. It identifies the need for strategies to enhance worker acceptance and offers recommendations for future research.

Key Words: Construction Safety, OSHA, Personal Protective Equipment (PPE), USACE

1. INTRODUCTION

In the United States construction industry, which as of early 2023 employed nearly 8 million individuals [1], a critical challenge persists: maintaining worker safety in an environment prone to high risks and fatalities. This sector, marked by its significant contribution to the nation's economy, is unfortunately also distinguished by a higher incidence of work-related accidents and injuries compared to other industries, leading the statistics in occupational fatalities [2].

The implementation of rigorous safety measures, including the mandatory use of Personal Protective Equipment (PPE), has been a cornerstone strategy in safeguarding construction workers [3]. Among these protective gears, hard hats are one of the most commonly used PPEs, worn by more than 30 million workers across the country to shield against head injuries. The evolution of PPE has seen a significant shift with the integration of modern wearable technology, transforming conventional safety equipment into sophisticated systems capable of real-time hazard monitoring and communication [4]. According to Awolusi et al., [5] wearable technology in this context is characterized by its incorporation into items routinely used in the construction sector, such as helmets, watches, and even clothing. These devices are typically equipped with advanced components like batteries, central processing units (CPUs), power management systems, and internet connectivity. This integration facilitates numerous of functions, from monitoring the wearer's health parameters to detecting environmental hazards, thereby enhancing the safety and productivity of the workforce.

However, the deployment of wearable technology in construction, particularly within the branches of the United States Army Corps of Engineers (USACE), is not without its challenges. Factors such as cost, regulatory compliance, and notably, employee acceptance and adherence, play pivotal roles in the successful adoption of these technologies. Understanding and addressing the human element—

involving both the ergonomic fit of the devices and the psychological readiness of the workforce to embrace technological integration—is essential for realizing the full potential of wearable safety technologies in the construction industry.

This research paper aimed to explore the integration of wearable technology in the USACE construction environment. It focused on identifying factors influencing employee acceptance of wearable technology, understanding user experiences, and examining additional elements affecting employees' willingness to use these devices. Through expert interviews and an employee survey, the study seeks to offer insights into wearable technology adoption in construction safety and health.

2. BACKGROUND

2.1. Evolution and USACE Standards of Hard Hats

The hard hat, essential for construction safety, has undergone significant evolution since its creation in 1919. Designed by Edward W. Bullard, the original "Hard-Boiled Hat" made of steamed canvas marked the beginning of head protection in high-risk environments [6]. Its usage became widespread in major projects like the Hoover Dam (1931-1936) and the Golden Gate Bridge (1933-1937), leading to innovations in materials from aluminum in 1938 to fiberglass in 1941, and later to thermoplastics in the mid-20th century [7]. Despite these advancements, as shown in Figure 1, the basic design of hard hats has seen minimal changes over the past five decades, highlighting an ongoing need for innovation.

Current standards for hard hats, as stipulated by the Occupational Safety and Health Act (OSHA) [8] in 29 CFR 1910 for General Industry and 29 CFR 1926 for Construction [9], require protective helmets for workers to prevent head injuries [10]. These standards ensure hard hats include essential safety information such as manufacturer details, American National Standards Institute (ANSI) standards [11], and specific type and class. Regular maintenance, guided by OSHA's protocols, is vital for their effectiveness. While these standards are comprehensive, they do not currently mandate the use of advanced wearable technology, suggesting an area for future development in regulatory practices.

(a) (b)

Figure 1: Comparison of original and modern hard hats used by construction workers: (a) vintage aluminum hard hat from the 1940s; (b) present day vented hard hat. [6]

2.2. What Are Smart Wearable Devices?

The beginning of smart wearable devices, which have become a fundamental technology in modern occupational safety, traces its origins to as early as 1644 with the creation of the first wearable smart abacus ring. Since then, the evolution of wearable technology has been marked by numerous milestones. Notable early examples include Dick Tracy's iconic two-way wrist radio in 1946 and a wearable camera mounted on a bird in 1907, demonstrating the imaginative foray into wearable tech. The 1960s saw significant advancements with the introduction of the first wearable computer, equipped with a predictive algorithm for roulette in 1961, and the digital hearing aid named "Phoenix" in the same year. The concept of integrating computational power with everyday wearables was further solidified in the mid-1970s with the release of the first calculator wristwatches, such as the Pulsar and HP-01 models, which included a stylist for operation [12], [13].

In the modern workplace, smart wearable devices serve multifaceted functions. They play a crucial role in tracking worker health and productivity [14]. These devices are capable of sending warnings to workers when they approach dangerous zones, thus facilitating timely responses to potential hazards. They also have the capability to detect falls or unusual motions, tracking body mechanics during work to ensure safe and efficient practices. Moreover, smart wearables enhance direct hazard detection for workers. They can sense hazardous gases, send alerts, monitor noise levels, and detect harmful materials like silica dust. This immediate detection capability is vital in preventing occupational health risks.

These devices also assist in enhancing workers' capabilities. Exoskeleton wearable devices, for instance, expand a worker's physical capabilities, preventing injuries due to excessive strain, improper lifting techniques, and physical fatigue. Additionally, they assist in the assessment of body mechanics and movement, with integrated sensors in wearable clothing providing valuable data on posture and motion during various work-related activities [15].

The incorporation of smart wearable technology in the construction industry thus represents a significant leap forward in occupational safety and efficiency. These devices have become indispensable tools in modern industrial and construction settings by enhancing the worker's abilities and providing real-time data and safety alerts.

2.3. Types of Current Wearables and Key Features

In the domain of construction safety, smart wearables have emerged as crucial systems for enhancing worker protection and labor productivity. These devices, equipped with advanced technology, serve various functions ranging from job site headcount and proximity alerts to spatial monitoring and contact tracing. Table 1 summarizes the specifics of different smart wearable types and their key features.

Table 1: Key Features of smart wearable devices in construction [5], [13], [15], [16].

Type of Wearable	Key Features
Smart Watch	○ Detects falls and automatically dials emergency numbers ○ Tracks worker location on-site ○ Facilitates hands-free communication ○ Monitors vital biological functions (heart rate, oxygen levels, temperature)
Smart Footwear	○ Tracks on-site movement using internal and external sensors ○ Capable of receiving and sending alerts ○ Includes sole sensors for fall detection
Smart Clothing	○ Made of lightweight, Cat 2 fabric ○ Offers arc flash and flash fire protection ○ Incorporates environmentally friendly TENCEL lyocell fibers
Smart Boots	○ Powered by kinetic energy, recharging with each step ○ Remote management for safety and productivity on high-risk sites ○ GPS and RFID for accurate location tracking ○ Integration with vehicles to prevent accidents
Smart Hard Hats	○ Sensors monitor movements and vital signs ○ Proximity sensors to prevent collisions ○ Capability to overlay maps and thermal images ○ Optional headbands for health and cognitive monitoring.
Smart Gloves	○ Ensure ergonomic correctness in task performance ○ Detect if correct tools are being used ○ Useful in surface sampling and monitoring ○ Touchscreen-compatible fingertips
Wearable Smart Monitors	○ Worn on various body parts ○ Chest-worn sensors for body temperature monitoring ○ Hazardous gas detection and noise level monitoring ○ Assist in monitoring work in confined spaces
AR Glasses	○ Combine safety goggles with smartphone functions ○ Provide flash warnings and alerts ○ Assist in training for tool and equipment operation
Exoskeleton Devices	○ Amplify, reinforce, or restore human performance ○ Target specific body areas or the whole body ○ Used in both industrial and therapy settings

By integrating smart technology into traditional safety gear like vests, hard hats, and glasses, these wearables are transforming into sophisticated devices capable of achieving heightened safety goals and reducing accident risks. Construction wearables are particularly designed to address major concerns such as falls, electrocution, and incidents involving contact with objects or equipment. The research conducted by Kim et al., [17] indicated that only 16% of workers who sustained head injuries were wearing hard hats. This raises critical questions about the reasons behind the low usage, such as the weight, heat accumulation, or style of the hard hats, and whether newer designs or safety wearable technologies could have prevented these injuries.

2.4. Future Trends of Wearables

The evolution of wearable technology in construction is marked by a shift towards more advanced, efficient, and user-centric designs. The next generation of hard hats is set to feature enhanced stability, improved airflow systems for better cooling, and lightweight designs that reduce user fatigue. These innovations aim to provide faster and more effective protection [18], [19].

Cost and accessibility are also key areas of development. Despite the current high costs, wearables are expected to become more affordable, facilitating wider adoption. Additionally, advancements in battery technology are anticipated to enhance the operational efficiency of these devices, allowing for longer use and broader coverage. A significant trend is the integration of wearables with advanced data technologies like AI, Big Data Analysis, and IoT, enriching their data processing and utility capabilities. This integration is poised to transform wearables into tools for sophisticated data analysis and real-time feedback, enabling workers to adjust and respond instantly to various environmental conditions [5], [13].

Communication technologies are also advancing, with faster networks like 5G improving data transfer and communication capabilities, which are essential for analytical and investigative processes in construction environments. Furthermore, the increasing academic focus on sensor technology, with numerous universities offering specialized programs, underscores wearable technology's growing importance and potential in industrial applications [13].

2.5. Employee Acceptance of Wearable Technology in The Workplace

Understanding employee acceptance of wearable technology in the workplace is crucial for its successful implementation, especially in environments like the USACE construction workplace. This acceptance is influenced by various factors, as suggested by behavior studies and models.

The key determinants of acceptance include performance expectancy or the belief that the technology will meet its intended objectives and contribute positively to job performance. Effort expectancy, relating to the ease of use of the technology, and social influence, the perception that influential peers or leaders endorse the use of the technology, are also significant. Other factors, such as age, gender, prior experience with the technology, and the voluntariness of its use, play a role. However, the primary driver of usage is often the behavior intention shaped by performance expectancy [20].

Employee acceptance is critical in the USACE construction workplace besides practical considerations like cost and regulatory compliance. This acceptance can vary based on several factors, including the cost of the device, its type, the user's relationship with the data evaluators, the employee's role and position within the company, and their experience with wearable technology. These variables suggest a need for further research to understand the nuances of wearable technology use among USACE workers.

This paper aims to investigate how various factors – organizational setting, individual employee characteristics, and the specific use case of wearable technology – influence attitudes towards its use in the USACE construction environment. The primary objective is to identify the predictors of employee acceptance of work-related wearable technology. Additionally, the paper seeks to understand factors that contribute to positive experiences among users who have previously interacted with such technology.

3. METHODOLOGY

The methodology for this research study involved a combination of qualitative and quantitative approaches, including interviews with USACE safety experts and an online survey to a select group of USACE personnel who regularly use PPE.

3.1. Safety Expert Interviews

The qualitative aspect of the research comprised one-on-one interviews with two high-ranking officials: the USACE Chief of Safety and Occupational Health for the Great Lakes and Ohio River Division and the Safety and Occupational Health Manager for HQUSACE. These interviews were focused on understanding the current use of wearable technology in high-risk situations and identifying potential areas for safety improvement with the adoption of wearable technology.

3.2. Online Questionnaire Survey

An online quantitative survey, administered through Microsoft Forms from October to November 2023, was conducted among USACE employees working in a District Operations Division. Approximately 95 employees received the survey via work email distribution lists, encompassing roles in construction, operation, maintenance, and administration. The survey did not collect demographic information to focus solely on participants' attitudes and experiences regarding wearable technology.

The survey aimed to gather data related to two primary objectives: identifying factors predicting employee acceptance of work-related wearable technology and understanding factors contributing to positive experiences among users who have already used such technology. The survey comprised 20 questions, including multiple-choice and open-ended responses, to gather extra feedback. Participants responded to questions on a 5-point ordinal scale, ranging from strong disagreement to strong agreement regarding their willingness to use wearables under various use cases. They were also asked to rate the quality of their prior experiences with work-related wearables on a similar scale.

4. RESULTS AND DISCUSSION

4.1. Results and Analysis of Expert Interviews

The two interviews with USACE safety experts revealed valuable insights into the use and potential of wearable technology in construction safety. Currently, wearable tech is predominantly used for environmental monitoring in confined spaces due to its effectiveness in alerting workers to hazards. The experts identified solo work scenarios, especially those requiring air monitoring, as high-risk situations where wearable technology could significantly enhance safety. Both interviewees concurred on the underutilized potential of wearable technology in broader applications, such as heat/cold stress monitoring and location tracking. They emphasized the importance of real-time monitoring and alerts in improving safety protocols. This suggests an opportunity to integrate wearable technology more comprehensively into construction operations, not only for enhanced safety but also for operational efficiency. The interviewees also indicated that expanding the technology's use would require both technological adoption and a cultural shift in safety management. Training and workforce acceptance are crucial for leveraging the full benefits of this technology.

4.2. Results and Analysis of the Online Survey

The online survey conducted among USACE employees garnered 40 responses, resulting in a 42% response rate (40/95). The respondents were primarily engaged in operations and maintenance tasks within USACE branches. Because of this article's page limit and its primary objectives, only results of the questions relevant to understanding employee acceptance and experiences with wearable technology in the workplace are included and discussed below.

The survey results reveal that most participants indicated either no prior experience or negative experiences with wearable technology (21 out of 40 participants). Also, there was a mix of neutral and positive reactions (19 out of 40) towards the use of wearable technology for hazard alerts. Figure 2 illustrates responses to this question.

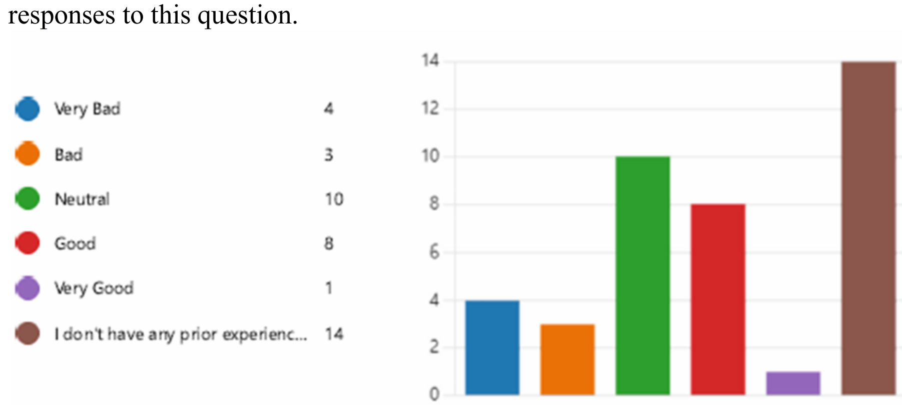

Figure 2: Respondents' previous experience with wearable technology.

A significant finding from the survey is the general reluctance towards the voluntary use of wearable technology for monitoring and improving safety and productivity, with a majority (23 and 27 out of 40) expressing disagreement. A notable proportion of participants (8/40) remained neutral on this matter. Figure 3 shows the distribution of the responses. This result indicates a significant barrier in employee acceptance. This reluctance could be due to concerns about privacy, perceived intrusiveness, or skepticism about the effectiveness of such technology in improving safety and productivity.

Figure 3: Respondents' perception on the voluntary use to wearables for monitoring and improving safety and productivity.

However, there was a comparatively higher level of support, with 14 out of 40 participants, as shown in Figure 4, for using wearable technology for alerts related to hazard proximity or levels, although the majority were still neutral or disagreed with its use. This finding suggests that employees see more tangible benefits in technologies that provide direct, immediate safety benefits. This indicates a potential area of focus for future implementation where the practical safety advantages are clear and immediate.

The fill-in responses provided by those who were disinclined to use wearable technology revealed concerns about workplace monitoring, perceived redundancy of such technology given existing systems, and reluctance to wear additional gear that might hinder work activities. These concerns highlight the importance of addressing employee perceptions and the ergonomic design of wearable devices to increase their acceptance and usage.

Figure 4: Respondents' perception on the use of wearables for alerts related to safety hazards.

In terms of advancing regulations to include wearable technology, a majority 28 out of 40) did not support such regulatory changes, though there was a group of participants (12 out of 40) who were neutral or favorable towards volunteering to use wearable technology at work (Figure 5). These mixed responses suggest a divided opinion among USACE employees. While there is some openness to exploring the technology, there's also a considerable degree of hesitation, likely due to unfamiliarity and concerns about the implications of such regulatory changes.

Figure 5: Respondents' opinion on supporting regulation changes to include wearable technology.

5. CONCLUSION AND RECOMMENDATIONS FOR FUTURE STUDY

This research paper has provided a preliminary exploration of the advancements in personal protective equipment (PPE), specifically focusing on the integration of wearable safety technology within the United States Army Corps of Engineers (USACE) organization. The study employed a mixed-method research methodology consisting of qualitative insights from interviews with USACE safety experts and quantitative data from an online survey.

The interviews provided expert perspectives on wearable technology's current use and potential applications in construction safety. In contrast, the survey assessed USACE employee attitudes towards the adoption and use of such technology in their everyday work environment. The survey results revealed significant challenges within USACE, particularly highlighting employees' reluctance to adopt wearable technology for work activity monitoring. This reluctance was found to stem from a lack of experience with such technology, coupled with concerns about privacy and the perceived burden of additional workload. Furthermore, the insights obtained from the interviews with safety experts and the survey responses highlighted a notable gap between the potential benefits of wearable technology and its current level of acceptance among construction workers. This gap is attributed mainly to apprehensions regarding the usability, necessity, and broader implications of implementing such technology in the workplace.

Future research in this domain should focus on implementing pilot tests for wearable technology in targeted construction settings, such as those requiring specialized monitoring. These tests, followed by comprehensive follow-up surveys, may provide valuable insights into the hands-on experience and changing perceptions of the end users. The aim is to assess the practical application of these technologies and to understand shifts in employee attitudes and acceptance over time. Continuous evaluation and adaptation based on feedback will also be crucial to align the technology with worker needs and to maximize its safety benefits in the construction environment.

Disclaimer: The views contained herein are solely those of the authors and do not represent the views of USACE.

REFERENCES

[1] W. Research, "Construction Labor Shortage Statistics in 2023," Workyard. Accessed: Jan. 27, 2024. [Online]. Available: https://www.workyard.com/research/construction-labor-shortage

[2] B. Y. Jeong, "Occupational deaths and injuries in the construction industry," *Applied Ergonomics*, vol. 29, no. 5, pp. 355–360, Oct. 1998, doi: 10.1016/S0003-6870(97)00077-X.

[3] R. Sehsah, A.-H. El-Gilany, and A. M. Ibrahim, "Personal protective equipment (PPE) use and its relation to accidents among construction workers," *Med Lav*, vol. 111, no. 4, pp. 285–295, 2020, doi: 10.23749/mdl.v111i4.9398.

[4] J. Hamilton, "How a new hard hat technology can protect workers better from concussion." Accessed: Jan. 27, 2024. [Online]. Available: https://www.wbur.org/npr/1121903266/how-a-new-hard-hat-technology-can-protect-workers-better-from-concussion

[5] I. Awolusi, E. Marks, and M. Hallowell, "Wearable technology for personalized construction safety monitoring and trending: Review of applicable devices," *Automation in Construction*, vol. 85, pp. 96–106, Jan. 2018, doi: 10.1016/j.autcon.2017.10.010.

[6] K. Forestell, "Hard Hats The History Of The Hard Hat| Blog | Prochoice Safety Gear," Pro Choice Safety Gear. Accessed: Jan. 27, 2024. [Online]. Available: https://prochoicesafetygear.com/ppe/blog/hard-hats/the-history-of-the-hard-hat/

[7] R. Baker, L. Stock, and B. Szudy, "Hardware to hard hats: Training workers for action (from offices to construction sites)," *American Journal of Industrial Medicine*, vol. 22, no. 5, pp. 691–701, 1992, doi: 10.1002/ajim.4700220507.

[8] "Home | Occupational Safety and Health Administration." Accessed: Jan. 27, 2024. [Online]. Available: https://www.osha.gov/

[9] "Code of Federal Regulations List of Subjects," National Archives. Accessed: Jan. 27, 2024. [Online]. Available: https://www.archives.gov/federal-register/cfr/subjects.html

[10] Safety_Admin, "OSHA Hard Hat Requirements | New Hard Hat Safety Rules," Safety By Design. Accessed: Jan. 27, 2024. [Online]. Available: https://www.safetybydesigninc.com/osha-hard-hat-requirements-hard-hat-safety-rules/

[11] "American National Standards Institute - ANSI Home," American National Standards Institute - ANSI. Accessed: Jan. 27, 2024. [Online]. Available: https://www.ansi.org/

[12] M. Kritzler, M. Bäckman, A. Tenfält, and F. Michahelles, "Wearable technology as a solution for workplace safety," in *Proceedings of the 14th International Conference on Mobile and Ubiquitous Multimedia*, in MUM '15. New York, NY, USA: Association for Computing Machinery, Nov. 2015, pp. 213–217. doi: 10.1145/2836041.2836062.

[13] V. Patel, A. Chesmore, C. Legner, and S. Pandey, "Trends in Workplace Wearable Technologies and Connected-Worker Solutions for Next-Generation Occupational Safety, Health, and Productivity - Patel - 2022 - Advanced Intelligent Systems - Wiley Online Library," *Advanced Intelligent Systems*, vol. 4, no. 1, Jan. 2022, doi: https://doi.org/10.1002/aisy.202100099.

[14] R. Costello, "Navigating Wearable Worker Safety Tech: Where Do We Stand and Where Are We Headed? -," Occupational Health & Safety. Accessed: Jan. 27, 2024. [Online]. Available: https://ohsonline.com/webcasts/2023/09/navigating-wearable-worker-safety-tech.aspx

[15] M.-L. Olar, M. Leba, and M. Risteiu, "Exoskeleton - wearable devices. Literature review," *MATEC Web Conf.*, vol. 342, p. 05005, 2021, doi: 10.1051/matecconf/202134205005.

[16] M. Chan, D. Estève, J.-Y. Fourniols, C. Escriba, and E. Campo, "Smart wearable systems: Current status and future challenges," *Artificial Intelligence in Medicine*, vol. 56, no. 3, pp. 137–156, Nov. 2012, doi: 10.1016/j.artmed.2012.09.003.

[17] S. C. Kim, Y. S. Ro, S. D. Shin, and J. Y. Kim, "Preventive Effects of Safety Helmets on Traumatic Brain Injury after Work-Related Falls," *Int J Environ Res Public Health*, vol. 13, no. 11, p. 1063, Nov. 2016, doi: 10.3390/ijerph13111063.

[18] C. Sethi, "Engineering Safety with Smart Helmets." Accessed: Jan. 27, 2024. [Online]. Available: https://www.asme.org/topics-resources/content/Engineering-Safety-with-Smart-Helmets

[19] E. F. Jay, "Say Goodbye to the Construction Hard Hat | Built," Built | The Bluebeam Blog. Accessed: Jan. 27, 2024. [Online]. Available: https://blog.bluebeam.com/safety-helmets-hard-hats-construction/

[20] J. V. Jacobs *et al.*, "Employee acceptance of wearable technology in the workplace," *Applied Ergonomics*, vol. 78, pp. 148–156, Jul. 2019, doi: 10.1016/j.apergo.2019.03.003.