

BOARD #114: Empowering Future Engineers: The Role of Advanced Technology in Construction Safety Education

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Abstract:

In the ever-evolving landscape of construction safety, integrating advanced technologies is crucial for effectively preparing future engineers. This paper explores the incorporation of cutting-edge technologies in construction safety education, highlighting a team project that investigated various forms of smart personal protective equipment (PPE). More specifically, the team project aimed to integrate smart sensing technologies with PPE such as smart helmet, smart vest, and smart wristband to provide critical physiological and environmental information that can significantly improve situational awareness while allowing workers to receive updates without diverting their attention from their tasks. Engaging in this hands-on project enabled students to apply theoretical knowledge to practical scenarios, enhancing their comprehension of the materials and concepts present in lectures. Throughout this hands-on team project, students gained a more comprehensive understanding of the multifaceted construction safety and health issues and how innovative wearable technologies leveraging sensing techniques are utilized on worksites nowadays. The team-based approach not only developed their technical skills but also significantly improved their communication and collaboration abilities. Students learned to articulate their ideas clearly, listen actively, and resolve conflicts constructively, creating a collaborative environment that nurtured mutual respect and understanding. Feedback from students regarding this pedagogical exploration was overwhelmingly positive. They expressed appreciation for the opportunity to test cutting-edge technologies in a practical setting, and highlighted how the project deepened their understanding of construction safety issues. They valued active learning, which made the theoretical aspects of their studies more relevant and applicable. This educational experience highlights the importance of a pedagogical framework that combines active learning strategies with advanced technology integration, as we strive to prepare students to become proactive leaders competent to tackle the complex safety challenges that they will encounter in the workplace after school.

Keywords:

Smart Sensing Techniques, Wearable Technologies, Undergraduate Education, Active Learning Strategies, Situational Awareness

1. Introduction

The construction industry is a dynamic and high-risk field, requiring continuous innovation to safeguard worker safety and maintain operational efficiency. Despite advancements in personal protective equipment (PPE) and safety protocols, workplace accidents remain a persistent challenge due to issues such as limited customization of protective gear, inconsistent safety practices, and the slow adoption of advanced technologies [1]. Traditional PPE often adheres to a “one size fits all” design, overlooking ergonomic and gender-specific needs, while high costs, data privacy concerns, and the need for specialized training hinder the integration of smart technologies into construction safety practices [2]. These challenges underscore the necessity of preparing a workforce equipped not only with theoretical knowledge but also with practical expertise to develop and implement innovative solutions that enhance safety. In this context,

construction safety education plays a pivotal role in preparing students to tackle the complexities of real-world challenges.

The integration of advanced technologies such as smart sensing systems and wearable devices has revolutionized how safety is managed on construction sites. Smart PPE, including smart helmets, vests, and watches, has emerged as a transformative solution, offering real-time physiological and environmental data that enhances situational awareness and decision-making. These innovations align with the broader trend of Industry 4.0, where digital technologies are seamlessly integrated into traditional practices to improve productivity, safety, and sustainability. To prepare future engineers for this rapidly evolving landscape, it is essential to incorporate these advancements into the educational framework. Active learning strategies, such as team-based projects, provide an ideal platform for students to explore and apply these technologies. By engaging in hands-on activities that simulate real-world scenarios, students develop a deeper understanding of construction safety issues and the role of smart technologies in addressing them.

As construction safety becomes increasingly complex and technology-driven, engineering education must adapt to prepare students for real-world challenges. A study on engineering curriculum development emphasizes the importance of connecting theoretical knowledge with skills tailored to career requirements. It advocates for incorporating practical, application-based learning into engineering programs to equip students more effectively for workforce challenges [3]. Integrating hands-on, technology-focused projects into the curriculum bridges this gap, enabling students to engage directly with advanced tools such as smart sensing technologies and wearable PPE. These experiential learning opportunities not only enhance technical knowledge but also foster essential soft skills like teamwork, communication, and adaptability. By working on innovative projects, students gain exposure to emerging trends and develop a mindset of continuous learning and innovation. This paper presents a case study on an undergraduate team project that utilized advanced sensing technologies to enhance construction safety education, highlighting the value of active learning in preparing future engineers to lead in safety, efficiency, and resilience.

2. Research Background

2.1 Smart Sensing and Wearable Technologies

Smart sensing and wearable technologies represent a paradigm shift in the field of construction safety, offering innovative solutions to mitigate risks and improve workplace efficiency [4]. Smart sensing technologies utilize sensors to collect, process, and transmit various types of information, including data on environmental and physiological conditions [5]. Sensors embedded in wearable devices such as accelerometers, gyroscopes, temperature sensors, and heart rate monitors enable continuous monitoring of worker status and site conditions. The data collected by these sensors are often processed using embedded systems or transmitted to cloud-based platforms for analysis, enabling real-time alerts and actionable insights. These technologies combine real-time data acquisition, advanced sensors, and user-friendly interfaces to enhance situational awareness and facilitate proactive decision-making [6]. This section

explores the core principles of smart sensing, the functionality of wearable technologies, and their applications in construction safety.

One key advantage of smart sensing is its ability to identify potential hazards before they lead to accidents. For instance, temperature sensors can detect extreme heat conditions that could cause heat stress [7], while gas sensors can alert workers to the presence of harmful substances [8]. These features provide a critical layer of safety, particularly in high-risk construction environments. Wearable technologies, integrated with smart sensing systems, are designed to address specific safety and health concerns in construction. Smart helmets, for example, are equipped with cameras, sensors, and augmented reality (AR) displays that enhance situational awareness [9]. They can detect proximity to hazardous equipment, monitor head impacts, and provide visual overlays of critical site information. Smart vests integrate advanced technologies such as GPS trackers, temperature sensors, and vibration-based alert systems to facilitate real-time location tracking and environmental monitoring, thereby enhancing worker safety and reducing occupational risks [10]. Similarly, smartwatches equipped with heart rate monitors and motion sensors track workers' physiological conditions, detect signs of fatigue, overexertion, or inactivity, and enable supervisors to intervene proactively [11]. These wearable devices are often interconnected through wireless communication protocols such as Bluetooth or Wi-Fi, forming an Internet of Things (IoT) ecosystem. This interconnectedness facilitates seamless data sharing, thereby improving the overall efficiency of safety management systems.

2.2 Applications in Construction Safety

The implementation of smart sensing and wearable technologies offers significant advancements in construction safety. Physiological sensors can monitor vital signs and alert supervisors to potential health risks, such as heat stress or elevated heart rates. Smart PPE enhances situational awareness by providing workers with real-time updates and warnings, including alerts about nearby heavy machinery or unstable structures [12]. Additionally, advanced hazard detection systems help prevent incidents by identifying risks like falls or exposure to harmful gases. Wearable technologies also play a crucial role in training by tracking workers' movements and offering feedback to improve techniques and ensure adherence to safety protocols.

Despite these benefits, challenges such as high implementation costs, data privacy concerns, and the need for worker training hinder the widespread adoption of these technologies [13]. However, ongoing advancements and decreasing hardware costs present opportunities to address these barriers. Incorporating these technologies into construction safety education provides students with practical experience and exposure to tools that are reshaping the industry. This approach not only enhances their technical proficiency but also instills an appreciation for the role of technology in creating safer workplaces.

The following sections discuss the educational framework used to introduce these technologies to students, with an emphasis on a team-based project designed to promote active learning and skill development.

3. Case Study and Class Implementation

3.1 Team-Based Learning in Undergraduate Construction Safety Course

The project for the 2024 Spring semester integrated advanced sensing technologies and beginner-friendly programming tools into construction safety education through a structured three-week, team-based activity. This project directly supports the use of sensing technologies and beginner-friendly programming tools to enhance safety practices in accordance with Occupational Safety and Health Administration (OSHA) standards [14]. The focus was on smart PPE and its role in enhancing worker safety for future engineers. Over the three-week activity, student teams of four members researched smart PPE options, programmed sensors, analyzed collected data, and presented their findings on how these technologies could address safety challenges in construction.

The key content components of the project focused on three interconnected areas: smart sensing technologies, OSHA standards compliance, and their integration into construction safety practices. Students were introduced to smart sensing technologies, such as wearable sensors, and used these technologies to collect real-time data on various environmental conditions, including temperature, noise levels, and physical activity. This data was used to monitor potential hazards, assess worker fatigue, and track vital signals to ensure safety on construction sites. The project emphasized the importance of adhering to OSHA standards by teaching students how to apply these guidelines in real-world scenarios, ensuring that the sensing technologies were not only innovative but also compliant with industry safety requirements. Additionally, students gained hands-on experience with Arduino microcontrollers and similar tools to gather and process sensor data, developing skills to program and configure setups that displayed results in accessible and user-friendly formats. Finally, to bridge the gap between traditional safety practices and modern technologies, students designed and developed a prototype based on traditional PPE, enhancing it with smart sensing capabilities. This transformation into “smart PPE” demonstrated the practical integration of advanced technologies to improve workplace safety in construction.

3.2 Project Design and Schedules

The team-based project was structured around four comprehensive team assignments designed to guide students step by step through the prototype design process (as shown in Figure 1). The initial phase centered on team discussions aimed at brainstorming and identifying the PPE for the project. During this stage, each team proposed a PPE design that included key details such as a unique design name, at least two sensing signals to be utilized, two potential workplace hazards the PPE is intended to mitigate, and the relevant OSHA standards to ensure compliance and safety.

Following the ideation phase, the project transitioned into the design and planning stage, during which teams created detailed sketches of their proposed PPE. This phase involved identifying and labeling the key components of the design, selecting a minimum of two suitable sensors to enhance functionality, and ensuring appropriate software tools were chosen and installed to facilitate sensor integration. This provided students with a foundation for understanding the technical requirements of their design. The necessary materials, including sensors, microcontrollers, and other electronic components, were provided in class for use. Sensors, such as temperature and light sensors, along with the Arduino board as the microcontroller, were

selected for their accessibility and cost-effectiveness, making them particularly well-suited for this application. The next assignment required teams to bring their designs to life by connecting the selected sensors to their prototype and collecting real-time data. This stage emphasized the practical application of sensing technologies, data acquisition, and troubleshooting sensor connectivity, helping students bridge the gap between theoretical knowledge and hands-on implementation.

In the final stage, teams focused on the full integration of the sensing technologies into their PPE prototypes. This involved testing the functionality of their designs, refining them based on performance, and ensuring that the prototype addressed the previously identified hazards effectively. The project culminated in a formal presentation, where each team showcased their innovative PPE designs, discussed the challenges they encountered, and highlighted how their solutions aligned with OSHA standards and contributed to enhancing workplace safety practices.

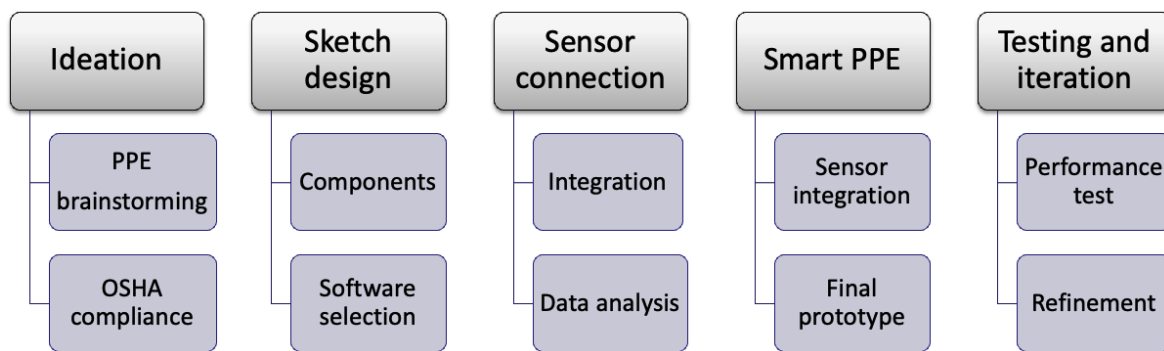


Fig. 1. Key components of the team-based project.

3.3 Collaboration Process and Final Showcase

The collaboration process formed the foundation of the project, emphasizing the integration of creativity, technical skills, and teamwork. Teams worked collaboratively to ideate, plan, and execute their prototype designs while ensuring alignment with project goals and safety standards. The process began with brainstorming sessions, where team members shared ideas and evaluated potential solutions to address workplace hazards through innovative PPE designs. This phase encouraged open communication and creative problem-solving, allowing teams to refine their concepts collectively.

As the collaboration progressed, teams developed detailed sketches of their designs, highlighting key components and sensor placements within the PPE. Each team member contributed to critical decisions, such as selecting suitable sensors, defining technical requirements, and identifying software tools for data collection and analysis, as shown in Figure 2(a), (b) and (c). This collective effort extended into the implementation phase, where tasks were distributed among team members to connect sensors, test functionality, and troubleshoot technical issues. The process underscored the importance of coordination and mutual support as teams worked through challenges to bring their prototypes to life.

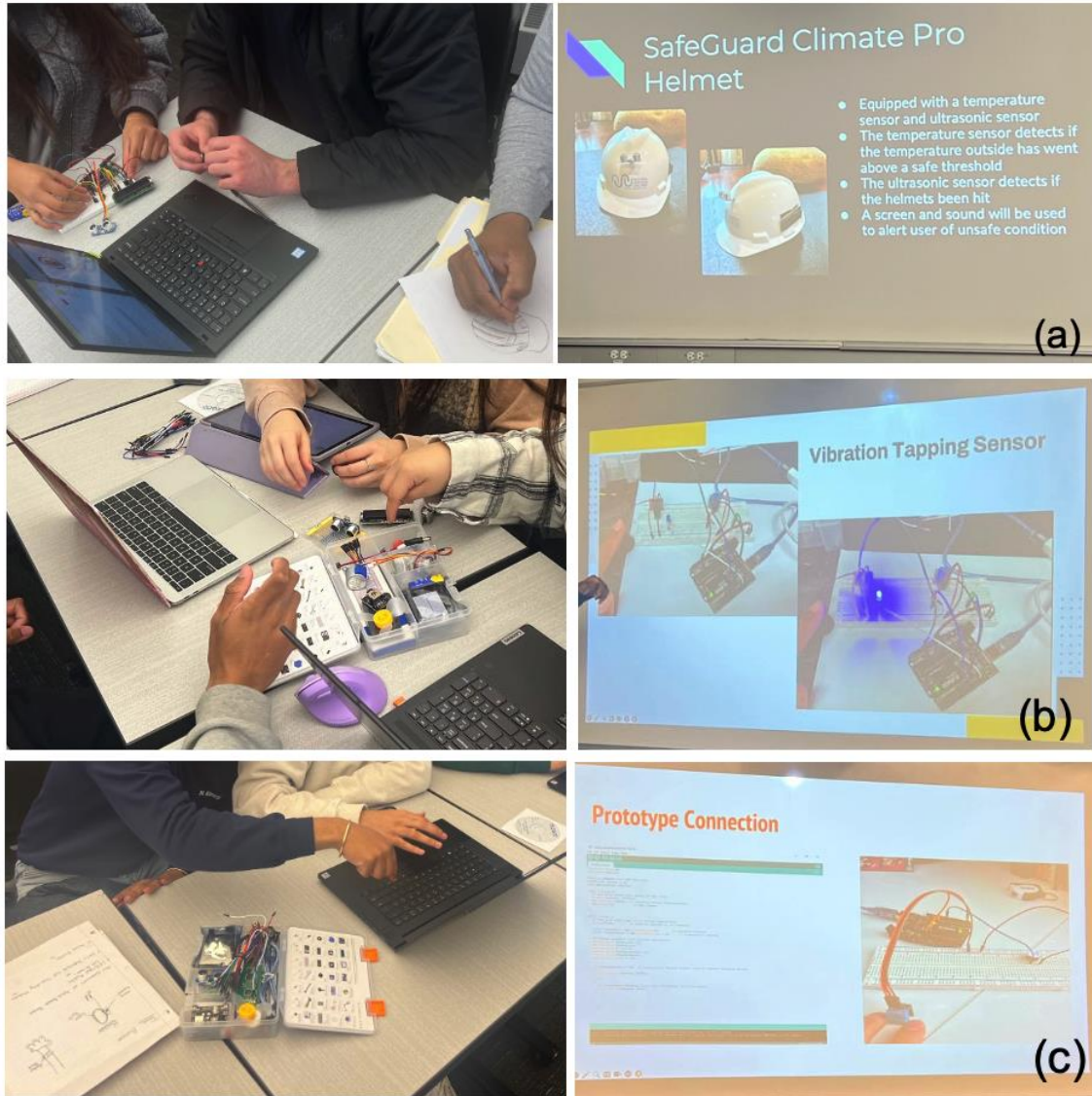


Fig. 2. Team collaborations and final presentations by three teams in the Construction Safety class: (a) smart helmet design, (b) smart vest design, and (c) smart wristband design.

The project concluded with teams presenting their innovative solutions, highlighting the outcomes of their efforts and demonstrating how collaboration and diverse perspectives contributed to practical and impactful results (see Figure 2). One team focused on the smart helmet, which was designed to detect head injuries from falls or collisions and immediately notify workers through alert lighting. Another team developed the smart vest, which featured embedded environmental sensors to monitor temperature and excessive vibrations. The vest was designed to alert workers when hazardous conditions, such as extreme heat or prolonged exposure to strong vibrations, were detected. The third team introduced the smart wristband, a wearable device designed to track workers' physiological conditions, such as heart rate and skin temperature. The team highlighted its potential to prevent accidents caused by excessive heat exposure. Teams rigorously tested their prototypes, refined them based on performance feedback,

and ensured their designs met the required safety standards while effectively addressing identified hazards. Each presentation underscored the role of sensor technology, real-time data monitoring, and user-centered design in enhancing workplace safety.

3.4 Impact on Student Learning and Assessment Plan

3.4.1 Student Learning Impact

This hands-on project fosters teamwork, problem-solving, and technical skills, while providing foundational exposure to sensing technologies and data-driven analysis, preparing students for future roles in construction safety and technology. Measurable learning outcomes for this course were:

1. Understand the role of sensing technologies in improving construction safety.
2. Apply basic programming skills to microcontrollers (e.g., Arduino) for sensor data collection.
3. Analyze real-time environmental data to identify safety risks.
4. Develop teamwork, problem-solving, and technical presentation skills.

The project is anticipated to have a strong impact on student engagement, understanding, and skill development by incorporating hands-on, team-based activities focused on real-world applications. By working with microcontrollers such as Arduino and smart sensing technologies, students are actively involved in designing and implementing solutions that address critical construction safety issues. This active learning approach fosters curiosity, motivation, and deeper engagement, as students see a direct connection between their work and practical safety challenges in the construction industry. The project enhances understanding by allowing students to explore how smart PPE can monitor environmental hazards like temperature, noise levels, or physical fatigue. By collecting and analyzing data from sensors, students gain practical experience in data-driven decision-making. Using beginner-friendly tools, they identify patterns and learn how technology can improve safety outcomes. This exposure clarifies emerging technologies and builds students' confidence in applying technology to solve real-world problems.

For the construction safety course, this project is particularly meaningful because it bridges the gap between theoretical concepts and hands-on skills. Students develop foundational technical competencies in PPE design, programming, sensor integration, and data analysis while also strengthening their critical thinking, problem-solving, and teamwork abilities. This approach ensures students are better prepared for the evolving construction industry, where integrating sensing technologies and AI-driven tools is becoming increasingly important for safety and innovation.

3.4.2 Assessment Plan

Student learning and project effectiveness were assessed through a combination of project deliverables, peer evaluations, and reflective surveys. The assessment focused on both the technical skills gained and the collaborative process throughout the project.

1. Project deliverables: Each team were required to submit a final prototype and presentation, showcasing their research, design, and analysis of one smart PPE solution. The deliverables were evaluated on the sensor connection, data analysis, the feasibility of safety solutions, and the integration of sensing technologies and programming tools.
2. Peer evaluations: Students completed peer evaluations to assess individual contributions to the team project. This helped gauge teamwork, communication, and collaboration skills, which are essential in real-world engineering environments.
3. Reflective surveys: At the end of the project, students completed a reflective survey to evaluate their understanding of the technologies used, their experience in applying programming tools, and their perception of the project's relevance to construction safety. These surveys provided insights into student engagement and learning outcomes.
4. Instructor feedback: Regular check-ins during the project allowed the instructor to assess progress, address challenges, and provide formative feedback. This feedback helped identify areas for improvement and adjust the project approach as needed.

The combined assessment results provided a comprehensive understanding of the project's impact on student learning. The findings highlighted the effectiveness of integrating advanced technologies in enhancing technical and collaborative skills while fostering student engagement in hands-on problem-solving. Additionally, the assessment offered valuable insights for the continuous improvement of instructional approaches. Furthermore, the integration of technology, collaboration, and experiential learning is inherently flexible and can be effectively tailored to diverse educational contexts by taking into account institutional resources, faculty expertise, and learner characteristics.

4. Conclusions

This paper introduces a novel approach to construction safety education by integrating hands-on sensing technologies and beginner-friendly programming tools into a team-based learning experience. Traditional methods in construction safety classrooms often rely on lectures, textbooks, and theoretical discussions about hazards and safety protocols, such as those outlined by OSHA. While these methods provide foundational knowledge, they often lack practical engagement and real-world applications that inspire deeper learning. What distinguishes this approach is the integration of technology and active learning. Specifically, through a hands-on team project, students work with microcontrollers to collect real-time environmental data, such as temperature, noise levels, or physical movement, simulating actual safety monitoring systems used on construction sites. Instead of passively learning about safety risks, students actively design, test, and analyze smart PPE solutions. By leveraging simple programming tools, students process and interpret sensor data to identify patterns and safety trends, introducing them to emerging technological concepts in an accessible way. This project also fosters innovation and critical thinking, encouraging students to brainstorm practical solutions to real-world safety challenges.

By integrating technology, teamwork, and practical application, this team-based project offers a unique and forward-looking learning experience that prepares students for the evolving demands of the construction industry. The construction sector is increasingly shaped by advanced technologies such as robotics and IoT, and incorporating these tools into educational frameworks

ensures students are equipped to enhance safety and optimize workflows. However, the assessment of this project's impact is currently limited to student feedback collected during the course and does not include its long-term influence on career readiness. Future efforts will focus on developing mechanisms for collecting post-graduation feedback to evaluate the lasting effects of this approach on students' ability to meet industry demands and its contribution to the continued advancement of safety practices.

References

- [1] 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.
- [2] Y. Ding, X. Luo, "Personal Protective Equipment Detection in Extreme Construction Conditions," arXiv preprint arXiv:2307.13654. 2023.
- [3] S. R. Brunhaver, R. F. Korte, S. R. Barley, and S. D. Sheppard, "Bridging the Gaps between Engineering Education and Practice," in University of Chicago Press eBooks, 2018, pp. 129–164. doi: 10.7208/chicago/9780226468471.003.0005..
- [4] V. Patel, A. Chesmore, C. M. Legner, and S. Pandey, "Trends in workplace wearable technologies and Connected-Worker solutions for Next-Generation occupational safety, health, and productivity," *Advanced Intelligent Systems*, vol. 4, no. 1, Sep. 2021, doi: 10.1002/aisy.202100099.
- [5] M. J. Rodrigues, O. Postolache, and F. Cercas, "Physiological and Behavior Monitoring Systems for smart healthcare Environments: a review," *Sensors*, vol. 20, no. 8, p. 2186, Apr. 2020, doi: 10.3390/s20082186.
- [6] T. Coito, B. Firme, M. S. E. Martins, S. M. Vieira, J. Figueiredo, and J. M. C. Sousa, "Intelligent sensors for Real-Time Decision-Making," *Automation*, vol. 2, no. 2, pp. 62–82, May 2021, doi: 10.3390/automation2020004.
- [7] National Safety Council. *Vital Signs Monitoring: Heat Stress*. National Safety Council, [n.d.], www.nsc.org/getmedia/cb48288d-afd5-45da-976a-fa6cb6e12e8b/wtz-wp-vital-signs-monitoring-heat-stress.pdf. Accessed 12 Jan. 2025.
- [8] J. P. P. Rajakumar and J.-H. Choi, "Helmet-Mounted Real-Time toxic gas monitoring and Prevention system for workers in confined places," *Sensors*, vol. 23, no. 3, p. 1590, Feb. 2023, doi: 10.3390/s23031590.
- [9] A. F. García et al., "Smart Helmet: Combining Sensors, AI, Augmented Reality, and Personal Protection to Enhance First Responders' Situational Awareness." *IT Professional* 25.6 (2023).
- [10] C. Nnaji, I. Awolusi, J. Park, and A. Albert, "Wearable Sensing Devices: towards the development of a personalized system for construction safety and health risk mitigation," *Sensors*, vol. 21, no. 3, p. 682, Jan. 2021, doi: 10.3390/s21030682.
- [11] S. S.-H. Liu et al., "Applying a smartwatch to predict work-related fatigue for emergency healthcare professionals: Machine learning method," *Western Journal of Emergency Medicine*, vol. 24, no. 4, Jul. 2023, doi: 10.5811/westjem.58139.
- [12] S. Márquez-Sánchez, I. Campero-Jurado, J. Herrera-Santos, S. Rodríguez, and J. M. Corchado, "Intelligent platform based on smart PPE for safety in workplaces," *Sensors*, vol. 21, no. 14, p. 4652, Jul. 2021, doi: 10.3390/s21144652.

- [13] S. Tabatabaee et al., “Investigating the barriers to applying the Internet-of-Things-Based technologies to construction site safety management,” *International Journal of Environmental Research and Public Health*, vol. 19, no. 2, p. 868, Jan. 2022, doi: 10.3390/ijerph19020868.
- [14] Occupational Safety and Health Administration (OSHA). (2023). *Safety and health regulations for construction (29 CFR 1926)*. Retrieved from <https://www.osha.gov/laws-regs/regulations/standardnumber/1926>.