ICCEPM 2024 https://dx.doi.org/10.6106/ICCEPM.2024.1212
The 10th International Conference on Construction Engineering and Project Management
Jul. 29-Aug.1, 2024, Sapporo

Enhancing Construction Jobsite Safety Training Through iSAFE-Education: A Novel Approach Using Industry 4.0 Technologies

Mehrtash SOLTANI[1*], Akeem PEDRO[1], Rahat HUSSEIN[1], Si Van TIEN TRAN[1], Aqsa SABIR[1], Doyeop Lee[1], Chansik PARK[1]

[1] *School of Architecture and Building Science, Chung-Ang University, Seoul 06974, Republic of Korea,*

E-mail address: mehrtashsoltani@gmail.com, lanrepedro3@gmail.com, rahat4hussain@gmail.com, sitran@cau.ac.kr, aqsasabir786@gmail.com, doyoeop@cau.ac.kr, cpark@cau.ac.kr

Abstract: Traditional safety training methods in construction, such as toolbox meetings and classroom sessions, fall short of addressing the challenges faced by workers, especially migrant workers hindered by barriers. The compliance-driven nature of safety management practices is identified as a core issue, often disconnected from the realities of the jobsite. To tackle these limitations, we propose iSAFE-Education, an approach harnessing Industry 4.0 technologies. By integrating Virtual Reality (VR) and Metaverse environments into safety training, this platform immerses workers in authentic jobsite contexts using 360-degree panorama images. Our method provides virtual walkthroughs, enabling workers to familiarize themselves with site-specific features and safety protocols. Additionally, iSAFE-Education facilitates site assessment and safety information sharing among project participants within the immersive jobsite environment. This paper highlights the importance of hazard information delivery and positions this solution as an answer for enhancing jobsite safety in contemporary construction settings.

Keywords: Industry 4.0, Virtual Reality, Metaverse, Safety Training, Construction, 360 Panorama, Digital Twin, Artificial Intelligence, Safety Culture.

1. INTRODUCTION

The construction industry faces a significant safety training conundrum, with a gap between current methods and the evolving challenges faced by workers ([1] ;[2] ;[3]). This is particularly evident in the management of multinational workforces, where compliance, cultural differences, and worker welfare pose complex challenges [4]. This paper examines the limitations of safety management practices, driven by compliance and lacking in contextual relevance to construction scenarios. The prevailing compliance-focused approach in construction safety creates a gap between knowledge and challenges on-site, exacerbated by barriers for migrant workers. Standardized training methods often overlook nuances, leaving workers ill-equipped to address safety risks. Recognizing these shortcomings, the paper advocates for a solution, iSAFE-Education, which integrates Industry 4.0 technologies like Virtual Reality (VR) and Metaverse to offer immersive, contextually relevant safety training experiences tailored to worksites.

The construction industry faces a challenge as its safety training methods fail to align with the realities of the job site. Current practices prioritize documentation over application, resulting in a disconnect between safety knowledge and on-site complexities. This issue is exacerbated for migrant workers, who encounter barriers that hinder their understanding and implementation of safety protocols [5]. Additionally, the generic nature of existing training neglects site-specific nuances, leaving workers ill-prepared to navigate job-specific risks, ultimately increasing the potential for on-site accidents and injuries. Figure 1 illustrates the existing safety management practices alongside their associated constraints and shortcomings.

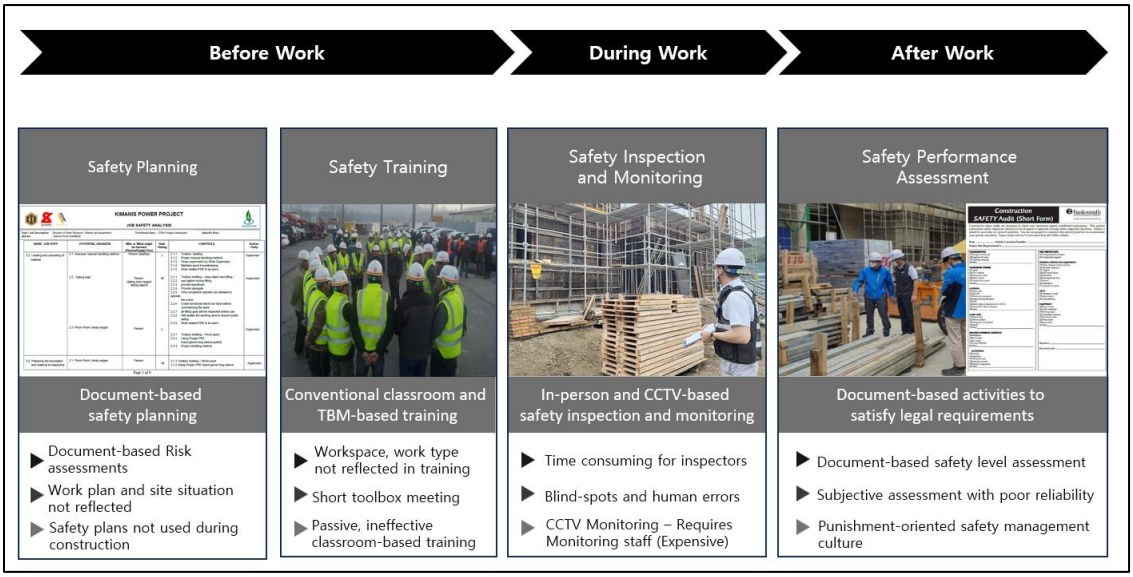

Figure 1. Current safety management practice and their limitations

To address industry shortcomings, a tailored safety training method is crucial, especially considering challenges faced by migrant workers like barriers. Incorporating site-specific nuances can bridge theory and practice, enhancing standards and workforce resilience. iSAFE-Education offers a solution by leveraging Industry 4.0 technologies such as the Metaverse and Virtual Reality to enrich construction safety training. Through 360-degree images, iSAFE-Education ensures application of safety knowledge on worksites, aligning training with dynamics for a workforce.

The objective of this study is to utilize VR Immersion and Metaverse Integration to enhance safety education in the construction industry by immersing workers in 360-degree construction site images and leveraging the metaverse for communication, addressing language barriers, and providing culturally relevant safety training for migrant workers.

2. LITERATURE REVIEW

The construction industry faces a significant safety dilemma due to the misalignment between existing safety training methodologies and the dynamic challenges of the jobsite [6]. Current safety management practices, which are largely compliance-driven, do not effectively address these challenges [7]. There is a need for a shift towards education, training, and information dissemination to improve safety [7]. Another study [8] suggests a multi-level approach to safety management, focusing on safety systems, skills, leadership, and behavior. The industry should also consider proactive measures and leading indicators to prevent accidents [9]. Effective safety-knowledge management strategies are crucial for adapting to the industry's dynamic nature [10]. The role of individual and situational factors in safety practices should be further explored [11]. Lastly, a work design perspective can provide practical measures to improve safety [12]. A range of studies have highlighted the challenges faced by migrant workers in the construction industry, particularly in relation to safety training. Language barriers and cultural disparities have been identified as key impediments to effective safety communication and knowledge transfer ([5]; [13]; [14]). These challenges are further compounded by the perception of safety and the use of coercive strategies [15]. To address these issues, a number of recommendations have been proposed, including the use of non-technical skills in safety training [14], the consideration of cultural and attitude barriers [16], and the

provision of mandatory safety training in multiple languages [17]. The role of occupational health nursing in addressing these challenges has also been emphasized [18]. The construction industry's safety training is hindered by a one-size-fits-all approach that fails to address site-specific nuances [13]. This approach is further limited by the transfer of responsibility to contractors [19], and the need for a focus on safety during the design phase [19]. Context-based assessment systems [20] and game technology-based safety training platforms [21] have been proposed as potential solutions. However, the industry still struggles with safety knowledge management [10] and insufficient safety education in curricula [22]. A range of studies have explored the potential of virtual reality (VR) and metaverse environments in construction safety training. These studies ([23] and [24]) highlight the potential of VR in engaging workers and enhancing safety knowledge, but also note the need for further improvements. In addition, other studies, ([25] and [26]) emphasize the importance of experiential training and the benefits of VR in creating immersive and interactive learning experiences. Meanwhile, other researches [27] and [28] further underscore the potential of VR in simulating real-world construction scenarios and improving safety performance and, [29] and [30] both propose innovative VR-based training solutions, with Acar focusing on e-learning and Chen on hazard recognition. These studies collectively suggest that VR and metaverse environments have the potential to revolutionize construction safety training, but also highlight the need for ongoing research and development in this area.

3. THE PROPOSED SOLUTION

The iSAFE platform (Figure 2) integrates technology to enhance job-site safety, comprising components such as iSAFE-Planning, iSAFE-Guard, and iSAFE-Incentive. iSAFE-Planning involves the placement of cameras and sensors for risk assessment, while iSAFE Guard utilizes video-based AI and sensor technologies for risk detection and monitoring. iSAFE-Incentive employs blockchain technology for data integrity and incentivizes workers for compliance with safety protocols, promoting a safety culture. Central to the system, iSAFE-Education offers safety education within a virtual environment that simulates construction site conditions. This component prepares workers to identify and respond to hazards, emphasizing the importance of safety practices by providing training through advanced immersive technologies such as virtual reality and the Metaverse. The integration of technology with education by the iSAFE platform aims to reduce accidents and enhance safety and efficiency on construction sites.

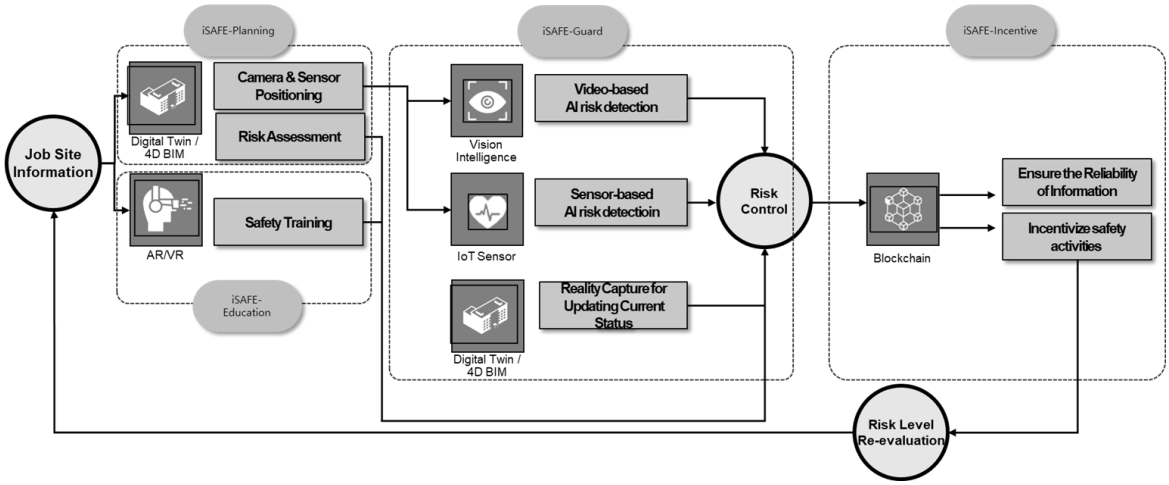

Figure 2. iSAFE Platform

3.1. iSAFE-Education Advancements

iSAFE-Education transforms education by seamlessly integrating virtual reality (VR) and metaverse technologies. Offering an environment that reflects changing jobsite conditions, the platform efficiently delivers safety education for trades and job types. Through content development, scenario simulations, and interactions facilitated by metaverse integration, iSAFE-Education enhances hazard recognition skills and promotes a collaborative safety management culture. By immersing workers in scenarios, this approach equips them with knowledge and skills to contribute to practices, improving safety outcomes and potentially saving lives in the construction industry.

3.2. Integrating Reality and BIM for Metaverse Modeling

To elucidate the evolution of iSAFE-Education's development process in generating virtual models grounded in reality capture and BIM data, it harnesses technologies like reality capture and Building Information Modeling (BIM). Through techniques like photogrammetry or LiDAR scanning, environments are digitally replicated, capturing spatial data. BIM data provides information about building components and structures. Creating a Metaverse environment is achieved through the integration of reality capture and BIM-3D Mesh matching techniques. This involves aligning 3D-Mesh data with BIM models, ensuring representation of physical spaces in the virtual world. The 3D-Mesh generation technology covers algorithms that process reality capture data, converting it into mesh models. Meanwhile, the BIM & 3D-Mesh Matching System employs algorithms to align BIM data with 3D-Mesh models, enabling integration of real-world and virtual environments. These technologies lay the foundation for immersive and accurate Metaverse environments, facilitating applications from virtual training simulations to design processes. Figure 3 depicts the process of generating virtual models through reality capture techniques and Building Information Modeling (BIM).

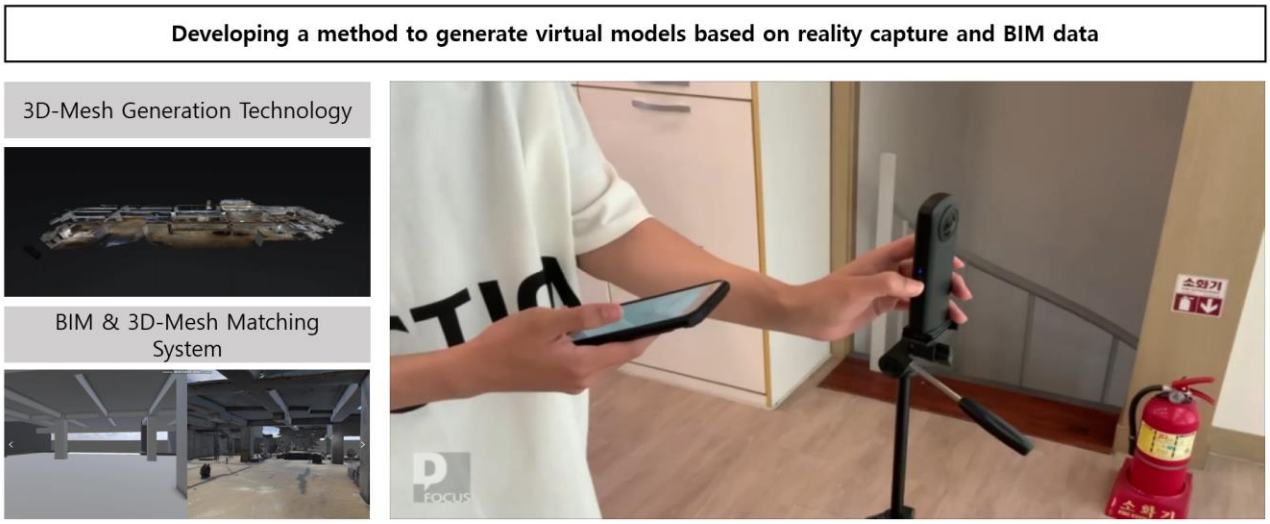

Figure 3. Generating virtual models based on reality captures and BIM.

3.3. Remote Monitoring & Custom Training

In iSAFE, site Risk Assessment and Management involves a comprehensive approach to identify, mitigate, and manage hazards on construction sites. Once hazards are identified through assessment processes, such as site inspections or risk analysis, appropriate mitigation and elimination procedures will be proposed. These procedures aim to reduce the likelihood and severity of potential accidents or incidents. What sets this approach apart is its ability to leverage remote monitoring and verification techniques, allowing for

real-time oversight of risk management activities. Also, the integration of 2D/360-based TBM (Toolbox meeting) Safety Training content generation as it demonstrated in Figure 4 enhances the safety culture by providing tailored training materials specific to potential hazards encountered during specific work situations. This approach ensures that workers are adequately trained to recognize and respond to hazards associated with TBM operations, thereby reducing the likelihood of accidents and injuries.

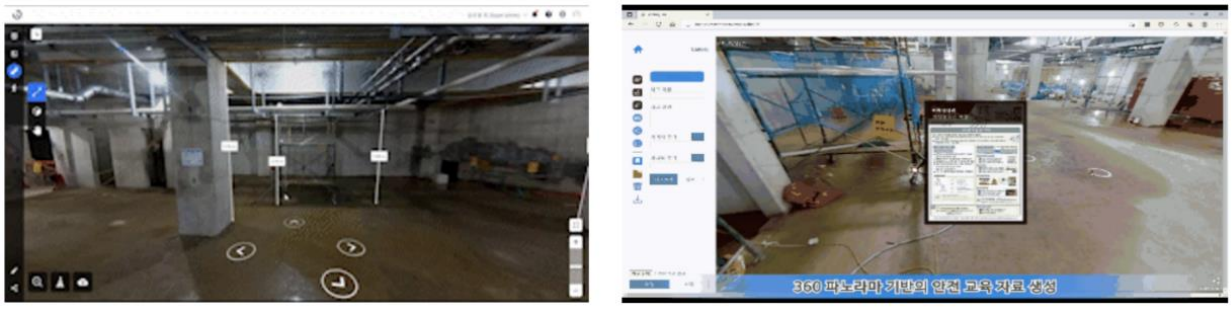

Figure 4. The iSAFE-Education Platform dashboard

4. METAVERSE SAFETY SOCIAL PLATFORM - DEVELOPMENT AND FUNCTIONALITY

The development of the creating virtual site model of iSAFE-Education involves technologies to blend construction sites into the metaverse. As explained in Figure 5, through computer vision algorithms, the platform processes photo-based 3D-Mesh information, converting images into virtual models. Additionally, the integration of BIM model-based 3D information ensures a representation of construction sites. This includes architectural, structural, and material properties details, providing users with a virtual environment. These models serve as the foundation for the platform's educational and simulation features.In the development of content generation tools, an approach caters to user requirements. Non-Player Characters (NPCs) guide users through safety guidelines and construction procedures. A physics engine simulates accident events based on user actions and environmental factors, fostering learning. Automatic translation features facilitate communication among users, enhancing collaboration on construction sites. Checklists ensure adherence to safety protocols. The platform promotes safety equipment and methods, facilitating an educational experience. Simulation capabilities allow users to visualize and interact with construction projects, advancing understanding. Communication between avatars enriches the environment.

The reward and trading system introduces an economic aspect to the metaverse, promoting safety and incentivizing user participation. Within the platform, cryptocurrency is assigned to contents, encouraging the creation of safety and construction-related materials. Users receive rewards for completing education modules, promoting learning among technicians and apprentices. Individual safety competency is evaluated, ensuring expertise within the platform. NFT transactions enable the exchange of virtual models and content. This establishes a virtual economy and promotes the sharing of construction methods within the metaverse. The integration of cryptocurrency and NFTs creates an incentive structure, fostering a community focused on construction safety and advancement.

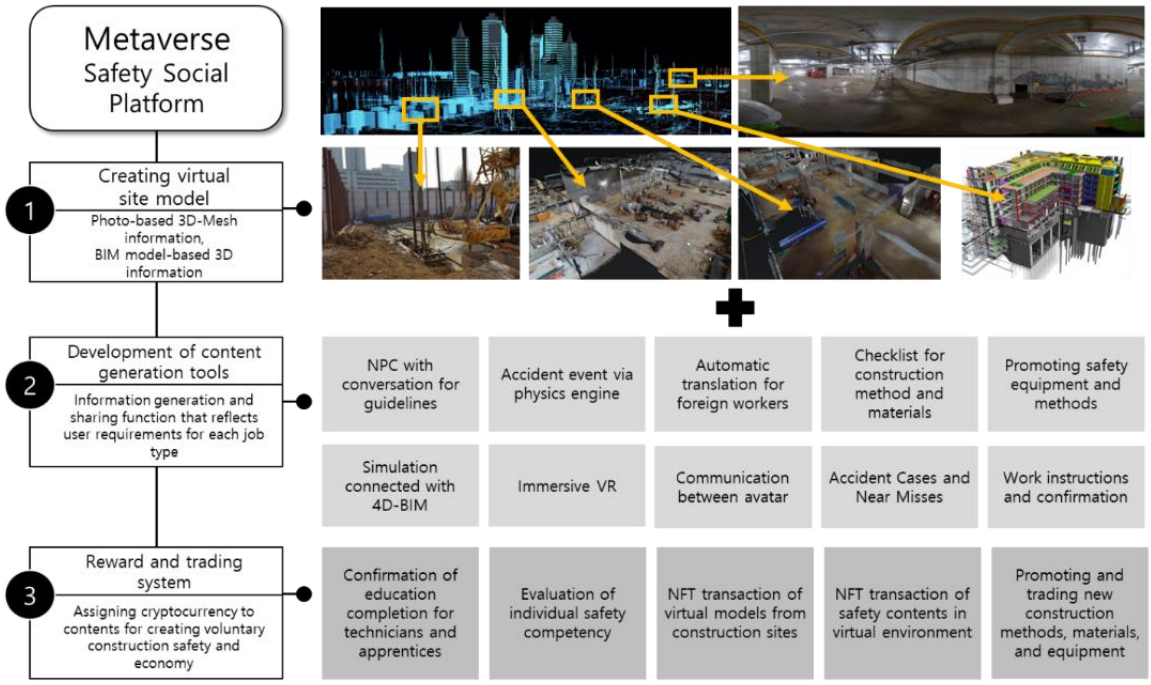

Figure 5. The Metaverse safety socials development

The social platform operates on a decentralized architecture utilizing blockchain technology to ensure transparency, security, and traceability of interactions. Each contributor, including health and safety agencies, workers, managers, and safety content creators, has a unique digital identity linked to a blockchain-based user profile. This profile securely stores user information, activity history, and token balances. Contributors interact with the platform through a user-friendly interface accessible via web or mobile applications. Upon accessing the platform, users can explore various features and functionalities tailored to their roles and interests. The social platform operates as an integrated ecosystem leveraging technologies to promote workplace health and safety. Users have the capability to create, upload, and share diverse content formats, ranging from articles to VR experiences, with content stored on a distributed file system and metadata recorded on the blockchain to ensure authenticity and integrity. Furthermore, the platform offers VR training modules developed in collaboration with health and safety agencies, enabling users to simulate scenarios and practice safety protocols in a virtual environment, with user progress and performance metrics tracked and stored on the blockchain for evaluation. Real-time chat and direct voice communication features facilitate collaboration and knowledge sharing among users, especially in emergency situations, while a rewards system incentivizes participation and contributions, with tokens earned through activities and governed by smart contracts to ensure fairness and transparency. The platform's blockchain infrastructure serves as a decentralized ledger to record all user interactions, content contributions, and token transactions, enhancing transparency and trust among users and stakeholders, fostering a community dedicated to promoting workplace health and safety.

5. CONCLUSION

In conclusion, the paper highlights the inadequacies of traditional safety training methodologies in the construction industry, particularly in addressing challenges faced by workers, including migrant laborers. It underscores the disconnect between compliance-driven safety management practices and the realities of construction sites, emphasizing the need for a transformative approach. The proposed iSAFEEducation

solution, leveraging Industry 4.0 technologies such as Virtual Reality and metaverse environments, offers a solution to bridge this gap. By immersing workers in realistic job-site scenarios and tailoring training to their specific work environments, iSAFEEducation revolutionizes safety education, fostering a collaborative safety culture and enhancing overall safety outcomes. With its potential to revolutionize safety training and elevate the construction industry's safety landscape, iSAFEEducation represents a significant step towards ensuring the well-being of workers and promoting a safer workforce in the digital age.

6. ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. NRF-2022R1A2B5B02002553). We also need to acknowledge the support of the "National R&D Project for Smart Construction Technology (No.RS-2020-KA156291)" funded by the Korea Agency for Infrastructure Technology Advancement under the Ministry of Land, Infrastructure and Transport, and managed by the Korea Expressway Corporation.

7. REFERENCES

[1] M. Namian, S. Kermanshachi, M. Khalid, and A. Al-Bayati, “Construction Safety Training: Exploring Different Perspectives of Construction Managers and Workers,” in *2020 ASEE Virtual Annual Conference Content Access Proceedings*,

[2] C. Choi, Dajeong ; Koo, “Impact of personal characteristics on learning performance in virtual reality-based construction safety training - Using machine learning and SHAP -,” *Korean J. Constr. Eng. Manag.*, vol. 24, no. 6, pp. 3–11, 2023.

[3] C. Park, Hyunsoo ; Koo, “No TitleEffect of virtual reality-based construction safety education on the learning performance of construction workers ? Using CAMIL theory -,” *Korean J. Constr. Eng. Manag.*, vol. 23, no. 3, pp. 104–115, 2022.

[4] D. Oswald, F. Sherratt, S. D. Smith, and M. R. Hallowell, “Exploring safety management challenges for multi-national construction workforces: a UK case study,” *Constr. Manag. Econ.*, vol. 36, no. 5, pp. 291–301, Oct. 2018, doi: 10.1080/01446193.2017.1390242.

[5] R. Hussain, A. Pedro, D. Y. Lee, H. C. Pham, and C. S. Park, “Impact of safety training and interventions on training-transfer: targeting migrant construction workers,” *Int. J. Occup. Saf. Ergon.*, vol. 26, no. 2, pp. 272–284, Jun. 2020, doi: 10.1080/10803548.2018.1465671.

[6] M. Helander, “Safety challenges in the construction industry,” *J. Occup. Accid.*, vol. 2, no. 4, pp. 257–263, 1980, doi: 10.1016/0376-6349(80)90001-2.

[7] H. A. Wilson, “Organizational behaviour and safety management in the construction industry,” *Constr. Manag. Econ.*, vol. 7, no. 4, pp. 303–319, 1989, doi: 10.1080/01446198900000030.

[8] M. T. Newaz, M. Ershadi, M. Jefferies, M. Pillay, and P. Davis, “A systematic review of contemporary safety management research: a multi-level approach to identifying trending domains in the construction industry,” *Constr. Manag. Econ.*, vol. 41, no. 2, pp. 97–115, Sep. 2023, doi: 10.1080/01446193.2022.2124527.

[9] F. J. Forteza, J. M. Carretero-Gómez, and A. Sesé, “Safety in the construction industry: Accidents and precursors,” *Rev. la Constr.*, vol. 19, no. 2, pp. 271–281, 2020, doi: 10.7764/RDLC.19.2.271.

[10] M. R. Hallowell, “Safety-Knowledge Management in American Construction Organizations,” *J. Manag. Eng.*, vol. 28, no. 2, pp. 203–211, 2012.

[11] N. Dedobbeleer and P. German, “Safety practices in construction industry,” *J. Occup. Med.*, vol. 29, no. 11, pp. 863–868, 1987, doi: 10.1016/0022-4375(88)90014-x.

[12] P. J. Leather, “Safety and accidents in the construction industry: A work design perspective,” *Work Stress*, vol. 1, no. 2, pp. 167–174, 1987, doi: 10.1080/02678378708258499.

[13] J. M. Peiró, K. Nielsen, F. Latorre, R. Shepherd, and M. Vignoli, "Safety training for migrant workers in the construction industry: A systematic review and future research Agenda," *J. Occup. Health Psychol.*, vol. 25, no. 4, pp. 275–295, 2020, doi: 10.1037/ocp0000178.
[14] M. Vignoli, K. Nielsen, D. Guglielmi, M. G. Mariani, L. Patras, and J. M. Peirò, "Design of a safety training package for migrant workers in the construction industry," *Saf. Sci.*, vol. 136, p. 105124, 2021, doi: 10.1016/j.ssci.2020.105124.
[15] A. Mahalingam and R. E. Levitt, "Safety Issues on Global Projects," *J. Constr. Eng. Manag.*, vol. 133, no. 7, pp. 506–516, 2007.
[16] B. S. M. Smith, T. Perry, and D. Moyer, "Creating a Safer WorKforce Training needs for Hispanic and foreign-born workers," *Prof. Saf.*, 2010.
[17] S. Trajkovski and M. Loosemore, "Safety implications of low-English proficiency among migrant construction site operatives," *Int. J. Proj. Manag.*, vol. 24, no. 5, pp. 446–452, 2006, doi: 10.1016/j.ijproman.2005.11.004.
[18] M. De Jesus-Rivas, H. A. Conlon, and C. Burns, "The Impact of Language and Culture Diversity in Occupational Safety," *Work. Heal. & Saf.*, vol. 64, no. 1, pp. 24–27, 2016.
[19] S. Bhattacharjee, Somik Ghosh, and Deborah Young-Corbett, "Safety Improvement Approaches in Construction Industry : A Review and Future Directions," 2011.
[20] A. Pedro, H. C. Pham, J. U. Kim, and C. Park, "Development and evaluation of context-based assessment system for visualization-enhanced construction safety education," *Int. J. Occup. Saf. Ergon.*, vol. 26, no. 4, pp. 811–823, Jan. 2020, doi: 10.1080/10803548.2018.1553377.
[21] H. Guo, H. Li, G. Chan, and M. Skitmore, "Using game technologies to improve the safety of construction plant operations," *Accid. Anal. Prev.*, vol. 48, pp. 204–213, 2012, doi: 10.1016/j.aap.2011.06.002.
[22] K. Ogundipe, A. Ogunde, H. F. Olaniran, A. Ajao, B. Ogunbayo, and Julius Akinola Ogundipe, "MISSING GAPS IN SAFETY EDUCATION AND PRACTICES: ACADEMIA PERSPECTIVES," 2018.
[23] S. Bhoir and B. Esmaeili, "State-of-the-Art Review of Virtual Reality Environment Applications in Construction Safety," in *AEI 2015*, Feb. 2015.
[24] M. Carney *et al.*, "CHALLENGES TO DELIVERING SAFETY TRAINING THROUGH VIRTUAL CLASSES," 2008.
[25] A. Addison, W. O'Hare, M. Kassem, and N. Dawood, "the Importance of Engaging Engineering and Construction Learners in Virtual Worlds and Serious Games," *Proc. 13th Int. Conf. Constr. Appl. Virtual Real.*, no. October, pp. 30–31, 2013, [Online]. Available: http://itc.scix.net/data/works/att/convr-2013-45.pdf
[26] Z. Xu and N. Zheng, "Incorporating Virtual Reality Technology in Safety Training Solution for Construction Site of Urban Cities," *Sustainability*, vol. 13, no. 1, p. 243, Dec. 2020.
[27] Xiaowei Luo, Chi-keung Wong, and Jiayu Chen, "A Multi-player Virtual Reality-based Education Platform for Construction Safety," 2016.
[28] L. Albert and C. Routh, "Designing Impactful Construction Safety Training Interventions," *Safety*, vol. 7, no. 2, p. 42, May 2021.
[29] E. Acar, J. Wall, F. McNamee, M. Carney, and E. Öney-Yazici, "Innovative Safety Management Training Through e-Learning," *Archit. Eng. Des. Manag.*, vol. 4, no. 3–4, pp. 239–250, 2008.
[30] A. Chen, M. Golparvar-Fard, and B. Kleiner, "SAVES: An Augmented Virtuality Strategy for Training Construction Hazard Recognition," in *Construction Research Congress 2014*, May 2014.