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Futureproofing the Workforce with Technical Skills Training for Human-Technology Interaction

Cassey-Jade Smith [1] and Fidelis Emuze[1]
[1]Nelson Mandela University

This paper aims to identify and explore the technical skills necessary to enhance the safety of human-technology interactions (HTI) and determine the most effective training methods for developing these skill sets, enabling the workforce to engage with emerging human-technology solutions (HTS) safely. Adopting an interpretive philosophical stance and an inductive approach, data were collected through semi-structured interviews with professionals and focus group discussions with artisans in Gqeberha (formerly Port Elizabeth), South Africa. The study identified the technical skills necessary for the proposed mitigation strategies following a thematic analysis. These findings have practical implications for the industry, as they outline effective methods for acquiring these skills in response to emerging HTS, making the research directly applicable to real-world scenarios. While previous research has extensively outlined the barriers to adopting HTS, including the safety risks associated with specific technology and strategies for mitigating these risks, this paper identifies the technical skills required to implement mitigation strategies effectively.

Keywords: Construction, Education and Training, Health and Safety, Human-Technology Interaction, Technical Skills

Introduction

The South African construction industry is among the most hazardous sectors in the country, marked by a high incidence of accidents and fatalities, which pose significant risks to human lives and result in considerable economic costs (Lopes et al., 2011). Nevertheless, there is potential for improvement, as many of these tragedies could be mitigated through the strategic integration of human-technology solutions (HTS), a potential that this paper seeks to explore (Smallwood et al., 2023). Although HTS has proven effective in improving safety-related accident rates within the South African construction industry, adopting innovative technologies in the sector has been slow (Van Wyk et al., 2021). Construction professionals recognize the potential benefits of HTS within the industry; however, numerous barriers persist, impeding its widespread adoption (Akinradewo, 2018; Akinradewo et al., 2021).

Van Wyk et al. (2021) identified the top five barriers to innovation implementation as high costs, limited knowledge, excessive time requirements, fear of change, lack of interest, and the inherent complexities of construction processes. They emphasized that while all these barriers significantly affect the adoption of HTS, some present more critical challenges than others. Identifying the most pressing barriers underscores the necessity of targeted investments to facilitate the effective implementation of these technologies; such investments not only enhance exposure to the technologies but also play a pivotal role in bridging knowledge gaps, thereby addressing the fundamental issue of limited familiarity and expertise (Agenbag & Amoah, 2021). However, implementing technologies while personnel are not adequately trained to oversee them will render the application ineffective.

While the industry demonstrates awareness of human-technology interaction (HTI), bridging the gap between this awareness and the skills required to adopt new technologies safely is essential, as it enables the development of technical expertise through targeted and diverse training exercises (Osunsanmi et al., 2018). Adopting a proactive, hands-on approach is paramount; without such commitment, the workforce will remain unprepared and vulnerable, lacking the requisite readiness and resilience to effectively adapt to the integration of HTS, particularly in developing countries such as South Africa (Mamphiswana & Sinha, 2019). In the context of the reported research in this paper, HTI on construction sites refers to the dynamic interplay between construction workers and technological tools designed to enhance safety management. This interaction encompasses how humans engage with, adapt to, and are influenced by technology on worksites. Effective HTI aims to improve hazard recognition, reduce accidents, and promote overall safety on construction sites, as illustrated with 12 types of technologies by Kenny (2024) in Construction Dive.

Although numerous studies have explored the barriers, benefits, and willingness towards HTS adoption, including industry awareness, few have focused on training models designed to equip the workforce with the requisite technical skills (Akinradewo et al., 2018, 2020, 2021; Van Wyk et al., 2021). The literature shows that the benefits of effective HTI include enhanced hazard recognition, improved training outcomes, real-time monitoring and alerts, and data-driven decision-making (Sidani et al., 2023). HTI challenges include user acceptance, training requirements, and integration with existing technology systems (Sidani et al., 2023). Notably, the construction industry in South Africa lacks practical training for HTI, a situation, which is a challenge that necessitates this paper. Addressing this gap can mitigate harm to individuals while enhancing project productivity and delivery (Akinradewo et al., 2021). The paper’s central question is, “How can HTI be improved in construction safety?” The paper aims to identify and examine the technical skills essential for enhancing HTI safety and determine the most effective training methods for developing the skills required for the workforce to interact safely with emerging HTS. The paper is structured to begin with a literature review, which provides foundational insights into existing research relevant to this study. Following the review, the methodology section offers a descriptive outline of the research methods employed, detailing the procedures and techniques used to gather and analyze data, followed by a discussion of the results obtained from the analysis, where key findings are explored. Finally, the paper concludes with recommendations based on these findings.

Literature Review

There is a growing trend in four broad categories of human technology. These include exoskeletons, off-site prefabrication systems, drones and autonomous cars, and automated and robotic systems installed on-site. Several reviewed studies suggested methods to combat safety risks associated with trending HTS and ways to smoothly adopt technology in the construction industry. However, only a few studies focused on the skills required to enable workers to implement mitigation strategies effectively. Additionally, there is limited emphasis on the training that could foster these skills, which is essential for facilitating successful HTI.

The results of a study conducted by Adami et al. (2022) found that Virtual Reality-based (VR) training significantly increased the workers' trust in a robot, self-efficacy, and situational awareness compared to traditional in-person training. Furthermore, the findings suggested that VR-based training could significantly increase beneficial cognitive factors over more traditional methods and has substantial implications for improving Human-robot Interaction (HRI) using VR, especially in the construction industry. The study's results can serve as a reference point or starting point for establishing the effectiveness of training, particularly training that utilizes technological solutions. This approach will likely be more beneficial in fostering the necessary skill set. However, it is important to note that explicitly identifying the necessary skill set for mitigation strategies is essential. A study conducted by Namian et al. (2021) relating to the safety risks of uncrewed aerial vehicles, more commonly known as drones in construction, revealed that adopting UAVs can expose construction projects to a variety of safety risks that the industry is not familiar with, thus exposing the workforce to risks that they might not be able to mitigate without the necessary training. The top three safety risks included accidents caused by distractions, collisions with properties, and collisions with humans. The study introduced effective strategies to mitigate these safety risks, such as having qualified crew members, proper drone model selection, and drone maintenance. However, it did not explore the technical skills needed to implement the mitigation strategies.

Jeonga et al. (2022) suggested management ideas towards the end of research relating to modular construction. This underscores the imperative for robust safety management protocols during installations, particularly in units with the highest accident rates. The researcher suggested a solution or management plan for each identified hazard. Falls during installations primarily stem from the absence of personal protective equipment (PPE) and unstable workspaces. In modular constructions, where prebuilt units are swiftly installed, safety measures such as fall prevention nets may be implemented for efficiency. This will follow OSHA recommendations in the USA, for example. It is also recommended that prior safety education, which can be in the form of training, be provided to workers and safety measures be integrated to enhance efficiency. Additionally, systematic procedures for verifying structural integrity during manufacturing and installing technologies such as vibration control systems for transportation are essential to minimize accidents. Modular construction offers safety advantages but presents unique accident risks, necessitating tailored safety protocols across manufacturing and construction phases. Thorough safety training and installing fall prevention measures are critical to mitigate falls and falling objects incidents inherent in modular construction activities. Modular construction requires distinct accident prevention measures despite its safety benefits due to its unique characteristics compared to traditional construction methods.

Nnaji et al. (2023) established potential strategies that could be implemented during preconstruction operation or before work begins at the work face to reduce the impact of the safety and health risks associated with using a specific HTS, namely exoskeletons, and these included ensuring compliance with safety procedures through periodic training and spot checks, designing work to be less complex, preventing unauthorized or improper maintenance and installation of robots, involving employees in safety decision-making regarding the use of robots, provide clear, concise, available, and up-to-date job aids accepted by the intended user population, incorporating manufacturer safety requirements into written company safety procedures, ensuring that only robots without sharp edges, crushing points, or other dangerous surfaces are used, wearing appropriate personal protective equipment, observing safety distances, checking for visible defects on robots before starting work, having checks performed regularly by skilled technologists/technicians, ensure proper ventilation and lighting in rooms/work locations, obtaining and reviewing safety data sheets from the exoskeleton manufacturer, selecting suitable hearing protection and make it available for use, procuring robots with low vibration intensity, using only robots that have been shown to be effective, using ergonomically designed wearable robots, fitting each worker individually with the robot before use, observing and adhere to the manufacturer's information on the scope of use and cleaning equipment regularly.

The literature emphasizes the importance and effectiveness of training and thoroughly explains the risks associated with HTI, including their origins and the recommended strategies for mitigating these risks. However, it falls short of addressing the skills workers must develop to navigate these challenges successfully. Engaging with diverse mitigation strategies is unlikely to yield successful outcomes if the specific skills and methods of acquiring the competencies are not addressed. Establishing appropriate training methods to obtain the necessary technical skills for mitigating risks is crucial.

Research Method

For this research, an interpretivism philosophical stance was adopted. Interpretive research aims to create new, richer understandings and interpretations of social worlds and contexts (Saunders et al., 2019). The research gained a deeper understanding of the perceptions of human-technology end-users. With the interpretive philosophical stance, data collection was guided through qualitative methods, resulting in theory generation. Hence, an inductive research approach was employed. The research strategy was suitable for exploring HTI in construction safety, as it allowed for an in-depth analysis of real-world contexts and rich, qualitative data collection from multiple cases, which comprised individuals and focus groups (Saunders et al., 2019). This aligned with the interpretive stance and inductive approach, and the research strategy helped to facilitate insights into complex interactions and emergent themes. Data were collected from the appropriate professionals within their fields of specialization using semi-structured interviews.

Sampling and data collection

The population studied comprised professionals in the construction industry based in Gqeberha (formerly Port Elizabeth), Eastern Cape, South Africa, who would be directly affected by HTI. Participants were selected purposively when they possessed the characteristics to meet the criterion: frontline on-site work with exposure to technology interaction. Snowballing was employed to allow existing participants to refer to others who met the selection criteria within their networks. This method was appropriate for this study because of the need to leverage trust and niche expertise to increase the likelihood of honest responses while minimizing the time spent searching for participants through databases or contact lists that are mostly unavailable. The study expedited semi-structured interviews until saturation was reached. Data were also collected through two focus groups.

After the transcripts were thematically coded, the data analysis was carried out, from which the identified themes emerged. The participants included Project Managers, Quantity Surveyors, Safety Officers, and Artisans working on active projects in the study locale. Eleven (11) multi-methods qualitative data collection sessions were conducted, including nine one-on-one interviews and two focus groups. Each focus group comprised four participants, selected based on their years of experience, geographic location, and employment status in the industry. Recruitment focused on firms with active sites in Gqeberha. A pre-designed discussion guide ensured consistency. Individual interviews were conducted virtually and in person, while focus group interviews were held exclusively on two construction sites.

Results

Tables 1 and 2 present the relevant demographics of the study participants. No specific details, such as names, company affiliations, or project information, were disclosed to protect their identities based on the ethical clearance requirements to be observed after the university's Research Ethics Committee (REC-H) approval. The interviewees are referred to by numbers based on the order in which they were interviewed, ranging from 1 to 9, along with two focus groups (4 workers per group) labeled Focus Group 1 and Focus Group 2.

Table 1. Demographics of participants

Participant	Gender	Profession	Years of Experience
1	Female	Quantity Surveyor	7
2	Male	Construction Manager	21
3	Female	Construction Manager	11
4	Male	Safety Officer	15
5	Male	Project Manager	12
6	Female	Quantity Surveyor	6
7	Male	Safety Officer	11
8	Male	Project Manager	13
9	Male	Safety Officer	21

Table 2. Demographics of Focus Groups

Focus Group	Gender	Profession	Years of Experience
1	Predominantly Male	Artisans	20-30
2	Predominantly Male	Artisans	1-45

Understanding of Technical Skills

Participants articulated their understanding of technical skills in diverse ways, reflecting various experiences and perspectives. This variability is understandable, as their responses were likely influenced by their professional backgrounds and roles in current and past projects. These reflections shaped their responses, with many participants describing technical skills primarily regarding the competencies required to fulfill their job responsibilities effectively. As a result, the participants' descriptions often focused on the ability to perform the tasks outlined in their job descriptions or the job descriptions of employees who report to them, highlighting the practical application of the necessary skills in their day-to-day work. This suggests that their conceptions of technical skills were closely tied to real-world applications, emphasizing hands-on skills and direct job relevance, as captured in the quotes below:

"Being able to pay attention to detail, to be accurate and know how to adapt, in different situations." – Participant 1

"Basic construction details and setting out. Attention to accuracy." – Participant 2

"Ability to use the plant and equipment that we use on site. Being competent also with the different advancements of these plants because different plants have different attachments on it." – Participant 3

The responses revealed that they primarily associated technical skills with the formal training they receive, training intended to equip them with specific competencies and provide certifications that validate their expertise in various areas. These certifications serve not only as proof of their capabilities but also as a means of demonstrating their readiness and qualifications to potential employers, should they choose to transition to a different firm, according to focus group 1. Additionally, possessing technical skills allows an individual to execute tasks efficiently and safely, minimizing the need for assistance from their colleagues, according to focus group 2.

Assessing Technical Skills

Firms employ various methods for assessing the technical skills of their employees, a practice that is understandable given that firms possess unique operational structures and cultures. Despite the differences, a prevalent method for assessing the technical skills of their employees prior to adopting new technologies was training, which was confirmed by multiple participants as well as both focus groups 1 and 2, which consisted of the individuals to whom technology will be introduced. A few firms employed alternative methods that set them apart, which were discovered through the participants' responses. The alternative methods involved reviewing experience, certificates of compliance, physical testing, and interviewing individuals suggested below:

"There is a particular person who said he could operate one of our roller vibrators, and we have put him on it just to monitor, and we can see that he can operate it. However, formally, we need to have him trained. So, some facilitators or people are coming through to conduct the training, and then he can be certified as an operator." – Participant 3

"We will start with checking whether they have any valid experience or have any sort of certificates of compliance." – Participant 4

"Assessed on site." – Participant 4

"We always take someone for testing." – Participant 8

"In conjunction with project managers and clients that we do work for, if a contractor gets appointed and they have a set of resources, in most instances, we do interviews of these resources, with these resources, having basic discussions on their experiences, what they have done, as part of their work career, their journey and, how it will align and fit in with this current project." – Participant 9

Technical Skills for suggested mitigation strategies

The researcher introduced and explained four trending HTS and the safety risks associated with each solution. Then, the participants were presented with possible mitigation strategies and prospective technical skills for each strategy derived from the literature. Individuals were then tasked with evaluating which technical skills would be most suitable for implementing the four mitigation strategies. Table 3 provides an overview of the various mitigation strategies and the specific technical skills considered essential for their effective implementation, which the multiple participants, including both focus groups, have evaluated. Participants were briefed on HTI safety risks and potential strategies for mitigation. Following this, they were tasked with assessing which technical skills, based on their experience and knowledge, would be most appropriate for effectively implementing the four identified mitigation strategies. By examining the table, readers will better understand how the proposed strategies align with the necessary expertise to execute them effectively.

Table 3. Suggested technical skills and mitigation strategies

Compliance and Safety Protocols		***Equipment Maintenance and Inspection***		***Environmental and Ergonomic Considerations***		***Employee Involvement and Training***	
Familiarity with safety procedures	✔	Expertise in maintenance installation	✔	Understanding specific requirements (ventilation lighting)	✔	Grasping complex work design principles	✔
Familiarity with manufacturer data	✔	Ability to identify and address defects	✔	Skills in fitting and adjusting human technology (wearables)	✔	Ability to evaluate the effectiveness of human technology	✔
Familiarity with safety data sheets (SDS) and interpretation thereof	✔	Ability to conduct safety checks and inspections	✔	Understanding intensity sensitivity levels	✔	Familiarity with safety procedures and regulations	✔
Decision-making skills	✔	Competence in using, managing, and cleaning specific human technology	✔			Competence in using, managing, and cleaning specific human technology	✔

After reviewing the technical skills, participants were asked how to acquire the suggested skill set best. Once again, multiple responses highlighted various forms of training, with several participants emphasizing the importance of continuous training and the need to focus on exposure and awareness regarding implementing these technologies.

“It could be depending on what equipment or what exposure they need. It can be training on the job, obviously under supervision. Sometimes it needs to be theoretical, like in class first, before you can implement it on site.” – Participant 3

“Ongoing training and awareness and the actual introduction of these various technologies into the work environment, so people can become familiar and understand the intention and all the positives that go with it. I think continuous training and awareness and actual exposure to such will assist.” – Participant 9

Ways of skills acquisition

Participants were asked to identify the most appropriate training exercises that would enable them to develop the skills necessary for safely and effectively using emerging technologies. Based on their responses, the three most suitable exercises were selected and are summarised in Table 4. This process allowed for a focused analysis of the training methods deemed most effective by participants, highlighting the exercises that were considered to best support skill acquisition in adapting to new technological trends.

Table 4. Forms of training preferred for safer HTI

	Exoskeletons	Modular Construction Systems	Drones	Automation a Robotics
Formal Education				✔
On-the-Job Training	✔	✔	✔	
Seminars	✔		✔	✔
Online (Self-study)				
Hands-on Practical	✔	✔	✔	
Work Experience				
Internships				
Workshops	✔	✔	✔	✔

Conclusion and Recommendations

The findings highlight that equipping employees with the right technical skills to mitigate human-technology risks can drive safer, more efficient industry practices. Contractors should promote the ability of their workers to handle complex work principles and the ability to use and evaluate the effectiveness of HTS on sites, including the required safety measures. These technical skills could be transferred through workshops, on-the-job training, seminars, and other forms of learning-by-doing on construction sites. This approach will ensure that workers can adapt to changes and be open to safely using exoskeletons, drones, robots, and modular construction systems. Training the workforce through the preferred methods in Table 4 would highlight the firms' dedication to fostering a skilled and adaptable workforce. Construction firms must take the initiative to provide training to their workforce, even if this training is delivered through virtual reality platforms. Such training can help ease employees' concerns regarding job security while shifting their mindset toward embracing HTI. Workers must understand that these advancements are designed with their safety in mind.

Although adopting HTS has been relatively slow in South Africa, the exploratory data collected during this period suggests that contractors will embrace them soon. Therefore, investing in technical skills training is not just a matter of keeping pace with technological changes; it is essential for fostering a culture of safety and adaptability within the workforce. However, the results presented are not without limitations. While qualitative research through interviews and focus groups provides rich insights, they have limits imposed on the interpretation of results. In this research, subjectivity and limited generalizability of the results are applicable. For instance, the data are shaped by the interview and focus group participants' on-site lived experience. The limited number of participants does not represent the population (construction workforce), which limits external validation. Nevertheless, the exploratory results provide the foundation for future studies in South Africa and countries with similar contexts.

References

Adami, P., Rodrigues, P.B., Woods, P.J., Becerik-Gerber, B., Soibelman, L., Copur-Gencturk, Y., & Lucas, G. (2022). Impact of VR-based Training on Human-Robot Interaction for Remote

Operating Construction Robots. Journal of Computing in Civil Engineering, 36(3), https://doi.org/10.1061/(ASCE)CP.1943-5487.0001016

Agenbag, H. & Amoah, C. (2021). The impact of modern construction technology on the workforce in the construction industry. *IOP Conference Series: Earth and Environmental Science, 654*. Available at: https://doi.org/10.1088/1755-1315/654/1/012001.

Akinradewo, O.I., Aigbavboa, C.O., Okafor, C.C., Oke, A.E. & Thwala, D.W., (2021). A review of the impact of construction automation and robotics on project delivery. *IOP Conference Series: Materials Science and Engineering*, *1107*, pp. 012011. doi:10.1088/1757-899X/1107/1/012011.

Akinradewo, O., Oke, A.E., Aigbavboa, C.O., & Molau, M. (2020). Assessment of the Level of Awareness of Robotics and Construction Automation in South Africa. In *Proceedings of the 11th International Conference on Construction in the 21st Century (CITC-11)*, London, United Kingdom, 9-11 September 2019, pp. 192–197.

Akinradewo, O., Oke, A., Aigbavboa, C., & Mashangoane, M. (2018). Willingness to adopt robotics and construction automation in the South African construction industry. In *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Pretoria / Johannesburg, South Africa, October 29 – November 1, 2018.

Kenny, L. (2024). Technology innovations in job site safety: Wearables and exoskeletons. Available at: https://www.constructiondive.com/news/technology-jobsite-safety-wearables-exoskeletons/715515 (Accessed: 7 January 2025).

Jeong, G., Kim, H., Lee, H. S., Park, M., & Hyun, H. (2022). Analysis of safety risk factors of modular construction to identify accident trends. *Journal of Asian Architecture and Building Engineering*, 21(3), 1040–1052. https://doi.org/10.1080/13467581.2021.1877141.

Lopes, M., Haupt, T.C., & Fester, F.C. (2011). The influence of clients on construction health and safety conditions in South Africa. Available at: https://www.occhealth.co.za/_assets/articles/205/1217.pdf

Mamphiswana, R., & Sinha, S. (2019). Machine and Human is the New Workspace in Emerging Economies: A Phased Approach as the Strategic Framework to Reach Sustainable Economic System Readiness. 2019 Portland International Conference on Management of Engineering and Technology (PICMET), pp. 1–6.

Nnaji, C., Okpala, I., Gambatese, J., Jin, Z. (2023). Controlling safety and health challenges intrinsic in exoskeleton use in construction. *Safety Science*, *157*. https://doi.org/10.1016/j.ssci.2022.105943.

Namian, M., Khalid, M., Wang, G., & Turkan, Y. (2021). Revealing Safety Risks of Unmanned Aerial Vehicles in Construction. *Transportation Research Record,* 2675(11), 334-347. https://doi.org/10.1177/03611981211017134

Osunsanmi, T.O., Aigbavboa, C. & Oke, A. (2018). Construction 4.0: The future of the construction industry in South Africa. *World Academy of Science, Engineering, and Technology: International Journal of Civil and Environmental Engineering,* 12(3), pp. 206–212.

Saunders, M., Lewis, P. & Thornhill, A. (2019). *Research methods for business students.* 8th ed. New York: Pearson.

Sidani, A., Poças Martins, J., & Soeiro, A. (2023). Catalysing Construction Safety: A Comparative Analysis of Technological Advancements across High-Risk Industries. *Buildings*, 13(11), 2885. https://doi.org/10.3390/buildings13112885

Smallwood, J. & Allen, C. (2023). Practitioners' perceptions of the potential impact of Industry 4.0 on construction health and safety. *Journal of Engineering, Design and Technology*, Vol. 21 No. 2, pp. 486–501. https://doi.org/10.1108/JEDT-11-2021-0635.

Van Wyk, L., Kajimo-Shakantu, K. & Opawole, A., (2021). Adoption of innovative technologies in the South African construction industry. *International Journal of Building Pathology and Adaptation*, 10(4), pp. 425-440. doi:10.1108/IJBPA-06-2021-0090.