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Application of Emerging Technologies to Promote Sustainable Workforce in Construction

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ABSTRACT

The construction industry has been one of the most hazardous and waste-generating industries in the United States for decades, due to the unique nature of work and high degree of organizational complexity on jobsites. A number of citations against OSHA (Occupational Safety and Health Administration) 29 CFR (Code of Federal Regulations) 1926 Safety and Health Regulations for Construction, primarily in sections that address fall protection and safety training in construction, appear in OSHA's annual top 10 list of most frequently cited violations consistently. Innovative, science-based, and technology-driven solutions become more and more utilized in the construction industry. Examples of these solutions include: situated learning approach to improve the effectiveness of training, wearable technology to enhance personal protection, remote-controlled drones to perform various functions specially to improve site security, prevention through design concept to minimize risks, total worker health initiative to advance worker well-being, etc. It is imperative that safety, health, and environmental professionals should attempt to clearly understand the impact of these emerging technologies on construction safety and health, and be able to apply scientific principles to anticipate, identify, analyze, and control workplace hazards within the construction industry. Specifically, the pros and cons of each solution need to be examined and compared in order to identify effective methods to promote sustainable workforce and improve safety and health in construction.

Keywords: Emerging technologies, Sustainable workforce, Safety and health, Construction

INTRODUCTION

Environment, society, and economy are frequently used to describe how sustainability can be incorporated into an organization's mission, goals, and operations (OSHA, 2016). Each of the three components is considered essential for an organization to achieve sustainable outcomes. It has been generally accepted that the environmental community has effectively leveraged the sustainability movement to advance improvements in environmental outcomes through typical actions including, but not limited to: usage of renewable resources, reductions of emissions and pollutions, investment in innovations, and promotion of transparency, etc.

Yet, the issues that are commonly classified under the social aspect of sustainability, e.g., occupational safety and health, human rights, labor relations, safety culture, diversity, equity, inclusion, the organization of work, supply chains, etc., are either not well understood or have received less attention. As a result, the models of "environmental sustainability" and "social sustainability" have been developed separately instead of being integrated for holistic sustainable outcomes. This singular focus on any one aspect of sustainability often results in unintended negative impacts or causing compromises between goals.

Sustainable organizations strive to balance people, planet, and profit to achieve long-term success and viability. This means that organizations cannot be sustainable without protecting the safety, health, and welfare of their most vital resource: workers. Sustainability is not just about what is done, but how it gets done. Protecting workers is crucial to good long-term business management, as there will not be sustainable organizations without an engaged, innovative workforce. Occupational safety and health is material to business, because materiality and human capital management are one of the critical areas that various business stakeholders are focusing on.

The construction industry has been one of the most hazardous and waste-generating industries in the United States for decades, due to the unique nature of work and high degree of organizational complexity on jobsites (Gambatese et al., 2019). Although construction comprises a small percentage of the overall U.S. workforce, about 20% of the total occupational fatal injuries in the U.S. are associated with construction operations every year (Abdelhamid and Everett, 2000). In addition, the rates of occupational injuries and illnesses among construction workers are generally higher than the average of all industrial sectors every year (BLS, 2016). A number of citations against OSHA (Occupational Safety and Health Administration) 29 CFR (Code of Federal Regulations) 1926 Safety and Health Regulations for Construction, primarily in sections that address fall protection and safety training in construction, appear in OSHA's annual top 10 list of most frequently cited violations consistently (OSHA, 2022).

Sustainable development is expected to reinforce social equality, health, and well-being of construction stakeholders to some extent (Gambatese et al., 2019). The U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) rating system is the most widely used green building rating system in the U.S. construction industry. It is developed to promote sustainable development. Such a rating system examines the environmental and economic aspects of sustainability associated with the design, construction, and use of facilities. But, the rating system has limited coverage on the social context of sustainability, especially workers' safety and health (Hinze et al., 2013). In order to attain a sustainably safe industry, social sustainability must be prioritized in the construction industry. According to Karakhan and Gambatese (2017), social or workforce sustainability in construction can be described as "a life-enhancing process to accomplish social equity among all construction stakeholders, including construction workers, in terms of health, education, economic welfare, and other human rights."

A workforce may exhibit a high or low level of sustainability, depending on whether it can collaboratively perform its functions safely (Gambatese et al., 2019). The assessment of workforce sustainability may be conducted no matter whether the time period is defined or not. In order to perform its desired functions successfully, a workforce may be self-sustaining or require external inputs to maintain its presence. Workforce sustainability can be developed and maintained through employment policies, procedures, and practices that connect employee work-life balance and well-being to employment experiences during the course of employees' working lives. This enables workers to perform well over time while also thriving in their personal and family lives (Kossek et al., 2014).

Considerations for aspects such as living wage and cultural rights have been discussed on a global political level. However, the consideration of worker well-being and life has been largely excluded from current discourses within the sustainable development in construction (Hinze et al., 2013). This is a major shortcoming that must be addressed, especially since there should be no conflict between the goals of preserving all valued resources. Protecting the environment and human resources should not be viewed as being mutually exclusive objectives. Workplace safety and health should not be separated from the need to protect the environment (Mogensen, 2006). The challenge is how to implement sustainable policy and practices consistently that generates win-win payoffs for co-optimizing growth, energy efficiency, environmental and consumer protection, and workers' safety and health.

ANALYSIS AND DISCUSSION

Over the years, innovative, science-based, and technology-driven solutions become more and more utilized in the construction industry to address workplace hazards and issues. Examples of these solutions include: situated learning approach to improve the effectiveness of training (Machles, 2003), wearable technology to enhance personal protection (Earnest et al., 2019; The constructor, 2019), remote-controlled drones to perform various functions specially to improve site security (Howard et al., 2017; Burger, 2019), prevention through design concept to minimize risks (Choi et al., 2016; CPWR, 2008; Lyon et al., 2016; NIOSH, 2007; Prevention through Design, 2017), total worker health initiative to advance worker well-being (NIOSH, 2017; Peters et al., 2020; Tamers et al., 2019), etc.

In general, the construction industry is taking steps to improve the safety and health of its workforce; nevertheless, continued efforts based through sustainable approaches are needed to prevent further injuries and fatalities from occurring. It is imperative that safety, health, and environmental professionals should attempt to clearly understand the impact of these emerging technologies on construction safety and health, and be able to apply scientific principles to anticipate, identify, analyze, and control workplace hazards within the construction industry. Specifically, the pros and cons of each solution need to be examined and compared in order to identify effective methods to promote sustainable workforce and improve safety and health in construction.

Situated Learning

Safety training continues to be one of the most important yet challenging tasks for the construction industry. Employers reply on effective safety training to not only teach safety and health knowledge and skills but also instill positive safety culture among employees, especially the newly hired ones. Eventually a successful training program helps facilitate sustainable workforce in order to produce safe and quality work. From the new hire orientation to on-the-job training, various technologies and techniques have been utilized to help improve the effectiveness of the training. The development of an exemplary construction safety training program usually includes several components: 1) Demonstrating management commitment to safety; 2) Quantifying training needs based on OSHA regulations; 3) Determining goals and objectives of the training program; 4) Identifying critical elements and key resources; and, 5) Budgeting for a comprehensive training program (Fiori and Fanning, 2014).

In order to continually improve the safety training program in construction, the effectiveness of training must be evaluated. Blair and Seo (2007) stated that safety and health training is most effective when there is a high level of engagement. Essentially, training that is highly engaging is conducted as a conversation or dialogue. One of the best things a trainer can do to improve his/her effectiveness is to select appropriate stories and include them in training. Stories grab attention and make trainees more alert. Additionally, safety training should be viewed as an ongoing process rather than a single event. Training itself is an activity, whereas performance is a combination of the training activity and the ongoing achievement of the desired behavior.

With a different focus on learning rather than teaching, situated learning is one of several social learning theories which implies that people learn through observation and interaction with others in a social setting (Machles, 2003). Employees might be better served if, instead of training with learning principles added, the focus were on learning with teaching principles added. Learning is not necessarily a result of teaching, but instead is a result of living and actively participating socially in a community of practice. For most employees, their legitimate participation within the workplace may be more significant than their participation in the training classroom.

As an example of promoting situated learning, the research project in the Construction Safety class that I have been teaching for the Occupational Safety, Health, and Environment program at Southeastern Louisiana University incorporates an experiential-learning component to supplement the classroom instruction. Students were first “randomly” assigned in groups to each construction company. The contact person of each company assigned a specific topic to each group. The company provided necessary information to the students through field trips to the company’s construction site as well as opportunities of visiting the company’s office, interviewing the company’s employees, attending the company’s safety and/or project meetings, etc. The students then conducted quantitative and qualitative analyses on the assigned topics/issues, and presented the study in the third unit of the class when the company’s representatives are invited. The contact person presented his view of the issue and his evaluation of the student groups' work. The student groups submitted a written report, following the guidelines for research project. The reports were sent to the companies so they were able to keep a record as well.

With employees being provided with real-life opportunities to focus more attention on learning, and by looking at learning as a contextual or situated experience, the effectiveness of safety, health, and environmental knowledge and skill acquisitions could become more efficient and effective. The situated learning approach can help establish a culture that includes the safety, health, and environment principles and learning opportunities necessary for higher levels of employee participation and involvement.

Wearable Technology

The construction industry is rapidly evolving with the influence of cloud and mobile technology (The constructor, 2019). Because there are inevitably high risks associated with the construction work, it is necessary to get technology involved keeping in view the safety and health concerns of the workers. This has led to the innovation of smart wearables or wearable technology that can be used on construction sites. Wearable devices and the related sensors are now available in many forms including clothing, helmets eyewear, and watches (Earnest et al., 2019). The advancement in wireless technologies and electrochemical biosensors has helped materialize a new generation of smart personal protective equipment.

Various types of devices have been used to reduce exposures to hazardous conditions. For example, workers who are near heavy construction equipment reply on the proximity detection and alert systems that are attached to them for the warning of danger. When workers work outdoor in the hot summer, physiological status monitors can be used to measure the potential for heat stress. Air quality, which is negatively affected by substances including carbon monoxide, hydrogen sulfide, and other environmental stressors, can be monitored by appropriate sensors. Exoskeletons can be used for reducing the physical load on a worker's body and potentially prevent musculoskeletal disorders caused by manual labor.

Additionally, wearable technologies may be used to measure and monitor physiological data including heart rate, breathing rate, and posture (Nath et al., 2017). Automatically monitoring the location and movement of people can help with the safety, security, and process analysis. According to Earnest et al. (2019), when wearable devices are used on worksites, they are often connected to a wireless mesh infrastructure via an IoT (Internet of Things) network that allows for integration of the physical world into the network. The IoT network can also be connected to a computer and/or smart phone for monitoring and analytics. This set-up expands the usage of such a network as messaging, warnings, and alarms in addition to monitoring location become available.

Smart wearable technologies have the potential to transform the construction industry by improving the safety and efficiency of the workers. They collect, store, transmit and receive information about the worker's location, nearby hazards, biometric signs, and other job-site data. Yet, cost, maintenance, and privacy could negatively affect the wide-range application of these technologies. Many of the systems, especially the IoT mesh network, require significant infrastructure spending besides the cost of the wearable devices.

On the other hand, more research is needed to fully understand the impact that these new technologies have on the workforce. There have been some concerns that wearables could be used for productivity monitoring or that a company could use a device to "secretly" track an employee's location, hours worked, breaks, and even their number of steps during the day. Fortunately, in many cases it is possible to set up a system that keeps the user information anonymous. When the concerns are fully addressed and resolved, wearable technology proves to be a great tool for improving safety and health among a sustainable workforce in construction.

Drones

Drones, also called unmanned aerial vehicles (UAVs), are increasingly used for military, commercial, recreational, and public purposes (Howard et al., 2017). In recent years, drones have been used in the construction industry to help with construction project planning through aerial mapping of the construction site as well as the actual building of structures. With the presence of drones, the way that the construction industry operates has changed significantly, and those changes will have continued and lasting effects (Burger, 2019). The common use of drones in construction include the following:

Monitoring and Surveillance: Monitoring a large construction site is practically challenging. A drone can capture video footage of site conditions and send the information to the management faster and more efficiently than can on-the-ground personnel. The progress of the project can be analysed when such a video is converted into a three-dimensional picture of the site and then compared to computerized architectural plans (Knight, 2015). Far and near infrared cameras, radar or laser-based range finders can be attached to drones to help improve the surveillance and monitoring capabilities at a construction site (Irizarry and Costa, 2016). They allow companies to keep track of working conditions and processes, and are considered an increasingly invaluable tool for supervision. In addition, drones have the ability to be practically everywhere at the same time. They not only reduce theft and keep workers safer but also create an around-the-clock, real-time monitoring system that can improve the overall security of a construction project.

Surveying and inspection: Drones greatly reduce the labor and time involved in producing accurate surveys. They eliminate much of the human error involved in the process and have the ability to capture necessary data in much less time than traditional methods would take. The aerial photography helps drones inspect a large worksite more efficiently and effectively. With drones performing remote site inspections and violation detections of hazardous conditions, materials, and dangerous structures at construction sites, it is more efficient, safer and less costly than traditional construction site inspection methods (Ashour et al., 2017; Irizarry and Costa, 2016). Drones can also help government conduct inspections of construction sites. Compared to an individual government inspector walking through an extensive construction site, drones could drastically increase the scope and frequency of inspections of construction projects (Hosier, 2017). Once aerial imaging identified potential violations, inspectors could use it as evidence and focus their investigation on sites where the potential violations were imaged.

Maintenance and transportation: Using drones to perform planned or reactive maintenance inspections of tall structures including bridges, skyscrapers, and towers, where it is difficult and costly to access and risky for workers to fall from a great height, presents a significant benefit for construction companies. Using drones to transport tools, equipment and materials aerially allows companies to keep track of everything that enters and leaves the job site. It saves money and time and keeps the site secure. Since drones are generally small with high levels of maneuverability, they are being used more and more as an alternative to traditional vehicles.

While the use of drones may present many benefits for construction, it is imperative to study the potential risks. When a drone flies in close proximity to a human worker, it can create new hazards at a construction site, although there is still lack of evidence that supports the hazard potential of drones for workers. Safety, health, and environmental professionals need to be aware of the new hazards, evaluate the potential risks, and apply control measures to reduce the risks. On the other hand, adequate training of drone operators is essential to ensure the safe operation of the system. The training should be aimed to produce competent drone operators who are capable of identifying any potential hazards of operating a drone and are authorized by the construction manager to implement prompt corrective measures to eliminate or mitigate any hazards associated with operation of the drone. Additionally, as new FAA (Federal Aviation Administration) rules on the use of drones are being updated regularly, it is important for the construction industry to follow the pertinent guidelines in order to safely use drones for various purposes.

Prevention Through Design

Prevention through design was launched as a national initiative by NIOSH (National Institute for Occupational Safety and Health) in 2007 to prevent occupational injuries, illnesses, fatalities, and exposures by eliminating hazards and minimizing risks to workers in the design and re-design of facilities; work methods; processes; equipment and tools; and products (NIOSH, 2007). Eliminating hazards and controlling risks to workers "at the source" or as early as possible in the life cycle of items or workplaces is the goal. The ways to achieve the goal includes the design, redesign and retrofit of work premises, structures, tools, facilities, equipment, machinery, products, substances, work processes and the organization of work, as well as the inclusion of prevention methods in all designs that impact workers and others on the premises.

Following the prevention through design concept and the hierarchy of controls model, hazards and risk that can be eliminated, avoided or minimized are the first choice in managing construction risks. It is commonly agreed among safety, health, and environmental professionals that those concepts and models should be employed early in the design and planning stages of construction projects and associated tasks. Effectively communicating the value of prevention through design interventions can be challenging for safety, health, and environmental professionals who lack the expertise or experience in such efforts. The prevention through deign risk assessment methodologies and application tools that are developed and promoted through different channels, including but not limited to: the construction solutions database created by CPWR (The Center for Construction Research and Training) in 2008 (CPWR, 2008); the publication on prevention through design for hazards in construction by Lyon et al. in 2016 (Lyon et al., 2016); and, the non-profitable webpage on prevention through design founded and maintained by Dr. Mike Toole (Prevention through Design, 2017), provide examples and guidance of how safety, health, and environmental professionals can successfully incorporate prevention through deign in construction-related tasks and the overall risk management and decision-making processes.

Total Worker Health

Total worker health is defined by NIOSH as policies, programs, and practices that integrate protection from work-related safety and health hazards with promotion of injury and illness-prevention efforts to advance worker well-being (NIOSH, 2017). It is a holistic, organization-wide approach to worker well-being. Understanding and applying the total worker health principles can help construction companies move from a compliance focus to a risk-based approach to safety and sustainability management. These principles help construction companies consider not only the physical work environment, but also the psychosocial work environment and their impact on workers.

According to Tamers et al. (2019), the framework of total worker health, while rooted in the fundamental principles of promoting worker health, must be a living, breathing entity, responding to the changing needs of workers, organizations, and the economy as a whole. The enduring challenges of the work environment, such as safety hazards, work fatigue and stress, mental health, substance abuse and misuse, and chronic disease, are prime targets for integrated, holistic approaches rather than the more limited, isolated ones of the past. As the worker health issues cross the boundaries of work and home, and with home more and more likely becoming part of the remote-work places, especially during the public health crisis including the COVID-19 shutdown periods, there are opportunities for the total worker health strategies to bridge the distance that affects the lives of workers in and out of the workplace.

Peters et al. (2020) proved that the use of a theory-driven participatory approach was a suitable model to achieve the important and necessary goals of developing an integrated organizational total worker health intervention to improve worker safety, health and well-being for commercial construction subcontracting companies. Such an approach allowed the researchers to consider the empirical evidence as well as relevant theories and tailor them to meet the needs of construction workers employed through subcontractors. The lessons learned from the research help address key total worker health implementation details, and ultimately convey the intervention process of increasing worker voice and input in order to resolve issues related to worker safety, health and well-being.

CONCLUSION

With various innovative, science-based, and technology-driven initiatives and efforts including situated learning approach, wearable technology, drones, prevention through design concept, and total worker health principle being implemented in the construction industry, it is optimistic that the construction industry is taking significant steps to improve the safety and health of its workforce. Yet, continued efforts based through sustainable approaches are still needed to prevent further injuries and fatalities from occurring. The analysis on the impact of the emerging technologies on construction safety and health may help safety, health, and environmental professionals apply scientific principles to anticipate, identify, analyze, and control workplace hazards within the construction industry. Based on the analysis results, effective methods can be identified and implemented to promote sustainable workforce with an ultimate goal of improving safety and health in construction.

REFERENCES

Abdelhamid TS, and Everett JG. (2000) Identifying root causes of construction accidents. *Journal of Construction Engineering and Management*. 126:1, 52–60.

Ashour R, Taha T, Mohamed F, Hableel E, Abu Kheil Y, et al. (2016) "Site inspection drone: A solution for inspecting and regulating construction sites," in: Circuits and Systems (MWSCAS), 2016 IEEE 59th International Midwest Symposium, 1–4.

Blair E, and Seo DC. (2007) Safety training: making the connection to high performance. *Professional Safety*. 52:10, 42–48.

BLS. (2016) Employer-Reported Workplace Injuries and Illnesses. The Bureau of Labor Statistics Website: https://www.bls.gov/news.release/archives/osh_11092017.pdf.

Burger R. (2019) 6 Ways Drones Are Affecting the Construction Industry. The liveaboutdotcom Website: https://www.liveabout.com/drones-affecting-construction-industry-845293.

Choi S, Yuan L, Borchardt J. (2016) Musculoskeletal disorders in construction: practical solutions from the literature. *Professional Safety*. January 2016, 26–32.

CPWR. (2008) Construction Solutions Database. The Construction Solutions Website: https://www.cpwrconstructionsolutions.org.

Earnest S, Echt A, Garza E, Snawder J, and Rinehart R. (2019) Wearable Technologies for Improved Safety and Health on Construction Sites. NIOSN Science Blog: https://blogs.cdc.gov/niosh-science-blog/2019/11/18/wearables-construction.

Fiori C, and Fanning F. (2014) "Safety training," in: Construction safety management and engineering, 2nd edition, Hill D (Ed.), 190–218.

Gambatese JA, Karakhan AA, and Simmons DR. (2019) Development of a Workforce Sustainability Model for Construction. CPWR (Center for Construction Research and Training) Small Study Report No. 17-8-PS.

Hinze J, Godfrey R, and Sullivan J. (2013) Integration of construction worker safety and health in assessment of sustainable construction. *Journal of Construction Engineering and Management*. 139:6, 594–600.

Hosier F. (2015) Could OSHA Use Drones for Safety Inspections? The Safety News Alert Website: https://www.safetynewsalert.com/could-osha-use-drones-for-safety-inspections.

Howard J, Murashov V, and Branche C. (2017) Can Drones Make Construction Safer? NIOSN Science Blog: https://blogs.cdc.gov/niosh-science-blog/2017/10/23/drones-construction.

Irizarry J, and Costa DB. (2016) Exploratory study of potential applications of unmanned aerial systems for construction management tasks. *Journal of Management in Engineering*. 32:3, 05016001.

Karakhan AA, and Gambatese JA. (2017) Identification, quantification, and classification of potential safety risk for sustainable construction in the United States. *Journal of Construction Engineering and Management*. 143:7, 04017018.

Knight W. (2015) New Boss on Construction Sites Is a Drone. The MIT Technology Review Website: https://www.technologyreview.com/s/540836/new-boss-on-construction-sites-is-a-drone.

Kossek EE, Valcour M., and Lirio P. (2014) "The sustainable workforce: Organizational strategies for promoting work-life balance and wellbeing," in: Work and wellbeing, Chen PY, and Cooper CL (Eds.), 295–319.

Lyon BK, Popov G, Biddle E. (2016) Prevention through design for hazards in construction. *Professional Safety*. September 2016, 37–44.

Machles D. (2003) Situated learning: New approach to SH&E training focuses on learning. *Professional Safety*. 48:9, 22–28.

Mogensen V. (2006) "Introduction," in: Worker safety under siege: Labor, capital, and the politics of workplace safety in a deregulated world, Mogensen V (Ed.), 13–29.

Nath N, Akhavian R, and Behzadan A. (2017) Ergonomic analysis of construction worker's body postures using wearable mobile sensors. *Applied Ergonomics*. 62, 107–117.

NIOSH. (2007) Prevention through Design. The NIOSH Website: https://www.cdc.gov/niosh/topics/ptd.

NIOSH. (2017) Let's Get Started with Total Worker Health® Approaches. The NIOSH Website: https://www.cdc.gov/niosh/twh/letsgetstarted.html.

OSHA. (2016) Sustainability in the Workplace. The Occupational Safety and Health Administration Website: https://www.osha.gov/sustainability.

OSHA. (2022) Top 10 Most Frequently Cited Standards. The Occupational Safety and Health Administration Website: https://www.osha.gov/top10citedstandards.

Peters SE, Trieu HD, Manjourides J, Katz JN, and Dennerlein JT. (2020) Designing a participatory total worker health® organizational intervention for commercial construction subcontractors to improve worker safety, health, and well-Being: The "ARM for Subs" trial. *International Journal of Environmental Research and Public Health*. 17, 5093–5109.

Prevention through Design. (2017) Prevention through Design: Spreading the Word about Design for Construction and Maintenance Safety. The Prevention through Design Website: https://designforconstructionsafety.org.

Tamers SL, Chosewood LC, Childress A, Hudson H, Nigam J, and Chang CC. (2019) Total Worker Health® 2014-2018: The novel approach to worker safety, health, and well-being evolves. *International Journal of Environmental Research and Public Health*. 16, 321–339.

The constructor. (2019) Top 6 Wearable Technology in the Construction Field. The Constructor Website: https://theconstructor.org/construction/top-wearable-technology-construction/156302.