

Utilizing BIM as a Tool for Managing Construction Site Safety: A Review of Literature

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Construction site fatalities continue to be a significant issue in the US as the Occupational Safety and Health Administration (OSHA) reported 937 deaths in 2015. The onus of safety management and site accident mitigation is shifting with the development of technology by incorporating Building Information Modeling (BIM) into project planning. The study aimed to identify how BIM has been integrated with project safety and implemented across a project lifecycle and identifies projects in which such strategies were effectively used. The study utilized extensive review of the literature to determine ways in which researchers have recommended integration of BIM with safety across the project lifecycle, with the aim of enhancing construction site safety during phases of construction, operation, and maintenance. In order to maintain the focus of the literature review, four topics were purposively selected for their integration and connectivity with BIM, including Prevention through Design (PtD) for Construction Worker Safety, Automated Rules-Based Safety Checking, BIM visualization tools for education and safety training, wearable technology and construction site sensors.

Key Words: Construction site safety, Safety management, BIM, Hazard identification.

Introduction and Background

Maintaining a safe environment on construction sites across the US is a continuous challenge that is impacting the industry. Between 2005 and 2015, 10,800 fatalities were reported in the construction industry including private sector wage and salary workers, government, and self-employed workers (BLS, 2016). According to the Occupational Safety and Health Administration (OSHA) in 2015, 937 fatalities were associated with the construction industry. The predominant cause of death on construction job sites is classified as "*Falls*" accounting for approximately 39% of fatalities (364 of 937 fatalities). For the fiscal year of 2016, the top 4 most cited OSHA violations occurred were *fall protection, construction hazard, communication standard and scaffolding* (OSHA, 2017). Thus, safety continues to challenge the construction industry even with the advent of new technologies (both in the physical and virtual world).

To foster safety on construction projects, adequate project planning, and hazard recognition must be conducted collaboratively (among the major projects' stakeholders) and throughout the project lifecycle (from design inception to project operations). Historically, construction safety planning has involved observation as well as the experiences of construction contractors and responding to perceived threats. The perception-based plan for safe sites can result in accidents that were not readily recognized by the project stakeholders. Also, "*the processes of implementing strategies and technologies that foster construction site safety is time-consuming, arduous and inefficient, thus presenting an opportunity to implement an automated safety checking system based on OSHA standards and regulations*," (Zhang et al., 2013). In this regard, the Construction Industry Institute (CII) categorizes hazard recognition into two categories: *reactive* and *predictive*. A reactive hazard recognition technique has been used in the past and involves communicating information about location and time where safety measures and equipment were necessary, in other words, a root cause analysis. Such a methodology can be challenging when a contractor relies solely upon conventional two-dimensional paper-based drawings, site observation, and job experience to develop a safety plan. On the other hand, predictive hazard recognition methodology involves Job Hazard Analysis (JHA) that concentrates on planning and visualizing future construction activities to identify possible hazards that may be confronted, while reactive methods focus on the analyses of past experiences to mitigate potential hazards (CII, 2013).

Design for Construction Worker Safety (DCWS) and Prevention through Design (PtD) were products of research in the 1990's, seeking to involve designers in safety planning as a building program was developed and brought to fruition. However, with the implementation of Building Information Modeling (BIM) in safety planning, this paradigm shift is now categorized as a "*predictive*" strategy by employing the virtual building model (Alomari, Gambatese, and Anderson, 2017). To gain a more accurate understanding of the fundamentals and chronology of construction safety research, the resulting paper will incorporate data based on studies conducted in the 1990's associated with the DCWS methodology and will offer a summary of recent research and trends regarding a) 4D visualization, b) DCWS or PtD, c) Automated Rule-Based Safety Checking Systems, and d) Wearable Technology and Jobsite Sensors.

For this study, BIM is defined as *"a cohesive group of building components with digital representations that contain data attributes identified in software applications and parametric rules which can be manipulated. These components include non-redundant data that describe their behavior, for analyses and work processes and that are represented in all views of the assemblies of which it is a part, and offers coordinated data in that all views of a model are represented in a coordinated manner"* (Eastman et al. 2011). The reason for the selection of BIM definition specific towards the technical aspects was because the study focused on identifying the BIM capabilities that can be associated with the tools/software that enhance safety on the construction sites. The data assemblies and different views of a building model generated in a virtual environment improve project visualization, one of many BIM functions identified by multiple researchers (Fountain and Langar, 2018; Langar and Pearce, 2017; Fox et al., 2016).
BIM also allows project stakeholders to share information about sequencing, physical site topography, and clash detection; improve communication among the project stakeholders; and identify potential locations and times of hazardous and non-hazardous construction project activities. Rajendran and Clarke (2011) outlined vital areas in which BIM can prove useful: 1) Worker safety training, 2) Design for safety, 3) Safety planning (job hazard analysis and planning), 4) Accident investigation, and 5) Facility and maintenance phase safety.

Construction industry injuries and fatalities are issues not exclusive to the US. For example, the BLS (2014) compared fatal work injuries in the US and the European Union (EU) and found that the fatal work injuries show similar trends and indicate that safety in construction is a concern for both.
Given the scale and impact of the problem on a global level, the study aimed to identify how BIM has been integrated with project safety and implemented. The study utilized extensive review of the literature to identify ways in which researchers have recommended integration of BIM with safety across the project lifecycle, with the aim of enhancing construction site safety during phases of construction, operation, and maintenance.

Method

The purpose of this study is to gain insight into the use of BIM to enhance worker safety on construction sites using a comprehensive literature review. To maintain the focus of the study, four topics were selected for their correlation with BIM: 1) PtD for Construction Worker Safety, 2) Automated Rules-Based Safety Checking, 3) BIM visualization tools for education and safety training, and 4) wearable technology and construction site sensors. During the initial literature review, the determination was made to apply controls by limiting the article search to 100 papers in which the subject or title corresponded with the essential search terms, as listed. After evaluating the initial one hundred research articles, additional filters were applied, and they were:

1. Publication date (preference was given to articles published after 2000 as the technology associated with BIM had considerably improved since the period. At the same time, specific studies before 1990 were selected due to their significance as the foundation of many construction safety planning methodologies)
2. Information accessibility to the researchers
3. Documents germane to the topic being investigated

After applying such filters, the number of research papers shortlisted for the analysis was reduced to 60. A total of 22 journal articles and 9 international conference papers were analyzed and included in this study. Additionally, statistics and hard data from 2005 to the present were gleaned from the OSHA, BLS and National Institute for Occupational Safety and Health (NIOSH) websites. Also, trade and industry news articles were limited to the past 4 years due to much of the information referring to contemporary issues facing technology. The motive to concentrate on recent research is due to the rapid development of technology, which tends to render specific tools obsolete; however, the earlier data is still applicable for analysis.

Results

Initial review indicated the implementation of various technologies, such as BIM-GPS integrated wearables, development of Artificial Intelligence (AI) technology to document and warn about hazardous conditions, augmented/virtual/mixed reality to enhance safety planning and training, especially for non-English speaking workers, design for safety, prevention through design, and parameter implementation based on OSHA standards to create mechanisms for "*automated safety checking*" are enhancing the use of BIM in safety planning.

Leveraging BIM for Construction Safety

During the design and preconstruction phase of a project, BIM can be used for collecting information involving the physical project and associated site, planning and coordinating sequencing, workflow, and logistics while enabling teams to conduct preconstruction risk assessments and implement modifications to safety plans daily. Upon completion of a 3D model, it can be used for employee orientation and worker safety training, site hazard identification, excavation hazards, traffic coordination on the site, and planning hoist installation/operations (Rajendran and Clarke, 2011).

Alomari et al. (2017) suggest that an added benefit of BIM is ease of communication and collaboration among stakeholders because the implementation of 4D visualization in the AEC industry can augment the way safety is approached by way of recognizing changes in scheduling and alleviating potential conflicting work activities that present a hazard to workers. It is during the preconstruction planning phase that a determination can be made to conduct specific assembly/prefabrication tasks offsite, a system of predictive safety planning as PtD. BIM-enabled prefabrication aided Gilbane Construction by eliminating "…*tens of thousands of excursions up ladders and lifts, and thousands of hours of hot work and general construction activities in difficult situations*," explained Tony O'Dea, Director of Corporate Safety (Barista, 2016). Early collaboration between designers/engineers and additional members of the project team can develop automated checklists of "*rule-based*" safety information founded on OSHA standards and company driven best practices (Azhar and Behringer, 2013), and it further integrates DCWS. The rule-based approach does not modify the design factors but evaluates the information based on the configured objects and consists of four stages: 1) Rule translation stage, 2) Model preparation stage, 3) Rule execution stage, and 4) Reporting stage (Zhang et al., 2013). Two approaches for software integration are a design- based plug-in or application that will allow scrutiny of the model during the design phase or to utilize IFC (Industry Foundation Class). IFC is "…*an international public standard schema for representing building information with ISO-STEP technology and libraries*" (Eastman et al., 2011).
Similarly, German researchers conducted extensive hazard analyses based on reports of 37,956 accidents to assist the industry in producing more effective mitigation plans (Melzner et al., 2013). Melzner et al. (2013) selected a high-rise building model to analyze fall protection rule-checking systems regarding holes in slabs and leading edges by utilizing both German and OSHA standards. The researchers found that an Industry Foundation Classes (IFC) model can provide contractors with a quantity takeoff of safety equipment.
Specifically, such a populated model will provide construction safety planners with "where, when, what and how much equipment is required for fall protection" (Melzner et al., 2013). At the same time, interoperability between platforms has proved a challenge as noted in a 2015 Construction Management Association of America (CMAA) report focusing on the integration of building information and related work process data. Interoperability is the capability of exchanging information by different systems, aiding in a reduction of data entry and modification that is tailored to the needs of the end user (Aranda et al., 2015). Utilizing 4D Visualization to foster safe job sites Construction scheduling and planning can use 4D technology to create dynamic site models which can be linked with the building components, temporary structures, and site production equipment (Sulankivi et al., 2010). In Finland, a pilot research project was initiated with Skanska as the contractor and structural engineer. Finnmap Consulting used Tekla (Structure and Construction Management) software to create a model that provided the basis for modeling hazard recognition and mitigation (Sulankivi et al., 2010). The work site was modeled utilizing ArchiCAD and then merged with the Tekla building model to use as a reference. The team incorporated safety railings to the edges of the upper floors and balconies in the model and input the erection of precast components into work sequencing. The test incorporated object groups and representational styles were given visualization definition to recognize the status of the railings on any given day. For example, railings to be assembled immediately (denoted in red), other railings needed on site on the same day, but were installed earlier (indicated in color by class) and railings that had been disassembled (shown as "hidden") (Sulankivi et al., 2010). Again, the disconnect in using these programs to their fullest potential are issues of interoperability in that libraries are software specific, and the programs have not been customized to include components for precise site safety planning. The Finnish pilot project research team concluded that the following are required for long-term substantive safety planning: a) more robust object and component libraries for site planning, b) enhanced site planning functions, and c) safety analysis procedures (Sulankivi et al., 2010).

As a predictive strategy, research conducted at Auburn University employed BIM, simulated animation and videos to conduct job hazard assessments and safety planning for excavations, crane safety, safety railings for fall protection near leading edges, roof construction and emergency response planning (Azhar and Behringer, 2013). In their conclusion, Azhar and Behringer (2013) note, "…, t*he fatality and injury rates are still not significantly declined*." They attribute part of the challenge to lack of adequate construction safety knowledge among designers resulting in safety hazard "*loopholes*" within the project design (Azhar and Behringer, 2013). However, higher education endeavors to change the paradigm about the education of designers through the inclusion of construction safety courses in the curriculum (Clevenger et al., 2015).

Turner Construction employed drone technology to obtain images of a building project and surrounding site, then establishes a point cloud, which is superimposed on a 4D as-built model to evaluate the actual project versus the intended design (Barista, 2016). A report is created that illustrates areas of concern using a color-coding classification system, which will warn of constructability issues and/or missing features (Barista, 2016). Laser scanning coupled with drone footage is enabling the use of more advanced visualization systems such as *"mixed reality representations*" that can be combined with a 3D model and compared to the original (Caulfield, 2017). The end goal is an accurate scanned image of a project so workers can walk through the site while wearing an *Augmented Reality* headset and view the BIM model as an overlay (Caulfield, 2017).

Additionally, research and development have led to the design of an Artificial Intelligence (AI) system to warn of safety hazards in construction photos and videos. The product is designed to mark and index frames in videos that are uploaded to its system. The objective of the developer is to establish a system to identify patterns in pixels of images, compare and match those patterns to a collection of objects, and highlight specific features. For example, empowering the AI system to recognize people in job site images, then enabling the technology to determine if people are wearing high visibility clothing and hardhats (Sawyer, 2017). In 2012, New York was the first US city to implement "*3D Site Safety Plans Program*", allowing firms to utilize BIM files to file safety plans for construction sites electronically. In doing so, the Department of Buildings can tour sites "*virtually*," ascertain the step-by-step process of how a building will be constructed, make a note of the site's complexities, and assess code compliance before an on-site review (Alderton, 2015).

Safety training videos using the building model extends the BIM capabilities enabling employees to understand project conditions and reduce language barriers with non-English speaking workers as instruction is accomplished through visualization (Azhar and Behringer, 2013). Such an application of BIM presents a critical milestone. According to the BLS, the rate of work-related fatalities for Hispanic and Latino workers has exceeded the rate for all US workers for much of the past twenty years. From 2003-2006 the fatality rate for Hispanic and Latino workers surpassed the rate for all workers by almost 35 percent (Byler, 2013; BLS, 2017). Another group identified as being more prone to incidents on job sites are workers that are new to the industry, such as interns and recent construction management graduates, in that they are more likely to be injured than seasoned employees (Clevenger et al., 2015). As a result, there is an effort to include the integration of more BIM-enabled visualization in undergraduate education. Construction safety education should offer students an interactive and site-specific educational experience (Clevenger et al., 2015). As Augmented Reality and Virtual Reality are embraced and implemented throughout the AEC industry, the practice will become seamless to incorporate these systems as teaching tools for safety planning and awareness.

Prevention through Design (PtD) and Design for Construction Worker Safety (DCWS)

PtD is the practice of, "*addressing occupational safety and health needs in the design process to prevent or minimize the work-related hazards and risks associated with the construction, manufacture, use, maintenance, and disposal of facilities, materials, and equipment*," (NIOSH, 2016). A building model can assist in the elimination of safety issues before beginning construction by including details in the design phase, permitting the stakeholders to recognize potential conflicts related to safety, such as clash detection and work sequencing (Kasirossafar and Shahbodaghlou, 2012). Traditional contracting methods, such as design-bid-build, have inherently produced a disconnect concerning different stages of construction, divorcing some participants from accountability for worker safety, and as a result creates a lack of awareness toward making progress in construction safety (Tymvios and Gambatese, 2016). Safety issues will arise from work conditions and/or worker behavior (Alomari and Gambatese, 2016). However, as design decisions and oversights are analyzed more acutely, and researchers determine that design influences can cause incidents (Gambatese et al., 2005), the significance in recognizing how design plays a role in working conditions has guided the industry to research and development of PtD as an effective method implemented during the design phase to eliminate hazards on job sites (Hecker et al., 2005). Traditionally, designers did not attend to construction safety when working on a project as they were advised by legal counsel to avoid any supposition of liability (Gambatese et al., 1997; Hinze and Wiegand, 1992). In order to identify knowledge and perceptions among general contractors within the US, Ghosh et al. (2015) surveyed General Contractors in the US, and nearly 61.5% respondents were familiar with PtD while only 7% were actively implementing the process. The top three challenges for PtD adoption among general contractors were (in the order of importance were): *Lack of financial incentive for A and E, Lack of regulatory requirement for A and E,* and *Lack of recognizable duty of A and E.* For Designers operating in the industry, Mehany et al. (2016) found that 12% of responding design firms were familiar with the concept, thereby depicting a large gap between the designers and general contractors regarding perception and knowledge for the concept of PtD. Also, Mehany et al. (2016) identified a greater need for education among the professionals so that PtD can be successfully adopted and implemented.

Many in the AEC industry undervalue the impact of design choices on construction site safety as each decision such as material choices, connection details, and building components is directly tied to methods used in the field (Tymvios and Gambatese, 2016). In the UK, Construction Design and Management standards mandate the involvement of health and safety managers in the planning and design of construction projects (Zhou et al., 2012), which relieves the contractor of sole responsibility for safety during construction. This arrangement fosters a collaborative approach to initiate a paradigm shift in the industry by directing all stakeholders involved in the development and construction process to consider issues of worker health and safety (Zhou et al., 2012). Hadikusumo and Rowlinson (2004) created the Design-for-Safety-Process (DFSP) Tool which employed the identification of safety hazards and could advise about precautionary measures to avoid accidents. Gambatese et al. (2005) cite the process of designing a structural steel frame building as an example of employing design for safety whereby the connections may be engineered with the safety of the worker in mind, as well as consideration of anchorage points in the steel members for workers to secure their fall protection equipment. ASCE Policy Number 350 on-site safety asserts that engineers have the responsibility of "*recognizing that safety and constructability are important considerations when preparing construction plans and specifications*" (ASCE 2012; Gambatese et al., 2005). To foster a predictive approach to construction safety planning, many firms in the AEC industry are executing their procedures. A Design-Build company in FL, US, requires OSHA 10-hour training for all designers, a codified system of warning signs on project plans that will alert constructors of possible hazards and safety focused design checklists that inform of latent dangers and advise design modifications (Gambatese et al., 2005). Zhou et al. (2012) refer to design-build as a natural iteration of DCWS where higher collaboration between project stakeholders exists.

Tymvios and Gambatese (2016) list three areas of concern regarding the application of DCWS: 1) Legal, 2) Economic, and 3) Contractual. Gambatese et al. (2005) conducted a study that sought to determine if DCWS is a viable path for the improvement of construction worker safety. Within their research, correlations between the implementation of DCWS and issues of feasibility and practicality were being evaluated through surveys of AEC professionals in the northwestern region of the US. Further, assessments were made based on factors that would impact the application of DCWS and outcomes resulting from DCWS. The prevailing factors determining implementation were: Designer understanding and methodology acceptance, education and training, motivation, facility in execution, availability of tools and resources, conflicting goals and criteria. Results based upon utilization of DCWS were: a) improved worker safety, b) project cost, quality, constructability, and schedule c) facility operations and maintenance, and d) liability, productivity, and profitability (Gambatese et al., 2005). Scarcity of construction safety courses in engineering programs at colleges and universities (Toole, 2005), focus on specializations within the design field (Gambatese et al., 2005), and designers' limited knowledge and understanding of the construction process (Gambatese et al., 2005; Toole, 2005) have contributed towards designers lack of knowledge regarding DCWS. Creation and execution of 3 key strategies have been advocated as an approach to promote the use and implementation of DCWS/PtD: 1) Creating a checklist and guidelines of the DCWS/PtD principles, 2) Establishing a website to allow for collaboration and suggestions of new concepts and principles for the database, and 3) Constructing a framework for a DCWS/PtD checking tool to employ in BIM software that will examine compliance with the principles (Qi et al., 2011).

Automated Rule-Based Safety Checking Systems

Employing BIM in pre-construction site safety planning consists of four components: 1) The virtual planning of work sequencing to incorporate necessary safety equipment and measures, 2) verification that all structures can be constructed safely and productively, 3) create a detailed Environmental Safety and Health (ES and H) plan to be dispersed among all workers, and 4) obtain timely information regarding work progress to manage workflows (Sulankivi et al., 2013). By analyzing incidents across the country, Turner Construction determined that falls from height and materials handling are instances that can be tackled by applying BIM technology (Sulankivi et al., 2013). They instituted a model-inspection system during the design phase in that the BIM professionals created a specific set of rules and parameters consisting of fifty safety items, which can then be utilized with other models (Sulankivi et al., 2013). Proprietary software, Solibri, can be a useful instrument for model-checking in the design phase as it can use the IFC format. A study comparing the safety rule implementation of fall standards between the US and Germany found that a rule-based checking system within BIM can assist in the detection of fall hazards using an IFC design model and prescribe safety equipment based on predefined sets of rules (Melzner et al., 2013). Chan et al., (2016) posit that Safety Information Modeling (SIM) is a viable path forward as it relies on model objects which contain characteristics and parameters relative to safety rules, scheduling, and geographic information. Their research in Hong Kong seeks to gather empirical data from construction safety managers, AEC professionals, and BIM experts to construct a comprehensive platform that will merge information and technical requirements for development and deployment of SIM within various scenarios on construction projects (Chan et al., 2016). Benjaoran and Bhokha (2009) suggest that safety plans must be defined in a manner that is consistent with construction work sequencing and integrated into the project schedule. In Thailand, researchers utilized a prototype 4D CAD model including a rule-based safety plan to identify spatial hazards at elevation and visualize the proper measures necessary within the sequence of construction (Benjaoran and Bhokha, 2009).

As job tasks are divided among many individuals, the general contractor may be unaware of subcontractors and their employees working at elevation. Communication regarding the necessary safety equipment may not be conveyed promptly and can lead to hazardous conditions (Melzner et al., 2013). An additional challenge involving 4D BIM is that schedules must frequently be updated to mirror work sequencing on a site at any time (Sulankivi et al., 2013). The early adoption of BIM for rule-based checking was to validate compliance with fire codes and the American with Disabilities Act (Melzner et al., 2013). The development of rule-based safety checking occurred at the Construction Safety and Technology Laboratory at the Georgia Institute of Technology.

Wearable technology and construction site sensors

Construction sites are dynamic and thereby are a challenge to scrutinize for safety hazards. For prompt and informed decisions during construction, stakeholders must gain an understanding of construction activities in real-time and in a visually engaging configuration (Cheng and Teizer, 2013). Latent technologies in automated safety monitoring are a tactic that employs continuous surveillance of site situations and conditions (Park et al., 2017). Methods utilized to identify workers at risk of hazards are centered on location and proximity information that is obtained from sensing systems, such as Bluetooth, Ultra-wideband (UWB), global positioning system (GPS), radio frequency identification (RFID), Geographic Information Systems (GIS), laser scanning, video camera, and magnetic proximity sensing (Park et al., 2017). Cheng and Teizer (2013) created an accurate spatial model of a construction site layout and terrain using commercially available laser scanning and modeling systems. A virtual world was generated, and data from real-time location tracking sensors (GPS and/or UWB) was integrated. User-defined safety rules like those developed by Zhang et al. (2013) were applied, allowing the user to observe and interact within the "virtual" world from the safe confines of the "real" world (Cheng and Teizer, 2013). The simulation created by Cheng and Teizer (2013) will aid the improvement of worker situational awareness through the representation of equipment and other hazards. Geographic Information Systems (GIS) are beneficial when approaching construction safety on a universal level as the data can reveal detailed information about the site and surrounding environs (Zhou et al., 2012). Combining GIS with 4D modeling supports site safety planning by assessing what hazard mitigation measures are necessary (Zhou et al., 2012). Radio frequency identification (RFID) and Ultra-Wideband (UWB) are 2 effective instruments in recognition of moving machinery, vehicles, workers, and materials and by linking 4D BIM, GPS, RFID and GIS there is improvement in safety planning, job hazard analysis, material inventory tracking and automation (Zhou et al., 2012).

Riaz et al., (2014) investigated the integration of BIM and sensing equipment using a prototype to monitor confined spaces in construction projects whereby BIM communicated oxygen levels and temperature data accumulated by the sensors, but the location of workers was not tracked. Development of proximity-based location tracking was undertaken in which RFID sensors, BIM, and cloud communication was employed for indoor construction but found to require many signal readers that could interfere with workers' ability to complete their tasks, and thus was deemed unwieldy (Fang et al., 2016). The recent development of a small wireless device that acts as a "personnel" sensor can be attached to a worker's belt clip while tracking their movements and activity. This proprietary technology combines an accelerometer, gyroscope, and altimeter to recognize the location and time at which a worker has stumbled or fallen (Rubenstone, 2016). The data is recorded and uploaded to the cloud which allows safety managers, site supervisors, and others to determine the height from which a worker fell, what direction, and the force of the impact (Rubenstone, 2016). Bluetooth sensing technology in a roadway work zone environment was the subject of a study in which a proximity detection and alert system were developed to a) provide real-time alerts for equipment operators and other workers in hazardous conditions, b) assist in mitigating risk, c) operate unobtrusively, and d) provide another layer of protection for workers (Park et al., 2016). However, with the increasing reliance on mobile technology at construction job sites, there are a new set of safety issues to be considered. Bechtel has created "mobile device zones" to protect heads-down workers from potential hazards. The corporation has also implemented a policy for employees found using mobile technology outside of the zone, at which time the worker is cited with a "*near miss*" (Abaffy, 2013). BIM-integrated GPS wearables are being employed at construction sites by construction companies such as Skanska USA. The wearable technology integrates with BIM and enables job-site superintendents to indicate hazardous areas and alert workers based on their work locations in real-time (Wood, 2016). Increased use of drones by New South Construction, Atlanta, GA, allows for better job-site imaging before construction mobilization, while consistently revising the site conditions and giving workers updates in real-time (Wood, 2016). In the process of generating enhanced visualization before construction, and real-time information during the construction phase, the company has the potential to improve the safety of the workers on the site and identify potential concerns to safety, over the project lifecycle. Coutts Brothers Construction, Randolph, ME, issues their employees "*V-watch*" personal voltage detectors that alert the wearer to the proximity of energized materials (Wood, 2016), thereby attempting to enhance the safety of the construction workers. Such product-based innovative approaches to using technology for improving construction safety is in response to the global necessity of improving construction safety, not only within the US.

Conclusion and Future Research

Based on the literature review, the findings of this paper are: 1) a firm commitment to improve construction worker safety via various technological avenues, 2) a foundation based upon research and development of automated rule-based safety checking systems has enabled the creation of software for use in examining building information models and construction sites to plan and recognize potential hazards prior to the start of construction, 3) DCWS or PtD is aiding in the diffusion of safety training throughout the AEC industry by expanding accountability for worker safety and academia is increasingly aware of the need to incorporate construction safety courses in undergraduate construction engineering and management programs, 4) the improvement and extension of wearable technologies and job site sensing mechanisms continue to advance through research and dissemination of information around the globe.

Persistent advancement in BIM and the integration of visualization technologies such as virtual reality (VR) and augmented reality (AR) will be of benefit to non-English speaking construction workers. Harnessing the capability to improve safety training as workers can "walk through" a job site or building increases understanding and helps prepare for the sequencing of tasks. At the same time, a significant portion of the AEC workforce continues to experience elevated numbers of fatalities. A marked number of Hispanic and Latino construction workers perish annually due to "*slips, trips and falls*"; thus, there exists an opportunity to partner with industry entities to initiate research concerning the efficient usage of BIM technology and implement systems to educate and train Hispanic and Latino workers about safe working practices while working at elevation. In addition, future studies can also analyze the effect of bravado among the new workforce and if bravado can be mitigated by enhanced visualization offered by BIM, thus, ascertaining if BIM has the potential to improve safety by addressing some of the identified concerns for safety.

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