IMPROVING CONSTRUCTION SAFETY USING BIM-BASED SENSOR TECHNOLOGIES

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Abstract
Construction sites are dynamic and complex environments which makes them difficult to control. Indeed, safety and performance efficiency are often inadequate. Construction industries are relying on new equipment and machinery to keep up with the dense and complex design projects. To cope with the development, new techniques and technologies are being adopted to deal with the rising safety risks.
Automated recognition of construction risks using Building Information Modeling (BIM), is being developed and looks promising to manage and minimize accidents. The objective of this research is to show the relation between BIM and construction health and safety. As well highlight some of the sensing techniques and technologies, used with the integration of BIM, that helps with identifying, monitoring, and training workers which may lead to lower on-site accidents.
The methodology adopted in this work consisted in the selection of several research papers using a reproducible approach and then a narrative and thematic analysis is performed to evaluate their contents. Several tools have been listed as well as the risks they are targeting.
Based on the result of the review it is believed that BIM is rapidly growing around safety. In the future, BIM should be integrated within the start of every project and develop to anticipate threats, to maximize the proficiency and ensure the safety and good performance of workers.

1. Introduction

Construction sites encompass several engineering and areas, all working under one schedule with different actions and different durations set for each task, as well utilizing different sets of skills and man power. Accordingly, construction industries tend to have dynamic and complex working environments, hence health and safety as well as performance is often inadequate [1].

The Construction Industry still holds a considerable amount of injuries and fatalities, making it one of the industrial activities with morefatalities (Figure 1) [2].
The Occupational Safety and Health Administration (OSHA) identified the most common accidents which are falls, struck-by-objects, electrocution, and stuck-in; these accidents, named "The Fatal Four", were responsible for 58.1% of worker deaths in 2014. There are several theories identifying the cause of accidents; according to Heinrich, accidents are events which are uncontrolled and unplanned, in which an act or effect of a certain person, object, material, or radiation results in injuries [3]. One of the theories identifies that three factors are responsible for triggering accidents, which are ignoring an unsafe condition and proceeding with the activity, not being able to identify an unsafe condition related to a certain task, and/or acting unsafe whatever the current environment was [3].

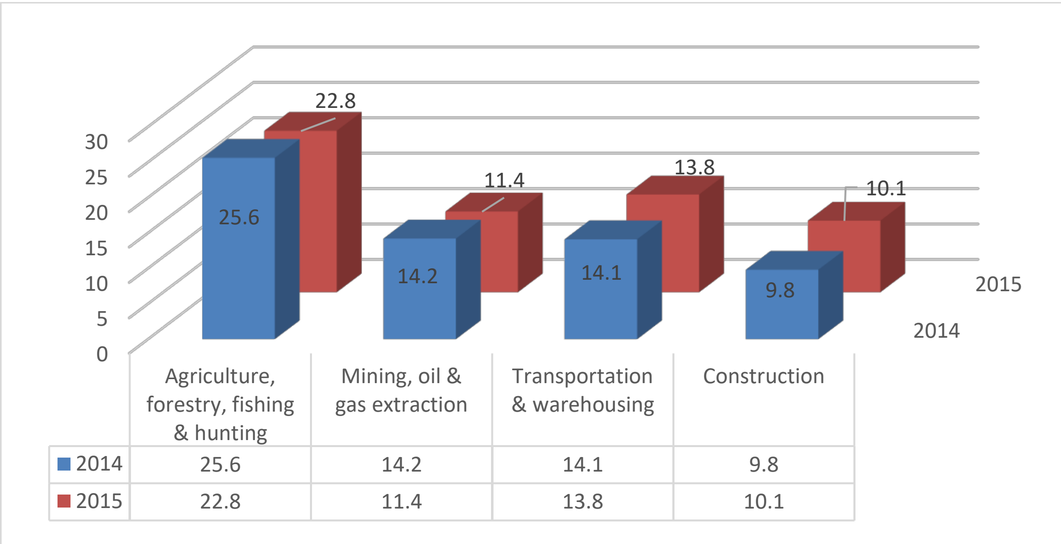

Figure 1: Fatal Injury Rates by Industries. Source:
https://www.constructconnect.com/blog/construction-news/construction-leads-industries-worker-deaths/

The unsafe construction environment exerts a risk related to the status of the workplace, tools or equipment. This includes unclosed edges and holes, flawed ladders, faulty scaffolding, overloaded or defected equipment, unorganized chemicals, explosives, and toxic material, unprotected nails, steel bars, wires and sharp objects. Natural disasters could also occur like earthquakes and storms.
The type of the construction works plays a major role in the safety status of the job. The hazardous construction jobs are shown in (figure 2) from the most dangerous to the least these jobs being, specialty trade construction which includes foundation, structure and concrete works. Heavy and civil engineering work is the second most dangerous which includes utilities, roads, oil and bridges. Building construction is the third most dangerous with works like houses remodeling, and residential. Equipment or mechanical construction is considered a little safer with works such as electrical, plumbing, and ventilating systems. And the safest type of construction works is the finishing works such as painting, flooring and insulation, which still account for 7% of deaths.

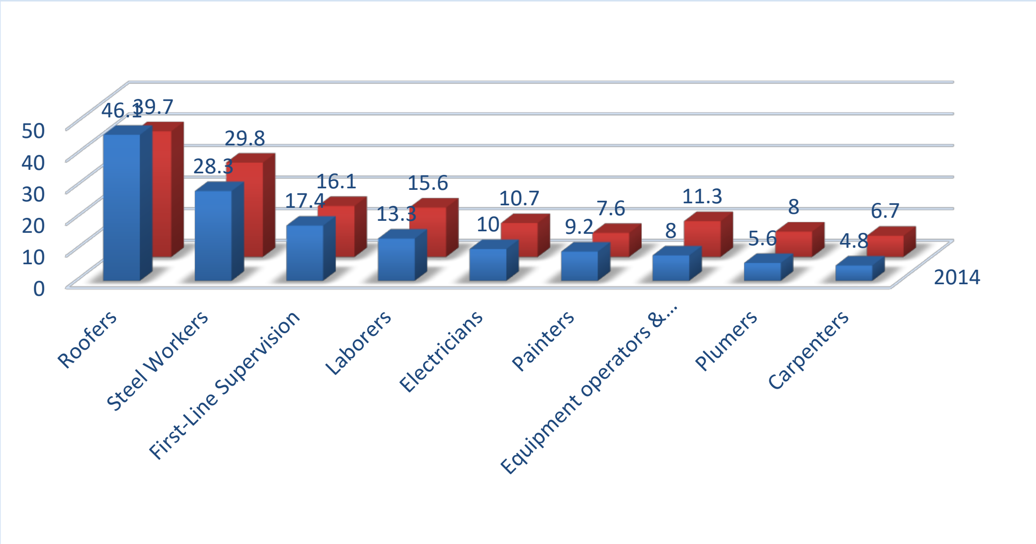

Figure 2: Fatal Injury Rates in Construction by occupation. Source: https://www.constructconnect.com/blog/construction-news/construction-leads-industries-worker-deaths/

Thus, the construction site needs to be regularly monitored and supervised. In addition, workers need to be trained to avoid unsafe actions. But manual monitoring and supervision is prone to error, due to the complex and dynamic site conditions. To assist the supervisors and visual inspection of the risks on site, automated safety monitoring such as using Building Information Modelling (BIM) is being adopted by the Architecture, Engineering and Construction (AEC) industry [4]. The implementation of BIM looks promising and could also assist the continuous advancements in construction processes. This could provide essential decision-support tools for engineers throughout the design stage, improving the safety and the performance of the workers, as well as enriching onsite training [5].
The objective of this review is to identify BIM methods that are being implemented into the construction projects to reduce the accidents. As well as listing some of the sensors and technologies that might be linked to BIM to assist in health and safety management, site monitoring, and workers training.

2. Literature Review

This chapter will highlight the major tools and techniques that are being researched and developed in the domain of BIM-based safety management and planning. Furthermore, it will mention some of the new technologies and equipment being implemented for construction safety.
Many efforts had been made to create a new approach for safety management to decrease accidents and hazards [2]. Some significant works target aspects such as changing schedules and timings of the activities to avoid hazards [6]. Saurin and Formoso (2007) develped a theory that was based on safe planning by estimating the risk distribution of a project developed safety planning and control model, which targeted safety by identifying the type of work being done,

based on proactive and reactive performance indicators of safe work, doing so by defining three levels of safety depending on the durations short-term, long-term and medium-term [7]. Construction Job Safety Analysis (CJSA) Rozenfeld, Sacks, Rosenfeld, and Baum aim to identify each work type and its level of safety by questioning workers and learn from their experience [8].
Developing tools and safety management systems enrich the safety management to a certain extend but it just states nonspecific information, and how to apply them for managing any project [2]. These strategies are not enough to prevent the accidents at an earlier stage at every different construction project. The limitations of these methods led managers to start thinking about automated safety management and virtual approaches to solve site safety issues. The Architecture, Engineering, and Construction (AEC) industry started implementing BIM, Augmented reality (AR), Virtual Reality and Geographic Information Systems (GIS). Robotics and machine learning are a major research field at the moment, not so much impact on the industry yet. These tools have become recognized for detecting and preventing hazards, as well as improving the efficiency and flow of work.
Using an automated approach for preconstruction work and design phases will assist designers and planners to relate health and safety to their work, which will be passed on to the site work accordingly further safety and health would be eliminate. Automated health and safety will have additional benefits such as visual and virtual training, the possibility to introduce regulations and standards, better communication between different employment levels, time and cost reduction, clearer schedules, and many other direct and indirect benefits.

2.1 BIM and Safety Management

BIM refers to a geometric model of a building or to the building information modeling which is the development and use of a computer software model to simulate the construction and operation of a project [9].Urbina Velasco, Blanco Fernández and Urbina (2012) considered BIM as a tool that improves the way in which information is produced, managed, transferred and visualized throughout the project lifecycle [10]. It strengthens the communication between all stakeholders and workers at all levels and phases of the project [11]. Nonetheless, BIM is being applied to manage feasibility studies and stakeholder concerns, cost, constructability, and environmental analysis, site organization and management, and facilities management [12].
Recent advancements of BIM technologies are providing suitable starting points for the development of solutions for pro-active site safety planning and management [13]. Recently, researchers are showing interest in developing safety using BIM for every phase in the project. Mallasi (2006) developed the Patterns Execution and Critical Analysis of Site Space Organization (PECASO) for site organization [14]. In the design phase, several developments have been achieved, including code checking and conflict anticipation. For example, based on 4D models and rule-based algorithms, Benjaoran and Bhokha (2010) developed a construction integrated system [15]. As a design for safety assistant tool for construction and safety management. Issa, Hinze, and Olbina (2011) formulated a design for safety suggestions by reviewing the developed model suggestions will be given to improve the safety aspects [16]. As for the onsite BIM integration, VTT Technical Research Centre of Finland developed 4D-construction safety planning, as a strategy to use BIM for onsite planning, management, and communications for safety and health [17]. This includes features such as tackling falls suggesting railings and covering edges and holes.

However, BIM as a stand-alone tool cannot acquire real-time data from the construction site, identify hazardous zones, monitor, supervise and train workers, and help with inspection. To assist in acquiring real-time data some technologies such as sensors and tracking devices are being deployed onsite [18]. These technologies vary from being Radio Frequency Identification Devices (RFID), magnetic field, Laser Detection and Ranging (LADAR), Radio Detection and Ranging (RADAR), ultra-wide band (UWB) [19], ultrasonic, infrared heat and magnetic sensors, sonar, Inertial Measurement Unit (IMU), Bluetooth, Global Positing System (GPS) Global Navigation Satellite System (GNSS), laser, video and static camera including Vision Cameras (VC), electrocardiogram (ECG/EKG), traffic management, Audio Technology and electromyography (EMG), galvanic skin response (GSR) [20], accelerometers, gyroscopes, and magnetometers and light sensors [21].

2.2 Sensors

In addition to site monitoring, sensors are being explored for other activities such as schedule and material flows, equipment uses and movement [22]. A study has been carried out, demonstrating that there are significant productivity gains when comparing traditional identification methods with the new and automated ones [23].

In order to improve health and safety management on site, three aspects need to be taken into consideration, being, obliged, continuously improved: identification of the hazardous areas, monitorization and inspection, and training [22]. Several research is done with this aim, including John Teizer (2007) who developed an algorithm to track workers' movement, at the same time it identified the hazards along their paths. Another study mentioned a real-time warning system working on Radio-Frequency Identification (RFID) technology with the same purpose [24]. Concerning training, an integrated system with a 3D virtual reality assisting workers to performed tasks related with steel elevations was reported by Teizer, Cheng and Fang (2013) [25].

A systematic review on this topic was addressed and it was found out that there are several sensors with different functions: location and tracking (of both workers and equipment), proximity detection, pressure sensing, scanning of structural deformation, environmental sensing (temperature, air quality) physiological monitors (for workers), amongst others. However, most authors used only the tracking/location type of sensor [1, 26-34]. The Bluetooth Low Energy beacons (BLE) was the most mentioned and it helps to decrease the risk of collisions (indicating places that can be potentially hazardous), providing alerts in real time for equipment operators, being a managing risk tool [26]. This monitorization occurs during normal operations with minimal distractions for its operators.

Li, Lu, Hsu, Gray, and Huang in their study considered Proactive Construction Management System (PCMS) which consists of two major parts: the real-time location system (RTLS) and the Virtual Construction Simulation System (VCS) [27]. With it, they could prevent risks such as falling, striking against objects or equipment, and being struck by moving vehicles. The experiment results showed that this system performed well on construction accident prevention and the Safety Index (SI) of the two project teams, with increased improvements by 36.07% and 44.70% respectively.

Lee, Lin, Seto, and Migliaccio (2017) had another approach to the safety mater as they made use of sensors (Total Worker Health – TWH by Zephyr BioharnessTM) which main goal was to measure physiological parameters such as heart rate, metabolic equivalents (METs), sleep quality, and on-duty and off-duty physical activity levels as the physiological and individual

features of the roofers, in order to try to understand the type of behaviours which lead to unsafe practises and unhealthy lifestyles [35]. Although some of the workers reported a highly satisfaction of the usage of such devices, it is crucial to understand the causes behind workers' unsafe behaviours or fatigue exposures as to remove these issues.
Despite the diverse methodologies with regard to the safety issue, combining technologies might improve their final result. Park, Chen, and Cho used a hybrid tracking system integrating BLE, motion sensors and a mobile BIM model which allowed to reduce the errors developed by each of the sensors when considered apart [32]. The integration of both the motion sensors and the map knowledge removed the problem of high fluctuation in an absolute positioning system, reducing positioning errors in about 42% which proved to be a model to improve tracking sensors.

3. Conclusions

This research demonstrated a literature review of some methods and ideas being used to promote health and safety in construction sites. The start of the research showed that health and safety is a major concern in the construction field and still have a significant number of injuries and fatalities. Currently, BIM is just being introduced to be a part of safety and health planning in the construction industry. In the past it was not meant to prevent injuries and save lives of workers, there is a rising interest in improving worksite safety through BIM with safer design and proper constructability methods [37]. BIM is being used for visualization and analysis procedures to improve health and safety programs during the project lifecycle. Even in a complex and dynamic environments BIM provides new tools and technologies, to improve site health and safety aspects in an efficient way. Prevention planning using BIM can be 4D visualization and transferred to all project levels and stakeholders. In addition, to the work space conflicts could be analyzed and prevented in earlier stages and avoid collisions according to construction schedules.
Safety training, safety planning, pre-task planning, job hazard analysis, site equipment planning, design for safety and accident investigations are major areas where Safety and Health professionals can use BIM [38]. BIM-based prevention through design (PtD) and designing for efficiency and optimization [12]. Before material installation BIM is used as a 4D model to review the installations for any further risks or accidents to be prevented. Monitoring the site using sensors could decresea the manual monitoring, a centralized data base could be used to store data and retrieve them whenever needed, that will help to take necessary actions and planning.
BIM is still facing some limitations, these limitations starts of BIM being an immeasurable tool, benefits that are related to any phase other than the design phase is hard to assess, never the less project managers also consider BIM as money and time. BIM requires model familiarity and good modeling skills, as well understanding the model and relate schedules and components, as well the person developing the model should also be familiar with the safety regulations and requirements. Furthermore, the models need to be detailed and having all necessary safety information for safety planning and checking, lacking these details will prevent identifying risks. In addition, still BIM is considered hard to use and for subcontractors, site workers and foremen they might be uncomfortable using it and they rather stick to the traditional 2D

drawings instead. As for health and safety professionals, access to BIM models could be limited and the technical skills and tools to use the model are not yet in place.
BIM is still not able to fully simulate the construction process, and still rely on manual assistance, as an example changes in the construction site were hazards arise might suddenly occur for workers, BIM do not simulate the rapid changes. Some accidents are still not able to be fully covered with BIM, for example operating from heights, machinery operation, personnel safety management. Nevertheless, BIM technology requires a high level of inter-organizational coordination. This coordination must be flexible in technological structure, secure, easy system to use and cost-effective. This is more effective and beneficial if and only if both parties adopt 3D CAD system, also either they use the same software, or any software which follows same standards.
Assisting BIM system by sensing tools improved the safety status but still most of the location tracking system do not gather accurate indoor data. As well as some sensors loose connection in underground or tunnel works where Wi-Fi is not available. The sensing technologies still rely on heavy infrastructure. In addition, the implemented system creates additional efforts to safety manager such as attaching Tags, analyzing data and training individuals. Results of the research also shows that sensor data may provoke false alarms and may cause inaccurate reading of sensing subsystem. Most of the sensing devices that relies on batteries have energy deficiency and cannot be continuously used for monitoring.
Future research will be necessary in several areas, for implementing BIM and making it reliable a validation strategy must be done and standardized in terms of performance, cost, field monitoring, risk recognition, and work interruptions. In addition to a measurable metric technique that will clearly show the benefits of BIM. Safety rule checking should be developed more till it be possible to influence a more complex and dynamic construction environment. Research in BIM should be widened to target more safety issues other than falls, moving vehicles, ungraded edges and holes, and temperature related threats. Research should also focus on developing high level of the detail to safety elements, as well making a stand razed format to facilitate data exchange.

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