Leading safety indicators and automated tools in the construction industry

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Abstract
Hong Kong is one of the cities with the largest number of skyscrapers. In this paper, we study the factors that lead to construction accidents on sites by interviewing the relevant parties. In the second part of the research, we extract the causes of accidents from court case report. Last but not least, we include a single case study from one of the largest construction companies in Hong Kong where robotics, drones, three-dimensional printing, virtual reality, wearable robotics and so on are applied on construction sites. It aims to study whether innovative tools can provide solutions to improve safety performance on sites.

Keywords
construction safety, skyscrapers, poor weather, robotics, virtual reality, 3D printing, infographics, Drone photogrammetry

1. Introduction

Lethal working environment in building industry has led to approximately 60,000 deadly losses every year which is higher than any other industries in the World (Edrei and Isaac, 2016, forthcoming). In addition, these mishaps not only affect workers' wellbeing, but also the living quality of the whole families (Alarcón et al., 2016) in particular when the victims are breadwinners. Despite we all wish to enhance construction safety performance, construction industry remains as one of the most perilous workplaces around the world, making a site dangerous free is exceptionally unease (Geoff, 2016). In recent decade, the ever increase in building height increases the complexity of construction projects so as the construction risks (Guo et al., 2015). Timely risk assessments are needed to deal with different construction projects (Guo et al., 2015).

Accidents on sites are not purely a freak of chance. Throughout these years, accidents have gone from being viewed as an arbitrary marvel to being the consequence of a progression of events that are conceivable to decide and control (Alarcón et al., 2016). large portions of these "misfortunes" happen on sites due to the absence of safety measures, for example, safety nets or guiderails (Edrei and Isaac, 2016, forthcoming, Li and Poon, 2013, Li, 2015). Temporary workers are used regularly to provide manpower due to time constraints on site. These workers are at increased jeopardy of injury because many of them change job site assignments several times a year. They are not always trained. Host employers are less willing to devote training resource to temporary workers because they are not permanent employees. It is not uncommon that a temporary worker is killed just after 1 or 2 days on the job (Mroszczyk, 2015).

Previous research also shows that designers play an important role on construction safety (Bong et al., 2015). Because of the oversight of designers or safety officers when they arrange or execute safety activities, utilization of innovation initiatives can upgrade safety development on sites (Edrei and Isaac, 2016, forthcoming). Any commitment to lessen work related accidents can be viewed as worthy (Alarcón et al., 2016).

Numerous sources, at individual and authoritative level, can bring about accidents. An example of 1180 firms and 221 individual practices over four years in Chile demonstrate that practices are the most important factors that affect accident rates (Alarcón et al., 2016).

In this research study, we firstly review the factors which lead to accidents on site from practitioners and judges' perspectives via extensive qualitative interviews. We compare the factors mentioned by the same group of interviewees with regards to skyscrapers and low-rise buildings. Besides, whilst the practitioners have day to day work experience on sites, their angles can be subjective due to their own personal experience, judges have to consider all the factors and evidences given by the victims,

employers, witnesses, book evidences etc that lead to accidents before they jump to conclusions and hence are often considered to be more objective. Hence, the second objective will be to compare the practitioners and the judges' perception on accident prone factors. Finally, in the era of information technology (IT), advances in various IT tools present an unprecedented opportunity to improve the safety performance on sites (Skibniewski, 2014, Hoła et al., 2015), we will use one single case study with regards to the new and innovative technological tools' application on construction sites. That shall provide some ideas on whether tools such as 3D printing, robots, aerial photogrammetry etc can reduce the chances of accidents on sites.

2. Leading and lagging safety performance indicators

Historically, construction industry examines safety performance via lagging indicators which include injuries, illnesses and fatalities' measurement and assessment. One noteworthy restriction of safety performance appraisal by means of lagging indicators is that incidents must happen before risks or hazardous conduct can be recognized. Leading indicators are safety measurements that proactively survey wellbeing execution safety performance by gaging procedures, exercises and conditions that characterize execution and can foresee future results (Marks et al., 2016).

One example of the leading indicator is a near-hit, characterized as an occurrence in which no property harm or individual damage happen, however could have happened given a slight change in time or position. The real preferred standpoint of this indicator, for example, near-hits is that information can be gathered and broke down without requiring a damage to happen. As noted, development organizations are required to report business related occurrences. These measurements, however, cannot reflect whether a peril, the occasion seriousness or causation has been alleviated. Leading indicators are measures of procedures, exercises and conditions that characterize execution which can anticipate future results. Unmitigated high-hazard circumstances bring about a genuine or lethal damage if permitted to consistently exist. Linear causation models, such as loss causation and domino models, recommend that accidents are the final consequence of a succession of occasions with a sound inspiration to gather and break down close hit information. Scientists have also found that most genuine wounds can be effectively prevented (Marks et al., 2016).

Construction safety is measurable from the behavior patterns of different stakeholders especially of workers through the ground theory method (Guo et al., 2015). Meanwhile, there are statistical analyses which specifically estimate the risk allocation in the construction project, for instance, the risk assessment of the Saudi Arabrian aviation construction uses ANOVA tests to identify risks (Banhdadi and Kishk, 2017). Alternatively, the ontological modeling and document modeling are used to facilitate a better measurement on the ignorance (Wang, 2015). Through assessing the ignorance of certain areas of safety requirement, managers enjoy better awareness on the construction risk. To certain extent, the above literatures show the potential of implementation of automated approach to the construction industry.

3. Innovative technologies used on site to enhance construction safety

3.1. Robotics

Modern robots can be utilized for execution of different building development exercises, for example, gathering of parts and construction of inside and outside building skin exercises, based on advanced control and detection (Warszawski, 1985). Some robots are designed to work in poor climatic conditions and tough work site environment (Skibniewski, 1988). Robots demonstrate that it can be a potential helpful builder via computerized gathering of black-top, programmed control of black-top movement and spreading; programmed guiding control with mechanical sensor and clearing velocity; consequently controlled begin/stop of all clearing capacities. Moreover, work can be performed naturally with man-made vision and sensors. Subsequently, graphical remote control framework allows human administrator control progressively with consistently altering procedure. Window glass mounting or board settling utilizing robot with pneumatic actuator and servo engine install window panel. Straightforward and independent robots collect two-dimensional structures utilizing pre-assembled modules as building pieces. Modules are able to do some data preparation, empowering them to share long range basic data and convey it to robots (Elattar, 2006).

3.2. Drone photogrammetry

Photogrammetry strategies have been used since a long time ago together with CAD and virtual models of building structures for architecture purposes. Photogrammetry utilizes two measurement pictures and fundamental

triangulation rule to figure the areas of focuses in three measurements. The expense and accessibility of computerized cameras gives a justifiable reason to the utilization of photogrammetry-based methodology for as-manufactured documentation. Cameras are less expensive, more compact and quicker to capture pictures nearby contrasted with other comparative information obtaining advances. The caught pictures are later handled utilizing programming, to get helpful geometric information (Akanmu et al., 2014). With the popularity of various types of drones in Hong Kong, many of these photogrammetry works are undertaken by the relative cheap drones instead of the expensive helicopter in recent years.

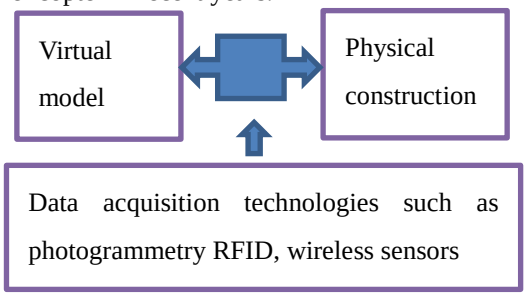


Figure 1 bi-direction data acquisition between virtual and physical construction (Akanmu et al., 2014).

3.3. Virtual Reality (VR) simulation and training

VR creates genuine work experience which has been proposed as a viable safety training in mining industry. VR can provide safety training exercise at whatever time in absence of talented administrators. A personal computer is sufficient to provide the environment for VR training. Furthermore, VR based training demonstrated that it is a useful platform for tower crane operation and iron laborer safety training. Nevertheless, critics comment that it is questionable whether VR frameworks can substitute the genuine experience. In Australia, the proposed VR training recognizes ranges in which formal training strategies and systems cannot reflect safety and health as honed by experienced laborers. It energizes innovative thinking and inspire specialists' thoughts for safety and health enhancements. It also connects with development specialists in acting and recording movies to outwardly speak to the safety learning; and allows users to collect safety and health data rapidly and effectively when the specialists need them. Thus, the VR training exhibit as a successful instrument for sharing and enhancing safety and health learning required nearby (Edirisinghe and Lingard, 2016).

3.4 Modular building structure

Modular construction are typically safer as compared with conventional build on site because of stable work area, where specialists are acquainted with knowledge about dangers, keeping away from work in tight spaces on site, performing off-site or on-ground gathering as opposed to working from statures, not being presented to unforgiving climate, less demanding approaches to screen dangerous exercises, less invested energy in development site, less contractual workers and laborers required nearby. Modular building includes assembling the entire building or some parts off-site. The study discovered 125 mishaps identified with pre-assembled fabricating development with the most frequent types of harm are “crack” and “fall” (Fard et al., 2015).

3.5 3D printing

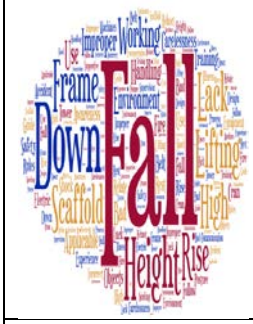
Many of us may of the view that the next step for modular building will be three-dimensional printing building structure. 3D printing's capability to empower structures to be built quicker with lower costs, further incorporation of building data into the development procedure makes it as one of the new direction in construction industry. Besides, that can decrease the number of labor on sites for safety reasons, lessening in development time nearby and increasing engineering flexibility. Nonetheless, the present 3D printing procedures are not yet suited to vast scale items, customary configuration approaches and have an exceptionally constrained scope of materials that can be utilized (Perkins and Skitmore, 2015).

3.6 Building Information Modelling

In construction projects, there are various participants involved in different stages of construction. The Building Information Modeling (BIM) is a useful means that collect various stakeholders (Liu et al., 2017). With the use of data-collecting sensors, it can sufficiently reduce the probability of worksite accident through the monitoring process of the data acquisition system (Druley et al., 2016). In a more sophisticated estimation on the response modification, the design of construction which is highly coherent with construction risk can effectively be converted from force-based design into probabilistic performance-based design procedure (Yarahmadi et al., 2017).

4 What are the leading safety indicators? A glance at the results from the interviews

In this research, we use the information graphics (infographics) approach which is a tool to visualize the frequency of the words' number of times mentioned. Infographics normally used in mainstream media in bar and line charts, making data visually beauty but at the same time convey the message and data easily (Li et al., 2015). It has been applied in previous research such as Li et al. (2016) in analyzing the objectives of competition law. In this paper, we adopts Tagul to visualize the data as word cloud (Tagul, 2016). Results from the interviews show that the first most important reason that leads to accidents in skyscrapers building site is fall from height as indicated with the largest size of the word.

Five most important factors that lead to construction accidents in skyscrapers	Five most important factors that lead to construction accidents in low-rise building
First most important factor 	First most important factor 
Second most important factor 	Second most important factor 
Third most important factor 	Third most important factor 
Fourth most important factor	Fourth most important factor

	
Fifth most important factor 	Fifth most important factor 

Table 1 Factors that lead to construction accidents on skyscrapers and low-rise building sites.

5 Results from court cases research

In the second part of the research, previous court cases from 1991 to 2015 are included. We extract the factors that are considered by the judge as the most important factors that lead to construction accidents on sites. After that, we use the infographics approach with (Tagul, 2016) to study the factors that are more important. Stopping words include Contributory, Provide, Onto, Defendant, Mentioned, 1st, Part, Had, common. The results show that the most important reasons in the eyes of judges are related to negligence, equipment, statutory issues. Unlike the practitioners, judges concern more on the distant factors that lead to construction accidents. Factors like bad weather is never the most important factors in their viewpoints.

Figure 2 Judges' viewpoints with regards to all types of construction work on sites

6 Case study: Gammon construction

In recent years, firms are confronted with difficulties identified with implanting new innovations and related practices for the advanced computerize work of significant foundation ventures. Dissemination of developments hypothesis is utilized to examine how advanced advancements diffuse crosswise over complex firms (Shibeika and Harty, 2015). In the third part of the research study, we shed light on one construction company's innovative strategies in enhancing construction safety.

6.1. Curtain Wall – Robotic Installation

Gammon introduces the first curtain wall installation robot in Hong Kong to encourage automation and lower labour intensity. Robot reduces manual operation, relieves serious shortage of curtain wall installer (that can reduce number of installation worker by 25%), enhances construction safety (Gammon Construction, 2016b). Furthermore, in order to deal with the upcoming labour shortage due to ageing problem and to avoid on-site construction risk, robotics is increasingly important (Gammon Construction, 2016a). For instance, it has introduced Exoskeleton and ZeroG Arm to assist workers to handle heavy loads or equipment. Specifically, Gammon provides exoskeleton which can automatically sense the workers' movement, then, provide back support for worker to lift heavy object. It can effectively reduce the risk of back injuries (Gammon Construction, 2016a). At the same time, ZeroG Arm can help to maneuver heavy equipment. The energy loss of workers can greatly be reduced as it provides almost weightless experience to hold heavy equipment for timely process. Therefore, the task can be finished in less time required (Gammon Construction, 2016a).

6.2. Virtual Reality Safety Training

Online game is a common trend nowadays especially to the younger generation. Gammon is the forerunner in taking the lead to incorporate virtual reality (VR) in safety training. Construction site is simulated in 2D and 3D game environment to enable trainees experience different scenarios in virtual construction site. Safety Manager Kwok Wai-yin comments that training as such is more effective and convincing than lectures. It can draw trainees' attention, stimulates their responses and enhance mutual communication. It changes workers' mode of thinking, boosts site safety and gets closer to the zero accident on sites (Gammon Construction, 2016b).

6.3. i-Core Development

It often requires heaps of work to track the location of materials from production to installation on sites. i-Core is a standalone, extendable and programmable electronic circuit with GPS, GSM, thermometer, Bluetooth, gyroscope and barometer which is integrated into one i-Core chip. Equipped with GSM/GPS chips, Gammon's i-Core provides logistic management solution for expensive construction materials such as chiller plants or precast concrete products. It is able to track real-time location and share location information via online database. It enhances efficiency, productivity and saves the manpower in the tracking process (Gammon Construction, 2016b).

6.4. Precast, prefabrication

Tuen Mun - Chek Lap Kok Link – Southern Connection Viaduct Section venture, it augments its use of precast strategy for the marine viaduct components, for example, the precast heap top shells. The shells are fabricated off-site, put straightforwardly on top of the perpetual heaps and dewatered to bolster the profound heap tops development, without the need of cofferdams or marine falsework. Thus, the quantity of rebar fixers, welders, woodworkers, riggers and jumpers could be diminished hugely. The precast approach likewise lessens material, working at stature, and minimizes the likelihood if unintentionally dropping cement into the ocean (Gammon, 2015). Precast heap top shells save 40,000 man-days and have vital wellbeing advantage as specialists work shorter time nearby (Gammon, 2015).

6.5. Drone photogrammetry for surveying

The imaginative automaton and drone photogrammetry affixes the looking over work with more subtle elements and less number of area surveyors and lower costs. Whilst the expense of customary reviewing work per square meter is HK$2, while the expense of photogrammetry per square meter is HK$0.1 (Gammon, 2015).

6.6. BIM technology and 3D scanning

In 2013, Gammon has advocated the application of the Building Information Modelling (BIM) into practice. Since BIM is a 3D model-based process to collaborate the participants of the construction project. It helps the construction project to draft detail project design and plan. The initial plan is much better to the traditional plans that the considerations are well-rounded so that the plan is optimized to the

actual need. Throughout the construction pr resources consumption is under BIM supervision. It suggests the way to resources in order to be efficient and cost less burden to environment. Therefore, after adopting BIM, the construction projects can be simulated digitally in ord achieve higher efficiency and lower waste production (Gammon Construction, 2013). The famous buildings which have adopted the BIM include Hysan Place, One Island East and Lee Garden Three. Moreover, with the assistance from BIM, Gammon puts a step forward to ado printing and scanning technology. Through 3D technologies, the construction projects will be more efficient and accurate in design stage.

7 Discussion and conclusion

Results of the interviews show that practitioners consider fall from height are the most important factors in leading towards on followed by bad weather and machine. Whilst the top three factors for low-rise buildings' construction related to lack of important safety equipment, training etc. Hence, the idea of "is spelt out explicitly in the diagram. The second and third most important factors include machine and bad weather. With regards to judges' perceptions, negligence is the most imp factors amongst all.

Can innovative with various information technologies nip construction accidents in the bud? The introduction of robotics, prefabrica precast building structures, i-core with GPS, aerial photogrammetry and 3D printing implies that the number of workers can be reduced on site, leading to a possible reduction in construction accidents. The VR training can reduce the mishaps due to lack of training / knowledg construction activities on sites.

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