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Application of digital technologies for health and safety management in the infrastructure sector

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***Abstract*---**Being one of the oldest industries in existence, the infrastructure industry is quite rigid and set in its ways. This is bound to happen as when the industry is moving forward without innovation, why invest more to change. This also means the same mistakes, issues, problems and hazards continue within the system. Without innovation factors like defective equipment, human error, hazardous activities, environments dangerous to work in etc. are major causes for concern in terms of health and safety. Today there are multiple digital technologies available, some more complex and exhaustive than others, which can be explored to ensure better health and safety standards and support management of the same. With multiple emerging technologies, the intent was to explore and study, categorise, identify the target point of research, analyse the core role and lastly understand how these digital technologies can be used to improve health and safety management in the infrastructure sector. Academic databases like the ASCE library, Science Direct, Web of Science, Taylor and Francis etc. paved the way for systematic and extensive literature review process which was employed to conduct the study. Through the study 20 digital technologies were identified specifically pertaining to health and safety, namely, unmanned aerial vehicle (UAV), game technology, case-based reasoning, rule-based reasoning, augmented reality (AR), virtual reality (VR), physiological status

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monitoring, ubiquitous sensor network, motion sensors, geographical information system (GIS), photogrammetry, virtual prototyping, building information modelling (BIM), robotics, wearables, online databases, 4D computer aided design (4D CAD), action/object recognition, e-safety management system, real time location with proximity warning and laser scanning. After having grouped the 10 most relevant and probabilistic technologies into three categories, these were analysed in depth under people, process and environmental technologies. Through the course of this study, it was obvious that digital technologies are the future of health and safety management in the infrastructure industry just as they have grown to be the revolution in so many other industries through their innovative, super adaptive and high-performance nature. The question that continues however, is how soon these technologies are going to be the way forward.

***Keywords*---**digital technologies, technologies, infrastructure, construction, health safety, digital, innovation.

Introduction

The digital age has been one of the biggest turning points in the progress of mankind. Ever since the digital age begun more than two decades ago, there has been an exponential growth in terms of innovation, technology advancements, availability of data etc. There has been a major change in terms of people's lives, communication, learning and work. The interest of researchers has peaked too in terms of implementing digital technologies into many fields like health and safety management of the infrastructure industry. Health and safety officials and government authorities have taken innumerable efforts in order to reduce fatalities and worker's injuries on construction sites by improving the health and safety standards but to no avail with alarming rates of the same (Li, 2015). Although researchers believe that a plateauing effect has occurred for safety; and digital technologies are the solution to opening up the safety management from a constriction to revolutionizing it, the actual industry seems to be running away from this reality.

Common causes of the aforementioned issues are human error, equipment defects, unsafe working conditions and high-risk work areas (Li, 2015; Hinze and Teizer, 2011). There are many who tried to systematically review research and eliminate these issues. Different strands of research were reviewed for digital tools in managing health and safety by considering technologies ranging back to 1986 (Zhou et al., 2012; Zhou et al., 2013). A majority of the papers focused on the role of some technologies which seem to be at the forefront of the digital technologies for safety management. Digital technologies application to construction health and safety management has been the key focus by emphasizing the role of the same after identifying the a few technologies that are most relevant. Wearables, laser scanning, sensor-based techniques, Building Information Modelling (BIM), Virtual Reality (VR), photogrammetry, Unmanned Aerial Vehicle (UAV), Geographic Information System (GIS), 4D Computer-Aided Design (4D CAD),

online databases and robotics for prevention of accidents on site and safety management were the most relevant. (Teizer, 2016; Zhou et al., 2011; Li and Ng, 2017; Linner and Ikeda, 2012).

There is so much data available now in the digital age about the new and innovative types of digital technologies which can benefit health and safety management on site. This is however scattered and lacks comparative studies in terms of the top contending digital technologies. After extensive research, the development and application of certain technologies have been identified and the functions have been analysed with respect to accident prevention and by and by health and safety management.

Methodology

The main target was to understand and study the various digital technologies with the core as health and safety management in the infrastructure sector. Keeping this in mind, a traditional literature review approach was adopted. A similar method was adopted like Zhou et al. (2013) which includes literature search, selection of literature and coding of the selected literature. Multiple academic and research databases including but not limited to Elsevier (Science Direct), Research Gate, Taylor and Francis, Emerald Insight, the ACSE library, Web of Science and Engineering village via online platforms was the key source of information. Using the initial descriptors like health and safety, construction site technology, technology and technologies based on functionalities; an extensive database search was put into action. Further, sensors, lasers, remote sensing, wireless network, robotics, innovative wearables were a few keywords to get more focussed results. Many important and reputable scholarly journals were reviewed and cited following which any significant papers related to the area of study were collated to be able to generate a database. Comprehensive research forms the backbone of any research, paper or journal and then the same research forms the basis for another's research. This is the literary research cycle which we hope to carry on.

Discussion and Categorization

There are numerous digital technologies available for the construction industry in recent times. Health and safety have become seemingly more important as employees and labourers now know their rights with the digital age's easy access to information. From the time of hard hats and protective glasses, digital technologies have been available to the industry (Li and Ng, 2017). With research and innovation at a peak across the globe, newer technology is being developed very often causing the reluctant industry to use more technology (Zhou et al., 2013). Construction sites has seen an improvement in health and safety via combination of it with big data and technological genius which is discussed further. Digital tools like VR, AR, BIM, drones, GIS, sensing and warning technologies, unmanned machines, automation, robotics, 4D CAD and many others have been identified as effective technology for safe project delivery with zero to minimum accidents or mishaps (Zhou et al., 2011). Further we can discuss the classification into environment, people and process technologies. It is also noteworthy how so many as interconnected.

Environment Technologies

Often misunderstood as for the social environment, environment technologies pertain to the construction environment. Hence, these are tools to health and safety within the confines of the construction environment. When tools like GIS and Global Positioning Systems (GPS) are combined, we can further understand the construction environment and its interactions based on project structure and external environment (Bansal, 2011; Zhou et al., 2011). GPS can also be integrated with wireless networks and sensors to monitor site workers, labour and equipment and not only help for safety management but also provide real-time information to management and contractors about other aspects of the project. (Teizer et al., 2015). Let us further understand environment technologies.

Integrated sensors with wireless networks

The first thing that comes to mind is how can a sensor network be used to monitor health and safety on a site. Well, by placing sensors at important locations, the sensors can relay data to a main server based on the type of sensor and this can be then transformed into the type of information we hope to receive from that particular area where the sensor is placed. Hence, sensors play a key role in real time monitoring on site (Zhang et al., 2017). The entire environment of construction site can be monitored using a network of sensors helping to prevent any collisions, mishaps or fatalities. In depth studies about sensors including sensor-based location, wireless sensor network and vision-based sensing has been highlighted by Ahsan et al. (2007).

A construction site is very complex in itself (Ahsan et al., 2007). Having a sensor network placed in the chaos seems like a lot with all the extra wiring which would need to cover the whole site. That's where the wireless network system comes into the picture. The sensors wirelessly transmit data via the wireless networks put into place and hence all the corners and strategic locations can be tracked, monitored and hence by doing so improve the feedback loop of the entire place. Flow of information is always an issue on sites which has been found to be much better by the use of wireless networks (Ward et al. 2004; Brilakis, 2007). Site operations have over the years tested networks like Wireless Local Area Network (WLAN), GSM and even Terrestrial Trunked Radio (TETRA) (Zhang et al., 2017). However, there is one network that seems to stand out which goes by the name Wi-MESH. This provides remote backend access and internet connection which proves beneficial (Ahsan et al., 2007).

Radio Frequency Identification (RFID)

By using radio frequency waves to encompass the data for identifying materials and workers' positions in the project (Yin et al., 2013). RFID comprises of tags (consists of antenna and microchips) and Reader. Unique serial numbers are used to store data in the tab. RFID with 10 to 100 m can be active or passive (ibid). Real-time data collection has been demonstrated using this technology (Li and Leung, 2017). This has been used to track movements of material, workers, and equipment (Zhou et al., 2013), such future occurrences can be avoided. CAPS

system designed by Chae (2009), estimate the size of work area. By gathering data of the site accidents can be avoided (ibid).

Virtual Reality (VR)

A virtual experience same that to real-life via electronically generated artificial simulation is known as Virtual Reality (VR) (Bouchlaghem et al., 2005). To make it as realistic as possible computed generated imagery and hearing systems are used. For example, working conditions for cranes can be simulated by safety teams via VR. Effective visualization and communication of the impact of important construction tasks in ongoing projects can be helpful, otherwise overlooked using traditional methods (Zhang et al., 2017). Authentic work experiences for safety training can be carried out (Li and Leung, 2017). Just by simulation of proper safety training on computers, eliminating the need for qualified safety personnel on-site (ibid). Same experiences as VR cannot be presented by traditional safety training like videos or slideshows, as they don't represent the opportunity for interaction and responsiveness Zhou et al. (2011). Such participated training can make personnel aware of real-life scenarios for the importance of safety.

Augmented Reality (AR)

Augmented reality is based on advanced technology used to amplify the existing built form (Bouchlaghem et al., 2005). Interactions developed via AR can be distinguished using mobile applications and electronic devices (Patrucco et al., 2010). As the person physically walks through the site, devices like mobiles or helmets can be used to create 3D imagery and present real-time geospatial data (Bouchlaghem et al., 2005). By providing access to personnel of such advanced AR, virtual safety drills and safety scenarios can be performed at a low cost (ibid).

People Technologies

Unlike environmental technologies, people technologies pertain directly to the human error factor. It is specific to the person. In other words, these are tools to ensure safety by what workers wear (Teizer et al., 2013) and can provide multiple layers of protection directly to the body. There is a long and standing ‘dangerous’ relationship between heavy machinery and workers which many have researched and studied (Li and Leung, 2017). It is often an issue with heavy equipment simply because the work is repetitive and hence the regard for safety norms goes out the window as work progresses. A lot of equipment and human error can be eliminated through automation and robotics. Regardless, here are a few of the technologies that were the most relevant and can be used on a large scale to ensure that the people and workers are safe with good results so far.

Smart Wearables and PPE Technology

Wearables, such as hats and watches, are items of clothing or accessories that combine technology. Waving heartbeats and other physical processes and gestures are collected and used to control a physical process or an external event (Zhang et al., 2017). Falls, electrocutions, and caught-in-the-middle mishaps can

all be mitigated using wearable devices. The smart hat or helmet is a safety device that includes unique glasses, 4D augmented reality, and a clear visor. DAQRI designed a hard helmet with a sensor bar for activity alignment and tracking (Teizer et al., 2010). The headwear detects potential hazards on the site and issues instructions and warnings. Smart PPE, such as safety vests with sensors and GPS, has also been built to safeguard construction workers in the event of a fall disaster (Zhou et al., 2013).

Automation through Robotics

The latest mode for fast-tracking and automating construction tasks is by using Robotic systems (Chu et al., 2013; Bock et al., 2012). Robots controlled by computers are used on-site for free-standing installations, lifting heavy material used in construction, thus reducing the extensive number of labour forces required to construct structures such as skyscrapers. (Niu et al., 2017; Jung et al., 2013; Li and Leung, 2017). The first automation system used in construction was the robot that laid brick walls up to 8m in length with bricks glues using adhesive. An automation machine which was used on- site to build straight bonded brick walls precisely, was discovered by Yu (2009) and it was called the "Blockbot". An engineer's model was developed for mitigating and managing the hazards in construction projects like fall risks by Navon and Kolton (2006). It was easy to determine via graphical representations with respect to high-risk zones in construction tasks (Azmy and Zain, 2016). A model was put forward by Balaguer et al. (2002) in which robots climbed and checked the steel structure constructed. Inspections are carried out in complex areas by using independent locomotive systems similar to a caterpillar.

Process Technologies

The process of construction in itself is a high-risk process with many dangers due to equipment, material and so on. Process technologies are those which help ensure safer activities are carried out on site. By refining the process level, significant changes can occur is health and safety on site (Zhou et al., 2011). Through software like 4D CAD, identification of potential risks in design can be analysed prior to ensure safety (Ku and Mills, 2010). Research tools are used on online databases to be able to assess competence of stakeholders and improve communication (Yu, 2009). In practice, BIM and 4D CAD have been used to plan and assess the health and safety management on construction sites (Merivirta et al., 2011).

Internet of Things (IoT)

In the history of technical growth, the Internet of Things (IoT) has recently become a huge innovation and trend (Cheung et al., 2004). The network is made up of embedded tools and equipment that are accessed and connected to the internet via wired and wireless networks. Site activities that demand constant careful attention are monitored using IoT monitoring solutions (Dodge Data and Analytics, 2017). Applications are intended to improve decision-making processes by allowing workers to send real-time responses (Jing et al., 2014). Sensors and gateways are utilised to collect health and safety data in smart construction, and

clouds are then used to wirelessly store, analyse, and review the data (Hopah and Vayvay, 2018).

Riaz et al. (2006) created a proactive communication system for construction sites to decrease human-machine collisions. To track site personnel and equipment and alert operations about imminent site hazards, a combination of GPS, smart sensors, and wireless networks is used. Reports on harmful actions and near-miss accidents are generated by the system (Azmy and Zain, 2016). Safety-related issues on site have been managed using the Wireless Application Protocol (WAP) and Multimedia Messaging Service (MMS) by delivering notifications to site employees, who then communicate quickly via text message when corrective action is taken (Bowden et al., 2006).

Online Databases

Several aspects of construction health and safety have been improved by using online technologies, including safety training and education, risk identification, safety monitoring and evaluation, and safety inspections (Dodge Data and Analytics, 2017). To detect potential site dangers and assess competency, online databases can be used (Zhou et al.,2012). Yu (2009) created a prototype web tool to help assess potential designers, contractors, and coordinators. During the evaluation process, the online system uses Artificial Intelligence (AI) to aid decision-making by identifying and assessing risks, as well as collecting and analysing data (Zhou et al., 2012).

The Construction Safety and Health System (CSHM) is a web-based safety monitoring system that detects possible site hazards and issues alerts for actions that require immediate attention (Cheung et al., 2004). Through remote internet access, the system improves data search, uploads, collecting, and documentation (Azmy and Zain, 2016). Health and safety indicators from a variety of projects are deciphered, and useful data is gathered to improve construction health and safety management. The performance of a project is tracked throughout time by examining the ratings awarded to particular factors (Yu, 2009). The development of a real-time communication system for monitoring construction safety on various projects was identified by Azmy and Zain (2016). The data is stored in a centralised database, which is then examined by site managers to help them make decisions on construction sites (ibid). This technology provides a different way to get construction health and safety data and statistics.

4D Computer Aided Design

3D CAD is quite commonly use in the field of safety management by health and safety experts for accident investigation and maintenance (Rajendra and Clarke, 2011). However, in order to simulate safety processes properly, we ned to use 4D CAD through which visualization becomes a reality for high-risk areas (Azhar et al., 2012). It is important that risks are identified early in the project especially due to design changes (Azmy and Zain, 2016). The ultimate goal using 3D and 4D CAD is to identify potential risks.

4D visualisation technology can pinpoint and analyse time-space congestion in the workplace (Mallasi, 2006). This Critical Space-Time Analysis (CSA) can be further used to obtain details about relative activities that occur parallel to each other and even draw up a comparison. In 2009, a rule-based infrastructure safety management system was developed using the same 4D CAD visualisation technology (Zhou et al., 2012; Benjaoaran and Bhokha, 2009). Height hazards was the major focus since majority of falls and accidents occur due to fall from heights on construction sites (Azmy and Zain, 2016). The 4D CAD system does require a lot of data inputs but still proves to be a quite accurate system similar to BIM which will be discussed next. Appropriate safety requirements can be custom made based on the site conditions and risks pertaining to the specific site rather than a generalized system.

Building Information Modelling (BIM)

BIM is nothing but a system to be able to visualise the entire construction site not specific to just the structure but everything around it too like roadways, silos, plants, boundaries (Azhar et al., 2012; Watson, 2010). Actual site conditions including small potholes in the roadways, boundaries of a swimming pool, falling debris areas can be seen on a screen enabling workers to visualise everything without even stepping on site (Watson, 2010). Through BIM, many training videos and health and safety norms can be easily converted into an interactive video to be displayed to the workers. BIM uses a lot of the other technologies spoken about like sensors, networks, databases to gather real time information on site and can hence reduce the likelihood of any hazards (Ganah and John, 2015; Druley et al., 2016).

In a rather interesting research conducted by Ku and Mills (2010) which stated that BIM promoted teamwork between the various stakeholders through automated systems once the guidelines, regulatory information and codes were fed and hence assessed the use of BIM as a safety tool. Based on this research, a system that assesses safety within construction activities was developed which automatically checked the BIM model for fall hazards (Qi et al., 2011).

Results and Recommendations

Digital technologies as seen through all the discussions are the only way forward for betterment of health and safety in the infrastructure sector. Project stakeholders like upper management, investors, contractors and more can benefit to a great extent with the use of digital technologies on construction sites. When accidents occur or health and safety is at stake, it automatically slows down the whole process of construction. This cause both time overruns as well as cost overruns, not to mention the amount losses incurred in terms of stakeholders not just in the monetary aspect. By investing a little bit of money and implementing the right digital technologies to mitigate any health and safety risks, the benefits are countless ranging from safety of workers to increased profits.

There can be tremendous reduction in accidents when the workers and employees are kept safe through technologies spoken about under people technologies. The construction process can be highly refined to mitigate any process risks by using

technologies like BIM and CAD in the right way hence using process technologies. Making the work environment safe is not only the duty of the upper management but having a safe work environment is the right of employees and workers. The various work environment hazards can be easily monitored and prevented using some of the environment technologies. This is the right time for the Indian infrastructure sector to move out of its shell and invest in up-and-coming technologies like IoT and Artificial Intelligence which will prove beneficial for years to come. Performance is always a key criterion and here, performance and productivity will both improve.

Conclusions

We initially selected the topic with the mindset that digital technologies are one of the best and accurate ways to mitigate the risks on infrastructure projects. Health and safety is not a very major concern in India. Although over the last few years as the digital age has set in and the access to information is easier, health and safety has had significant growth. Companies like TATA, L&T, Gammon India etc. which take on larger projects and have high liability factors, ensure to put into place certain norms that take care of health and safety of personnel to a certain extent. However, with the complexity of a construction site, it is almost impossible to continuously track individuals to ensure the health and safety of each individual. Hence, digital technology comes into the picture.

After having done a traditional comprehensive literature review of the aims of this paper were completed quite successfully. The identification of digital technologies was done following which the top contenders and most probable ones were analysed. Through the study 20 digital technologies were identified specifically pertaining to health and safety, namely, unmanned aerial vehicle (UAV), game technology, case-based reasoning, rule-based reasoning, augmented reality (AR), virtual reality (VR), physiological status monitoring, ubiquitous sensor network, motion sensors, geographical information system (GIS), photogrammetry, virtual prototyping, building information modelling (BIM), robotics, wearables, online databases, 4D computer aided design (4D CAD), action/object recognition, e-safety management system, real time location with proximity warning and laser scanning. The top 10 were then analysed and explained in detail.

It is our understanding after this study that although there exists a lot of digital technologies in the research world in terms of theories, experiments, papers and so on; there is very little to no research of the on-ground real use of digital technologies for health and safety management. This leaves a big gap on whether the digital technologies practically improve performance due to lack of hard evidence.

Digital technologies will continue to be the future and are the top contenders or rather the only contenders for the health and safety management segment. Many industries have already fine tuned their process as their processes are only repetitive and hence permits them to continue refine the process using digital technologies. While the technologies are available, the Indian infrastructure sector is years if not decades away from implementing these digital technologies for health and safety management. This is simply because, health and safety needs to

first be a major concern to then actually adopt innovative measures and methods to mitigate risks. Major companies like L&T are using very basic digital technologies to monitor sites which too are only used on mega sites. Smaller companies do not even provide harnesses to employees let alone the implementation of digital technologies to manage health and safety.

All said and done, through the course of this project it has been made clear and hence we can conclude by saying that although not soon, application of digital technologies is the next step to ensuring the health and safety management across the infrastructure sector. While some countries are already using these technologies, India will soon use these and this will bring about a major reformation in the health and safety sector of our country.

References

Ahsan, S., El-Hamalawi, A., Bouchlaghem, D. and Ahmad, S. 2007. Mobile Technologies for Improved Collaboration on Construction Sites, *Architectural Engineering and Design Management*, 3, pp.257- 272.

Azhar, S., Bahringer, A., Khalfan, M., Sattineni, A. and Maqsood T. 2012. BIM for Facilitating Construction Safety Planning and Management at Jobsite, *Proceeding of the CIB W099 International Conference on Modelling and Building Health and Safety*, pp.82-92.

Application of geographic information systems in construction safety planning," *International Journal of Project Management*, 29, pp.66-77.

Benjaoran, V. and Bhokha, S. 2009. Enhancing visualization of 4D CAD model compared to conventional methods. *Engineering, Construction and Architectural Management*, 16(4), pp.392-408.

Bock, T., Linner, T. and Ikeda, W. 2012. Exoskeleton and Humanoid Robotic Technology in Construction and Built Environment, *The Future of Humanoid Robots - Research and Applications*, Intechopen.

Brilakis, I., 2007. Long-distance wireless networking for site – office data communications, *ITCon*, 12, pp.151–164.

Ku, K. and Mills, T. 2010. Research needs for Building Information Modelling for Construction Safety, *International Proceedings of Associated Schools of Construction 45th Annual Conference*, Boston, MA. Li, R.Y. 2015.

Li, R. Y. and Leung, T. 2017. Leading safety indicators and automated tools in the construction industry, *34th International Symposium on Automation and Robotics in Construction*.

Mallasi, Z. 2006. Dynamic quantification and analysis of the construction workspace congestion utilizing 4D visualization, *Automation in Construction*, 15, pp.640–655.

Rajendran, S. and Clarke, B. 2011. Building Information Modelling: Safety benefits and opportunities, *Professional Safety*, pp.44-51.

Riaz, Z, Edward, D. and Thorpe, A. 2006. Sight Safety: A hybrid information and communication technology system for reducing vehicle/pedestrian collisions, *Automation in Construction*, 15, pp.719- 728.

Teizer, J., Caldas, C.H., and Haas, C.T. 2007. Real-Time Three-Dimensional Occupancy Grid Modelling for the Detection and Tracking of Construction Resources. *ASCE Journal of Construction Engineering and Management*, 133, pp.880-888.

Yu H. 2009. *A knowledge-based system for construction health and safety competence assessment*. University of Wolverhampton. United Kingdom.

Zhou, Z., Irizarry, J. and Li, Q. 2013. Applying advanced technology to improve safety management in the construction industry: a literature review, *Construction Management and Economics*, 31, pp.606-622.