Industry 4.0 & Construction H&S: Comparative Perceptions

James Beale, John Smallwood*

Department of Construction Management, Nelson Mandela University, South Africa, E-mail address: s215160959@mandela.ac.za; john.smallwood@mandela.ac.za

Abstract: Historical construction health and safety (H&S) challenges, in terms of a range of resources and issues, continue to be experienced, namely design process-related hazards are encountered on site, workers are unaware of the hazards and risks related to the construction process and its activities, activities are commenced on site without adequate hazard identification and risk assessments (HIRAs), difficulty is experienced in terms of real time monitoring of construction-related activities, workers handle heavy materials, plant, and equipment, and ultimately the experience of injuries. Given the abovementioned, and the advent of Industry 4.0, a quantitative study, which entailed the completion of a self-administered questionnaire online, was conducted among registered professional (Pr) and candidate Construction H&S Agents, to determine the potential of Industry 4.0 to contribute to resolving the challenges cited. The findings indicate that Industry 4.0 technologies such as augmented reality (AR), drone technology, virtual reality (VR), VR based H&S training, and wearable technology / sensors have the potential to resolve the cited H&S challenges as experienced in construction. Conclusions include that Industry 4.0 technologies can finally address the persistent H&S challenges experienced in construction. Recommendations include: employer associations, professional associations, and statutory councils should raise the level of awareness relative to the potential implementation of Industry 4.0 relative to H&S in construction; case studies should be documented and shared; tertiary construction management education programmes should integrate Industry 4.0 into all possible modules, especially H&S-related modules, and continuing professional development (CPD) H&S should address Industry 4.0.

Key words: Construction, Health and Safety, Industry 4.0, Performance

1. INTRODUCTION

The fourth industrial revolution, or Industry 4.0, is gaining momentum, and entails a paradigm shift that will have a significant impact on the management of occupational H&S. The adoption of Industry 4.0 related technology offers the construction industry a chance to improve efficiency, productivity, and H&S. The Construction Industry Development Board (cidb) highlighted the considerable number of accidents, fatalities, and other injuries that occur in the South African construction industry in their report 'Construction Health & Safety Status & Recommendations' [1]. Historically, construction has experienced more deaths and injuries than any other industry. Although not inherently dangerous, construction is known as a hazardous industry that presents many factors that are potentially dangerous to workers. Park and Kim reveal that most accidents associated with construction work were attributable to a lack of proactive and preventive measures such as H&S workforce training, HIRA, H&S awareness and education [2]. "At the organisational and site level, poor construction H&S performance is attributable to a lack of management commitment, inadequate supervision and inadequate or a lack of H&S training" (Construction Industry Development Board (cidb), 2009) [1]. Construction H&S monitoring relies heavily on manual observation to monitor and identify any potential hazards that may expose workers to H&S risks. This can become challenging as construction sites must be continuously monitored to detect unhealthy and unsafe working conditions in order to protect workers from potential injuries and fatal accidents. Industry 4.0 brings technology such as drones, AR, VR, and wearable sensors that can mitigate many of these challenges. Considering the numerous challenges experienced in construction, H&S included, it is inevitable that Industry 4.0 is considered to overcome these.

According to Autodesk & CIOB, digital technologies are transforming every industry, and construction is no exception [3]. Given the continuing poor H&S performance in South African construction, the aim of the study was to evolve an Industry 4.0 response to H&S challenges encountered in construction to determine the:

- Frequency at which ten H&S phenomena are experienced on projects;
- Potential of Industry 4.0 technologies to improve H&S performance;
- Potential of AR to assist designers and workers in identifying design process-related hazards on site;
- Potential of AR to assist designers in identifying design process-related hazards on site;
- Potential of using VR systems as a method of training to enable workers to identify potential hazards and mitigate risks on site;
- Potential of using drone technology to improve HIRA before activities commence on site;
- Potential of using drone technology to assist real time monitoring of construction activities;
- Potential of equipping workers with wearable technology / sensors to mitigate the hazards and risk accompanying the handling of heavy materials, plant, and equipment, and
- Potential of Industry 4.0 technologies to reduce the occurrence of H&S phenomena.

2. REVIEW OF THE LITERATURE

2.1 The potential of VR and AR in H&S Management

In recent years visualisation technologies such as VR and AR have been developed and used to improve construction productivity, H&S, and quality [4]. Both AR and VR have the potential to improve on site construction processes [4]. According to Park et al., AR based applications and systems have been developed to improve on-site tasks such as data visualisation, work inspection, and checking for omissions. These systems have improved on-site H&S performance to some extent [5]. According to Silliker, VR is rapidly gaining traction as a training tool in occupational H&S [6]. VR technology provides a virtual environment that allows users to immerse themselves in a virtual world that uses sight, sound, and sometimes motion to provide a realistic experience [6]. Wang et al. state that the construction sector is a high-risk industry where accident rates remain high [7]. It was highlighted that some of the reasons leading to the high level of risk include limited H&S knowledge of on-site workers and lack of H&S awareness and training of these individuals. Construction H&S training has traditionally been carried out in a classroom setting with slide presentations or videos. However, the H&S information provided in the presentations and videos often do not represent real construction site conditions [7]. A study conducted by Sacks et al. determined that VR-based training was more effective than traditional H&S training methods, which made use of classrooms and slide presentations [8]. The study determined that workers had better recall in identifying and assessing construction H&S risks, than they would have using traditional conventional methods. According to Wang et al., there are currently a few VR-related technologies that have been developed to improve the current construction H&S training practices [7]. VR is becoming more popular in the occupational H&S space as it provides a method of training workers relative to their actual job tasks in a safe environment [6].

2.2 The potential of drones to improve real time monitoring and HIRAs

A study conducted by Gheisari and Esmaeili [9] determined that using unmanned aerial systems (UASs) commonly referred to as 'drones', to monitor construction activities could help identify potential on site hazards and therefore improve H&S management. Tatum and Liu [10] determined that the construction industry is already making use of drones to carry out various tasks related to the construction processes and its activities. UASs provide an effective solution to carry out real-time monitoring and improve H&S monitoring and control practices on site [9]. According to Alizadehsalehi et al. [11], UAS technologies can easily monitor the entire construction site by flying around the construction area under a H&S manager's control and transmit real-time information for inspecting H&S issues related to the project. UAS technology can enable H&S managers to identify hazards at different stages of the project and develop suitable mitigation strategies [11]. Borck states that in addition to remote H&S inspections, drones are being used for many other tasks in the construction industry, including the monitoring of construction work without disrupting ongoing work; assessing and

determining the integrity of structures; identifying problems before they develop through the use of maintenance assessments; facilitating communication and surveillance; documenting jobsite conditions from the commencement to the end of the project, and increasing the scope and frequency of inspections [12].

2.3 The potential of wearable technology / sensors in H&S management

Seo et al. [13] state that due to the hazardous working environments on construction sites, workers are frequently faced with potential H&S risks throughout the entire construction process. Nath et al. [14] state that "construction works are labour-intensive and often stipulate the workers to go beyond their natural physical limits to cope up with the increasing complexities and challenges of their assigned tasks". Traditional approaches of measuring H&S performance indicators are largely manual in nature [15]. To overcome these limitations of manual efforts, automated H&S monitoring is considered one of the most promising methods for accurate and continuous monitoring of H&S performance on construction sites [15]. Wearable technologies can enable the continuous monitoring of a wide range of vital signals which can provide early warning systems for workers with high-risk health issues [16]. A study conducted by Nath et al. [14] determined that wearable technology was able to prevent work related-injuries and fatalities by ergonomically designing the work environment based on previous data collected [14]. The use of this technology was able to identify and eliminate the ergonomic risks at the source to prevent similar incident from re-occurring [14].

3. RESEARCH

The exploratory study entailed the completion of a self-administered online questionnaire survey. The sample strata for the research study was limited to 92 Professional Construction Health and Safety Agents (Pr CHSAs), and 139 Candidate (Can) CHSAs registered with the South African Council for the Project and Construction Management Professions (SACPCMP). The questionnaire consisted of eighteen questions – seventeen closed ended, and one open-ended. Twelve of the close ended questions were Likert scale type questions, and five were demographics related. 63 Responses were included in the analysis of the data, which entailed the computation of frequencies, and a measure of central tendency in the form of a mean score (MS), to enable the interpretation of percentage responses to Likert point scale type questions, and the ranking of variables. The 63 responses equate to a response rate of 31.2%. As stated in the 'Introduction' above, in terms of the study reported on, the following Industry 4.0 technologies were considered: AR; drones; VR, and wearable sensors.

Table 1 indicates the frequency at which ten H&S phenomena are experienced on projects in terms of MSs between 1.00 and 5.00, based upon percentage responses to a scale of never to constantly. It is notable that 7 / 10 (70.0%) of the mean MSs are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to perceive the phenomena to be experienced on projects. The mean MS of the phenomenon 'similar incidents reoccur' falls on the cut point. It is notable that no phenomena are experienced between often to constantly / constantly (MSs > 4.20 ≤ 5.00). 4 / 10 (40.0%) of the mean MSs are > 3.40 ≤ 4.20, which indicates the frequency is between sometimes too often / often - workers handle heavy materials, plant, and equipment, delays, on site hazards, and difficulty is experienced in terms of real time monitoring of construction-related activities. The remaining 6 / 10 (60.0%) of the mean MSs are > 2.60 ≤ 3.40, which indicates the phenomena are experienced between rarely to sometimes / sometimes - activities are commenced on site without adequate HIRAs, workers are unaware of the hazards and risks related to the construction process and its activities, design process-related hazards are encountered on site, similar incidents reoccur, accidents, and injuries.

A notable difference between the sample strata is that six of the Pr CHSAs' MS are higher than the highest Can CHSA MS. There are no major differences between the two in terms of the ranks achieved by the phenomena.

Table 1. Frequency at which ten H&S phenomena are experienced on projects

Phenomenon	Can CHSAs		Pr CHSAs		Mean	
	MS	Rank	MS	Rank	MS	Rank
Workers handle heavy materials, plant, and equipment	3.50	1	3.70	2	3.60	1
Delays	3.20	3	3.85	1	3.54	2
On site hazards	3.28	2	3.70	3	3.50	3
Difficulty is experienced in terms of real time monitoring of construction-related activities	3.17	4	3.66	4	3.42	4
Activities are commenced on site without adequate HIRAs	3.11	6	3.64	5	3.39	5
Workers are unaware of the hazards and risks related to the construction process and its activities	3.00	8	3.53	6	3.27	6
Design process-related hazards are encountered on site	3.14	5	3.27	7	3.21	7
Similar incidents reoccur	3.03	7	2.97	8	3.00	8
Accidents	2.86	9	2.88	9	2.87	9
Injuries	2.73	10	2.88	10	2.81	10

Table 2 indicates the respondents' self-rating of their awareness of / exposure to four Industry 4.0 technologies in terms of MSs ranging between 1.00 and 5.00, based upon percentage responses to a scale of 1 (limited) to 5 (extensive). It is notable that none of the mean MSs are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to rate themselves below average. Only 1 / 4 (25.0%) mean MSs are > 2.60 ≤ 3.40, which indicates a rating of below average to average / average - drones. The remaining 3 / 4 (75.0%) mean MSs are > 1.80 ≤ 2.60, which indicates a rating of limited to below average / below average - VR, wearable technology / sensors, and AR. The findings indicate that the respondents have generally a low level of awareness / had limited exposure to the four technologies to date.

A notable difference between the sample strata is that three of the Can CHSAs' MS are higher than the corresponding Pr CHSA MSs. It is notable that the ranks are identical for the two sample strata and the mean.

Table 2. Respondents' self-rating of their awareness of / exposure to four Industry 4.0 technologies

Aspect	Can CHSAs		Pr CHSAs		Mean	
	MS	Rank	MS	Rank	MS	Rank
Drones	2.64	1	2.69	1	2.67	1
Virtual Reality	2.52	2	2.13	2	2.31	2
Wearable technology / sensors	2.39	3	2.03	3	2.20	3
Augmented Reality	2.13	4	2.03	4	2.07	4

Table 3 indicates the potential of Industry 4.0 technologies to improve H&S performance in terms of percentage responses to a scale of 1 (minor) to 5 (major), and a MS ranging between 1.00 and 5.00. It is notable that all the MSs are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to perceive the potential to be above average. Although the Pr CHSAs' MS (4.19) is marginally below the lower point of the upper range, all the MSs are > 3.40 ≤ 4.20, which indicates between potential to near major / near major potential. Despite the respondents' generally low self-rating of their awareness of / exposure to the identified four Industry 4.0 technologies, they recognise the potential of Industry 4.0 technologies to improve H&S performance as per the literature. A notable difference between the sample strata is that the Pr CHSAs' MS is higher than the Can CHSA MS.

Table 3. Potential of Industry 4.0 technologies to improve H&S performance

MS		
Can CHSAs	Pr CHSAs	Mean
4.00	4.19	4.11

Table 4 indicates the potential of VR to improve aspects of H&S performance in terms of percentage responses to a scale of 1 (minor) to 5 (major), and a MS ranging between 1.00 and 5.00. It is notable that the all the MSs for both sample strata (100.0%) are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to perceive the potential to be above average. 3 / 3 (100.0%) of the mean MSs are > 3.40 ≤ 4.20, which indicates between potential to near major / near major potential - assist designers to identify potential design process-related hazards on site, enable workers to identify potential hazards and mitigate risks on site, and H&S training. Despite the respondents' generally low self-rating of their awareness of / exposure to the identified four Industry 4.0 technologies, they recognise the potential of VR to improve aspects of H&S performance as per the literature.

Table 4. Potential of VR to improve aspects of H&S performance

Aspect	Can CHSAs		Pr CHSAs		Mean	
	MS	Rank	MS	Rank	MS	Rank
Assist designers to identify potential design process-related hazards on site	4.12	3	4.34	1	4.24	1
Enable workers to identify potential hazards and mitigate risks on site	4.32	1	4.06	3	4.18	2
H&S training	4.29	2	4.06	2	4.16	3

Table 5 indicates the potential of AR to assist workers to identify potential design process-related hazards on site in terms of percentage responses to a scale of 1 (minor) to 5 (major), and a MS ranging between 1.00 and 5.00. It is notable that all the MSs are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to perceive the potential to be above average. All the MSs are > 3.40 ≤ 4.20, which indicates between potential to near major / near major. Despite the respondents' generally low self-rating of their awareness of / exposure to the identified four Industry 4.0 technologies, they recognise the potential of AR to improve the aspects of H&S performance as per the literature. A notable difference between the sample strata is that the Can CHSAs' MS is higher than the Pr CHSAs' MS.

Table 5. Potential of AR to assist workers to identify potential design process-related hazards on site

MS		
Can CHSAs	Pr CHSAs	Mean
4.05	3.82	3.92

Table 6 indicates the potential of drones to improve aspects of H&S performance in terms of percentage responses to a scale of 1 (minor) to 5 (major), and a MS ranging between 1.00 and 5.00. It is notable that all the MSs for both sample strata (100.0%) are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to perceive the potential to be above average. 'Assist in terms of real time monitoring of construction activities' has a mean MS > 4.20 ≤ 5.00, which indicates between near major to major / major potential, whereas 'Improve HIRAs before activities commence on site' has a mean MS > 3.40 ≤ 4.20, which indicates between potential to near major / near major potential. Despite the respondents' generally low self-rating of their awareness of / exposure to the identified four Industry 4.0 technologies, they recognise the potential of drones to improve the aspects of H&S performance as per the literature. There are no major differences between the two in terms of the ranks achieved by the aspects.

Table 6. Potential of drones to improve aspects of H&S performance

Aspect	Can CHSAs		Pr CHSAs		Mean	
	MS	Rank	MS	Rank	MS	Rank
Assist in terms of real time monitoring of construction activities	4.18	1	4.25	1	4.22	1
Improve HIRAs before activities commence on site	3.82	2	3.91	2	3.87	2

Table 7 indicates the potential of wearable technology / sensors to mitigate the hazards and risk accompanying the handling of heavy plant, equipment, and materials in terms of percentage responses to a scale of 1 (minor) to 5 (major), and a MS ranging between 1.00 and 5.00. It is notable that all the MSs for both sample strata (100.0%) are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to perceive the potential to be above average. Both mean MSs are > 3.40 ≤ 4.20, which indicates between potential to near major / near major potential. Despite the respondents' generally low self-rating of their awareness of / exposure to the identified four Industry 4.0 technologies, they recognise the potential of wearable technology / sensors to mitigate the hazards and risk and improve the aspects of H&S performance as per the literature. It is notable that the MSs for the Pr CHSAs are the same for both aspects - heavy plant, and equipment, and heavy materials.

Table 7. Potential of wearable technology / sensors to mitigate the hazards and risk accompanying the handling of heavy plant, equipment, and materials

Aspect	Can CHSAs		Pr CHSAs		Mean	
	MS	Rank	MS	Rank	MS	Rank
Heavy plant, and equipment	3.62	1	3.72	2	3.67	1
Heavy materials	3.50	2	3.72	1	3.62	2

Table 8 indicates the potential of four Industry 4.0 technologies to reduce the occurrence of H&S phenomena in terms of MSs ranging between 1.00 and 5.00, based upon percentage responses to a scale of 1 (minor) to 5 (major). It is notable that all MSs (100.0%) are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to perceive the potential to be above average. It is notable that no mean MSs are > 4.20 ≤ 5.00 - between near major to major / major potential – observation. 12 / 13 (92.3%) mean MSs are > 3.40 ≤ 4.20, which indicates between potential to near major / near major potential. 3 / 12 (25.0%) of these phenomena fall in the upper half of the range, namely > 3.80 ≤ 4.20 – risks, hazards, and accidents. The remaining 9 / 12 (75.0%) mean MSs are > 3.40 ≤ 3.80, two of which have mean MSs of 3.79, 0.01 below 3.80 – injuries, and unsafe acts. Despite the respondents' generally low self-rating of their awareness of / exposure to the identified four Industry 4.0 technologies, they recognise the potential of Industry 4.0 technologies to improve the stated H&S-related interventions / goals.

A notable difference between the sample strata is that eight of the Pr CHSAs' MS are higher than the highest Can CHSA MS. There are no major differences between the two in terms of the ranks achieved by the first six phenomena.

Table 8. Potential of Industry 4.0 technologies to reduce the occurrence of H&S phenomena

Phenomenon	Can CHSAs		Pr CHSAs		Mean	
	MS	Rank	MS	Rank	MS	Rank
Risks	3.79	2	4.13	1	3.97	1
Hazards	3.79	3	4.06	2	3.93	2
Accidents	3.85	1	4.00	4	3.93	3
Injuries	3.63	4	3.94	7	3.79	4
Unsafe acts	3.62	5	3.94	6	3.79	5
Unsafe working conditions	3.46	8	3.97	5	3.74	6
Difficulty in terms of monitoring workers	3.43	10	4.00	3	3.73	7
Difficulty in terms of monitoring on-site activities	3.52	7	3.88	8	3.72	8
Similar incidents reoccurring	3.54	6	3.77	9	3.66	9
Sprains and strains among workers	3.39	11	3.71	10	3.56	10
Unhealthy working conditions	3.29	12	3.60	12	3.45	11
A shortage of workers with the necessary skills	3.44	9	3.43	13	3.44	12
Delays	3.11	13	3.62	11	3.37	13

4. CONCLUSION

Given the frequency at which H&S phenomena are experienced on projects by respondents, it can be concluded that the respondents experience the range of these phenomena on projects. It can further be concluded that there is a need for H&S improvement, and a need for the implementation of Industry 4.0. related technologies.

In light of the respondents' self-rating of their awareness of / exposure to four Industry 4.0 technologies, it can be concluded that there is a need for interventions by government, statutory bodies, and tertiary education programmes to raise the level of awareness, and to integrate such technologies into built environment / construction education and training.

In general, it can be concluded that there is a need for the implementation of Industry 4.0 in construction given the potential of Industry 4.0 technologies to improve H&S performance.

Given the potential of the following Industry 4.0-related technologies to improve H&S performance it can be concluded that there is a need for their implementation: VR in terms of assisting designers to identify potential design process-related hazards on site, enabling workers to identify potential hazards and mitigate risks on site, and H&S training; AR to improve H&S performance by assisting workers to identify potential design process-related hazards on site; drones in terms of real time monitoring of construction activities, and improved HIRAs before activities commence on site, and wearable technology / sensors to mitigate the hazards and risk accompanying the handling of heavy plant, equipment, and materials.

Industry 4.0 technologies such as VR, AR, drones, and wearable technology / sensors have the potential to contribute to resolving many of the H&S challenges experienced in construction.

5. RECOMMENDATIONS

Built environment-related tertiary education must include, or rather embed Industry 4.0 in their programmes, and H&S-related modules should address the role of Industry 4.0 technologies.

Construction employer associations, and built environment associations and statutory councils must promote, and preferably provide H&S-Industry 4.0 continuing professional development (CPD), and evolve related guidelines and practice notes.

The Construction Industry Development Board (cidb) should evolve a position paper relative to Industry 4.0 in construction, and deliberate the development of a related industry standard.

Researchers should actively conduct and document H&S-related Industry 4.0 case studies to record the benefits of implementing Industry 4.0 technologies.

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