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Improving Health and Safety (H&S) on South African Construction Projects with Industry 4.0

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Abstract

The South African construction industry experiences a high level of accidents, injuries, and fatalities, despite efforts to reduce their occurrence. This study aims to investigate the potential of Industry 4.0 in terms of improving H&S on South African construction projects. A detailed survey was conducted among medium to large general contractor members of the East Cape Masters Builders Association (ECMBA), and candidates or professionally registered persons with the South African Council for the Project and Construction Management Professions (SACPCMP) who are based in the Eastern Cape such as H&S practitioners, construction project managers (CPMs), and construction managers (CMs). The salient findings include: monitoring H&S hazards onsite is difficult; design-originated and onsite hazards are often experienced onsite; fatalities, injuries, illnesses, and worker fatigue often occur; drone technology has the potential to improve H&S monitoring in construction; building information modelling (BIM) has the potential to reduce design-originated hazards, and virtual reality (VR) has the potential to improve H&S training. It is concluded that implementing Industry 4.0 technologies in construction will improve H&S. Recommendations include: construction H&S-related training and tertiary education should address Industry 4.0 technologies, and various industry stakeholders should promote Industry 4.0-related construction continuing professional development (CPD).

Keywords

Construction, Health and Safety, Industry 4.0.

1. Introduction

Many workers within the construction industry sustain injuries or are killed annually worldwide due to accidents. Despite H&S legislation and regulations having been evolved and implemented, there has been a limited reduction in accidents (Azmy and Zain, 2016). Furthermore, H&S-related challenges have persisted despite a range of H&S-related developments and interventions in addition to H&S legislation and regulations.

Research findings indicate that the advent of Industry 4.0, and a range of related technologies, if adopted, have the potential to provide a long-lasting solution to construction H&S-related issues. Many studies have focused on the implementation of VR, BIM, robotics, and sensors to improve H&S in construction by reducing the number of injuries and fatalities (Haupt, Akinlolu and Raliile, 2019). Investing in equipment to ensure H&S, better communication and training of workers, alongside adopting digital technology, will greatly assist in improving the H&S issues faced in construction (Haupt et al., 2019).

Given the continuing poor H&S performance recorded in the construction industry in South Africa (Construction Industry Development Board (cidb), 2009), the aim of the study was to evolve a framework of interventions to improve H&S in construction using Industry 4.0 technologies, the objectives of the study being to:

- Identify the number of injuries and fatalities in construction;
- Identify the occurrence of H&S phenomena on construction projects;
- Analyse Industry 4.0 technologies that can mitigate fatalities, injuries, and illness;
- Identify the potential of using VR in H&S training;
- Identify the potential of Industry 4.0 technologies and robots to reduce worker fatigue;

- Identify the potential of BIM to mitigate design-oriented hazards, and
- Identify the potential of drones in monitoring onsite H&S hazards.

2. Review of the literature

2.1 Drone technology for construction H&S monitoring

According to Gheisari and Esmaeili (2016) unmanned aerial systems (UASs) or drones can be used to monitor construction on site, collect real time information, and assist in terms of the identification of hazards, and improvements in H&S. Drone technology enables hazard identification at different stages of the construction project which assists in the creation of mitigation measures (Gheisari and Esmaeili, 2016). Drones have the potential to improve H&S as they can operate faster than supervisors conducting inspections in areas which are unsafe, or which are inaccessible to humans. The study proposed that drones or UASs can ideally act as an H&S inspection assistant, enabling the provision of real-time access to images or videos from various areas on the construction site and voice interactions with the construction workers onsite (Esmaeili, Gheisari, Kosecka, and Rashidi, 2019).

2.2 BIM

A study was conducted, which determined that BIM and 4D models can identify and prevent construction hazards such as falls onsite from occurring. BIM enables risk identification to take place prior to a construction project which enables the reduction of design-originated hazards (Turner, Oyekan, Lampros and Griffin, 2020). Design-originated hazard mitigation methods and solutions can be tested or practiced through BIM, the solutions are assessed and compared against other possible measures allowing for H&S risks to be mitigated during the design state. A virtual site can be created where the potential hazards can be explored without the need to put construction workers in danger or expose them to these hazards (Health and Safety Executive, 2018). The system can also be used to assess the viability of the equipment and the structures available to designers. design-originated hazards can be mitigated through BIM as possible clashes using the 3D models can be detected. BIM models are utilised for virtual prototyping of more complex structures and construction procurement processes to assess possible H&S risks, enabling the analysis of different construction methods which can result in the identification, removal, and reduction of site hazards (HSE, 2018).

2.3 VR

A study conducted by Sacks, Perlman and Barak (2013) determined that VR based training was more efficient and effective than traditional H&S training, which occurred in classrooms and from presentations using slides. Virtual reality provides simulated environments for the user, using software, computers, and hardware which is peripheral. The environment may be simulated to be more real or may be imaginary. This form of training enables the worker to analyse, and assess the situations which are presented virtually, decide regarding the action to be taken, implement that action, and observe the results instantly. 3D Game based VR, uses 3D gaming technology to enable the worker or user to interact within an environment. Tasks which are included in the real construction process are designed and included in VR training enabling users to collaborate and interact during the training process (Wang, Wu, Chi, 2018).

2.4 Robots and automation

Robotics are often used to survey construction sites and collect data used to generate 3D models of buildings. These robots can reduce fatigue associated with heavy lifting, as they assist workers in carrying heavy materials and tool kits. Just-in time manufacturing of buildings' components and 3D printing technology allow for less manual labour to take place, as additive methods can build 3D structures through block laying robots or welding arms (Turner et al., 2020). Wearable robotics can provide support to workers by supporting their backs, this is done by sensing the workers motion and a signal is then sent to motors which rotate the gears. Supporting their upper body reduces lower back stress of the worker by 15 kilograms (Li and Ng, 2018). This technology enables workers to carry heavy loads such as construction tools more easily, with less stress on the body as its configuration transfers the loads through the skeleton to the ground when the construction worker is kneeling or standing (Haupt et al., 2019). Robotic arms are ergonomic tools for arms, designed to operate or use heavy tools weightlessly, the Esko Bionics Zero G arms can hold up to 19 kilograms and balance this weight. Robots enable the worker to maneuver the load safely and more accurately in all directions without injury or fatigue. The possible application of robotic arms in construction was investigated and it was found that they can be used to improve workers comfort and H&S through stabilising, bracing, and reducing the effort necessary to carry out repetitive construction activities (Haupt et al., 2019).

2.5 Sensors

Applying sensors in H&S is essential for real time monitoring of construction activities to ensure that structures are safe. Sensory technologies have been implemented to prevent accidents from occurring and workers from being injured due to collisions, through monitoring of the entire construction site. Sensors can be categorised as location based, vision based and wireless sensor networks as the numerous types of sensory based technologies are implemented to ensure H&S management in construction. Wireless sensor networks have been found to improve and facilitate the flow of information within the design team on construction sites (Haupt et al., 2019).

3. Research

3.1 Research Method and Sample Stratum

The quantitative research study entailed an online questionnaire survey. The sample included 70 potential respondents in the form of general contractor members of the East Cape Master Builders Association (ECMBA), and H&S practitioners, CMs, and CPMs in the Eastern Cape registered as candidate and professionals with the SACPCMP. The questionnaire consisted of eighteen questions – seventeen closed-ended, and one open-ended. Ten of the close-ended questions were Likert scale type questions, and seven were demographic related questions. 31 Responses were included in the data analysis, which entailed the computation of frequencies, and a measure of central tendency in the form of a mean score (MS), which equates to a response rate of 44.3%.

3.2 Results

Table 1 indicates the frequency at which H&S phenomena occurred on the respondents' construction projects in terms of percentage responses to a range of never to constantly, and a MS with a minimum value of 1.00 and a maximum value of 5.00. MSs > 3.00 indicate that in general, respondents can be deemed to perceive that the frequency at which the H&S phenomena occur on their construction projects is frequent as opposed to infrequent, as in the case of MSs ≤ 3.00. It is notable that 2 / 8 (25.0%) of the MSs are > 3.00. 7 / 8 (87.5%) Phenomena have MSs > 2.60 to < 3.40, which indicates that the respondents can be deemed to perceive their frequency of occurrence to be between rarely to sometimes / sometimes – workers experience fatigue followed by onsite hazards, injuries, design-originated hazards encountered onsite, illnesses, ineffective training, and difficulty in monitoring H&S onsite. The MS of fatalities is ≥ 1.00 to ≤ 1.80, which indicates that they occur between never to rarely.

Table 20. Frequency of H&S phenomena occurring on construction projects

Phenomenon	Response (%)						MS	Rank
	Unsure	Never	Rarely	Sometimes	Often	Constantly		
Workers experience fatigue	3.2	0.0	12.9	48.4	29.0	6.5	3.30	1
Onsite hazards	0.0	3.2	9.7	51.6	25.8	9.7	3.29	2
Injuries	0.0	3.2	22.6	48.4	25.8	0.0	2.97	3
Design-originated hazards are encountered onsite	0.0	0.0	25.8	51.6	22.6	0.0	2.97	4
Illnesses	3.2	3.2	19.4	64.5	9.7	0.0	2.83	5
Ineffective H&S training	6.5	6.5	22.6	48.4	12.9	3.2	2.83	6
Difficulty in monitoring H&S onsite	6.5	6.5	32.3	45.2	9.7	0.0	2.62	7
Fatalities	3.2	51.6	38.7	3.2	3.2	0.0	1.57	8

Table 2 indicates the extent to which H&S-related processes need improvement in construction in terms of percentage responses to a range of 1 (minor) to 5 (major), and a MS with a minimum value of 1.00 and a maximum value of 5.00. It is notable that all the MSs > 3.00, which indicates that in general, respondents can be deemed to perceive that the extent to which the H&S-related processes need improvement in construction is major as opposed to minor, as in the case of MSs ≤ 3.00. 6 / 9 (66.7%) Processes have MSs > 3.40 to ≤ 4.20, which indicates that the respondents can be deemed to perceive the need for improvement of the H&S-related processes to be between some extent to a near major extent / near major extent - mitigation of injuries followed by reduction of design-originated hazards, mitigation of

fatalities, automation of onsite activities, and monitoring H&S hazards. The MS of mitigation of illnesses, reduction of construction-originated hazards and H&S training is > 2.60 to ≤ 3.40, which indicates that respondents perceive that they need improvement in construction between a near minor extent to some extent / extent.

Table 2. Extent to which H&S related processes need improvement in construction

Process	Response (%)						MS	Rank
	Un-sure	Minor 1	2	3	4	Major 5		
Mitigation of injuries	0.0	0.0	9.7	35.5	35.5	19.4	3.65	1
Reduction of design-originated hazards	0.0	0.0	9.7	41.9	32.3	16.1	3.55	2
Mitigation of fatalities	0.0	6.5	9.7	35.5	25.8	22.6	3.48	3
Automation of onsite activities	6.5	3.2	9.7	29.0	41.9	9.7	3.48	4
Monitoring H&S hazards onsite	0.0	0.0	9.7	45.2	38.7	6.5	3.42	5
Mitigation of illnesses	3.2	3.2	6.5	45.2	32.3	9.7	3.40	6
Reduction of workers' fatigue	6.5	3.2	3.2	32.3	41.9	12.9	3.39	7
Reduction of construction-originated hazards	3.2	0.0	12.9	41.9	35.5	6.5	3.37	8
H&S training	0.0	3.2	12.9	45.2	25.8	12.9	3.32	9

Table 3 indicates the potential of Industry 4.0 technologies to improve the H&S-related processes in construction in terms of percentage responses to a range of 1 (minor) to 5 (major), and a MS with a minimum value of 1.00, and a maximum value of 5.00. It is notable that all the MSs are > 3.00, which indicates that in general, respondents can be deemed to perceive that Industry 4.0 technologies have the potential to improve the H&S-related processes in construction to a major as opposed to a minor extent, as in the case of MSs ≤ 3.00. 4 / 9 (44.4%) Processes have MSs > 3.40 to ≤ 4.20, which indicates that the respondents can be deemed to perceive that the Industry 4.0 technologies have between some potential to near major potential / near major potential to improve H&S-related processes in construction - automation of onsite activities followed by H&S training, reduction of design-originated hazards, and monitoring H&S hazards onsite. 5 / 9 (55.6%) Processes have MSs > 2.60 to ≤ 3.40, which indicates that the respondents can be deemed to perceive that Industry 4.0 technologies have between near minor potential to some potential / some potential to improve the H&S-related processes in construction – fatigue experienced by workers followed by reduction of construction-originated hazards, and mitigation of fatalities, injuries, and illnesses.

Table 3. Potential of Industry 4.0 technologies to improve the H&S-related processes in construction

Process	Response (%)						MS	Rank
	Un-sure	Minor 1	2	3	4	Major 5		
Automation of onsite activities	6.5	0.0	12.9	19.4	48.4	12.9	3.66	1
H&S training	3.2	0.0	6.5	45.2	35.5	9.7	3.50	2
Reduction of design-originated hazards	3.2	0.0	6.5	35.5	38.7	16.1	3.48	3
Monitoring H&S hazards onsite	0.0	0.0	9.7	48.4	25.8	16.1	3.48	4
Fatigue experienced by workers	6.5	3.2	12.9	32.3	41.9	3.2	3.31	5
Reduction of construction-originated hazards	9.7	0.0	16.1	54.8	6.5	12.9	3.18	6
Mitigation of fatalities	16.1	3.2	12.9	45.2	16.1	6.5	3.12	7
Mitigation of injuries	0.0	3.2	12.9	61.3	16.1	6.5	3.10	8
Mitigation of illnesses	3.2	9.7	9.7	54.8	16.1	6.5	3.00	9

Table 4 indicates the level of awareness or knowledge the respondents have of Industry 4.0 technologies in terms of percentage responses to a range of 1 (limited) to 5 (extensive), and a MS with a minimum value of 1.00 and maximum value of 5.00. MSs > 3.00 indicate that in general, the respondents can be deemed to perceive that their level of knowledge or awareness of Industry 4.0 technologies is extensive as opposed to limited, as in the case of MSs ≤ 3.00. It is notable that 3 / 6 (50.0%) of the MSs are > 3.00. The MS of BIM technology is > 3.40 to ≤ 4.20, which indicates that the respondents can be deemed to perceive that their level of awareness or knowledge of BIM is between average to above average / above average. 5 / 6 (83.3%) Industry 4.0 technologies have MSs > 2.60 to ≤ 3.40, which indicates

that the respondents can be deemed to perceive their level of awareness or knowledge of Industry 4.0 technologies to be between below average to average / average – automation followed by drones, VR, wearable technology / sensors, and robotics.

Table 4. Respondents' level of awareness or knowledge of Industry 4.0 technologies

Technology	Response (%)						MS	Rank
	Un-sure	Limited ..... Extensive						
		1	2	3	4	5		
BIM	6.5	3.2	6.5	35.5	41.9	6.5	3.45	1
Automation	6.5	9.7	3.2	41.9	32.3	6.5	3.24	2
Drones	0.0	6.5	3.2	54.8	32.3	3.2	3.23	3
Virtual reality	6.5	6.5	16.1	51.6	12.9	6.5	2.97	4
Wearable technology / sensors	0.0	9.7	29.0	38.7	12.9	9.7	2.84	5
Robotics	6.5	16.1	22.6	48.4	6.5	0.0	2.48	6

Respondents were requested to indicate the potential impact Industry 4.0 will have in terms of improving H&S in construction in terms of percentage responses to a range of 1 (minor) to 5 (major). Given that the resultant MS of 3.41 is > 3.40 to ≤ 4.20, the respondents can be deemed to perceive that Industry 4.0 has between some potential to near major potential / near major potential to improve H&S in construction.

Table 5 indicates the potential of drones in terms of improving H&S-related processes in terms of percentage responses to a range of 1 (minor) to 5 (major), and a MS with a minimum value of 1.00 and a maximum value of 5.00. MSs > 3.00 indicate that in general, respondents can be deemed to perceive that the potential of drones to improve the H&S-related processes is major as opposed to minor, as in the case of MSs ≤ 3.00. It is notable that 2 / 3 (66.7%) of the MSs are > 3.00. The MS of identifying H&S hazards is > 3.40 to ≤ 4.20, which indicates that drones have between some potential to near major potential / near major potential to identify H&S hazards. The other 2 / 3 (66.7%) processes have MSs > 2.60 to ≤ 3.40, which indicates that the respondents can be deemed to perceive that drones have between near minor potential to some potential / some potential to improve H&S related processes – monitoring H&S hazards in construction, followed by reducing H&S design-originated hazards.

Table 5. Potential of drones to improve H&S-related processes

Process	Response (%)						MS	Rank
	Un-sure	Minor ..... Major						
		1	2	3	4	5		
Identifying H&S hazards	6.5	3.2	0.0	35.5	35.5	19.4	3.72	1
Monitoring H&S hazards in construction	9.7	6.5	12.9	41.9	12.9	16.1	3.21	2
Reducing H&S design-originated hazards	3.2	12.9	22.6	45.2	12.9	3.2	2.70	3

Table 7 indicates the potential of BIM to improve aspects of H&S in terms of percentage responses to a range of 1 (minor) to 5 (major), and a MS with a minimum value of 1.00 and maximum value of 5.00. MSs > 3.00 indicate that in general, respondents can be deemed to perceive that the potential of BIM to improve the aspects of H&S is major as opposed to minor, as in the case of MSs ≤ 3.00. It is notable that all the MSs are > 3.00. 2 / 3 (66.7%) Aspects have MSs > 3.40 to ≤ 4.20, which indicates that the respondents can be deemed to perceive that BIM has between some potential to near major potential / near major potential to improve H&S – reducing H&S design-originated hazards followed by identifying H&S hazards. The MS of reduction of construction originated hazards is > 2.60 to ≤ 3.40, which indicates that BIM has between near minor potential to some potential / some potential to reduce construction originated hazards.

Table 6. Potential of BIM to improve aspects of H&S

Aspect	Response (%)						MS	Rank
	Un-sure	Minor ..... Major						
		1	2	3	4	5		

Reducing H&S design-originated hazards	12.9	3.2	0.0	32.3	35.5	16.1	3.70	1
Identifying H&S hazards	9.7	3.2	6.5	45.2	19.4	16.1	3.43	2
Reduction of construction originated hazards	16.1	6.5	19.4	38.7	3.2	16.1	3.04	3

Respondents were requested to indicate the potential of VR to improve aspects of H&S training in terms of percentage responses to a range of 1 (minor) to 5 (major). The resultant MS of 3.63 is > 3.40 to ≤ 4.20, which indicates that the respondents can be deemed to perceive that VR has between some potential to near major potential / near major potential to improve aspects of H&S.

Table 7 indicates the potential of wearables and sensors to mitigate fatalities, injuries, and illnesses in terms of percentage responses to a range of 1 (minor) to 5 (major), and a MS with a minimum value of 1.00 and the maximum value of 5.00. MSs > 3.00 indicate that respondents can be deemed to perceive that the potential is major as opposed to minor, as in the case of MSs ≤ 3.00. It is notable that 2 / 3 (66.7%) of the MSs are > 3.00. All the impacts have MSs > 2.60 to ≤ 3.40, which indicates that the respondents can be deemed to perceive that wearables and sensors have between near minor potential to some potential / some potential mitigate fatalities, injuries, and illnesses.

Table 7. Potential of wearables and sensors to mitigate fatalities, injuries, and illnesses

Impact	Response (%)						MS	Rank
		Minor.....				Major		
	Un-sure	1	2	3	4	5		
Mitigate fatalities	22.6	0.0	12.9	32.3	22.6	9.7	3.38	1
Mitigate injuries	6.5	3.2	16.1	45.2	25.8	3.2	3.10	2
Mitigate illnesses	9.7	3.2	19.4	48.4	19.4	0.0	2.93	3

Respondents were required to indicate the potential of robots and automation to reduce worker fatigue in terms of percentage responses to a range of 1 (minor) to 5 (major). Given that the MS of 3.83 is > 3.40 to ≤ 4.20, the respondents can be deemed to perceive that robots and automation have between some potential to near major / near major potential to reduce worker fatigue.

4. Discussion

The findings indicate that eight H&S-related phenomena are experienced on projects, and in the case of 25.0%, frequently as opposed to infrequently - workers experience fatigue, and onsite hazards predominate. The former is an issue frequently cited in the literature due to the physically demanding nature of the industry, long working hours, and weekend work. Robots and automation constitute interventions to mitigate the physically demanding nature of construction. Onsite hazards are a challenge as they introduce risk, and are the gateway for injuries, fatalities, and illness. Constant monitoring of the workplace in terms of identifying hazards and risk is challenging, however, drones can facilitate such monitoring, including accessing areas that are physically difficult to reach. Injuries, and design-originated hazards are encountered onsite follow, both of which have MSs of 2.97. The mitigation of injuries, fatalities, and illnesses are largely dependent upon the mitigation of hazards. The reduction of design-originated hazards is dependent upon 'designing for H&S' interventions, however, it can be facilitated using BIM. Ineffective H&S training can be remedied through the use of VR due to the trainees experiencing immersion, and involvement. The difficulty in monitoring H&S onsite can be remedied by the deployment of drones.

The extent to which nine H&S-related processes need improvement in construction is major as opposed to minor. As stated above, the mitigation of injuries, fatalities, and illnesses are largely dependent upon the mitigation of hazards. The reduction of design-originated hazards has been discussed above. The reduction of construction-originated hazards is dependent upon a range of interventions, however, it can be facilitated by the use of drones for monitoring. Automation of onsite activities has a role to play in the reduction of construction-originated hazards, and along with the deployment of robots, the reduction of workers' fatigue. The role of VR in enhancing the delivery of H&S training is addressed above.

The automation of onsite activities, H&S training, reduction of design-originated hazards, and monitoring H&S hazards onsite, predominate in terms of the potential of nine Industry 4.0 technologies to improve the H&S-related processes in construction, followed by fatigue experienced by workers, reduction of construction-originated hazards,

and the mitigation of fatalities, injuries, and illnesses. These findings reinforce the potential of Industry 4.0 technologies to mitigate the occurrence of eight H&S-related phenomena on projects, and to contribute to improving nine H&S-related processes.

The respondents' level of awareness or knowledge is above average relative to three, and below average relative to a further three Industry 4.0 technologies is notable. Despite this, respondents identified the potential impact Industry 4.0 will have in terms of improving H&S, the potential of drones to improve H&S-related processes, the potential of BIM to improve aspects of H&S, the potential of VR to improve aspects of H&S training, the potential of wearables and sensors to mitigate fatalities, injuries, and illnesses, and the potential of robots and automation to reduce worker fatigue. However, the level of awareness or knowledge is notable due to the origination of Industry 4.0 in German manufacturing in 2011, and the coining of the term in 2016 by Klaus Schwab, founder, and executive chairman of the World Economic Forum (WEF).

Although the findings are not novel, and underscore the international findings reported on in the literature, they do provide a snapshot of the status quo in a province in South Africa.

5. Conclusions

Given the frequency at which H&S phenomena occurred on respondents' construction projects, it can be concluded that the respondents' experience the majority of these phenomena on their construction projects. In conclusion improvement is required, and there is a need for Industry 4.0 implementation. Given the extent of the need for improvement of H&S processes in construction, it can be concluded that the perceptions of the respondents reflect the general experience in construction in South Africa, which amplifies the need to implement Industry 4.0 technologies.

Given the respondents' level of awareness or knowledge of Industry 4.0 technologies it can be concluded that there is a need for an increase in the level of awareness through education by tertiary education programmes, and to integrate these technologies into construction training. Given the potential of Industry 4.0 technologies to improve H&S processes in construction it can be concluded that there is a need for the implementation of Industry 4.0 in construction.

Given the potential of drones to improve H&S processes, it can be concluded that the implementation of drone technology has the potential to improve several H&S processes in terms of identifying H&S hazards, monitoring H&S hazards in construction, and reducing H&S design-originated hazards. Given the potential of BIM to improve aspects of H&S in terms of reducing H&S in terms of reducing H&S design-originated hazards, identifying H&S hazards and reducing of construction originated hazards, it can be concluded that there is a need for the implementation of Industry 4.0 related technologies.

Given that VR can improve aspects of H&S training, the potential of wearables / sensors to improve H&S-related processes in terms of mitigating fatalities, injuries, and illnesses, and that robots and automation can reduce worker fatigue, it can be concluded that there is a need for the implementation of Industry 4.0 related technologies.

Given the size of the sample, and the geographical location of the study, the findings cannot be deemed to be representative, but indicative.

6. Recommendations

Recommendations include: the cidb should compile 'Industry 4.0 in Construction' guidelines; construction H&S-related training and tertiary education should address Industry 4.0 technologies, and various industry stakeholders should promote, and preferably deliver Industry 4.0-related construction H&S continuing professional development (CPD).

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