THE ROLE OF INDUSTRY 4.0 IN CONSTRUCTION OCCUPATIONAL HEALTH (OH)

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Historical occupational health (OH) challenges, in terms of a range of issues, continue to be experienced, namely not following procedures, unsafe acts, unsafe conditions, non-compliance, sprains and strains, fatigue, and heat stress among workers, materials containing hazardous chemical substances, untrained workers undertaking work, commencement of activities without conducting hazard identification and risk assessment (HIRA), data gathering and recording, and monitoring. Given the abovementioned, and the advent of Industry 4.0, an exploratory quantitative study, which entailed a self-administered questionnaire, was conducted among registered Construction Health and Safety (H&S) practitioners to determine the OH challenges experienced, OH performance, and the perceived potential of Industry 4.0 to contribute to resolving the former cited challenges. The findings indicate that: A range of historical challenges, which negatively impact OH performance, continue to be experienced in construction; H&S practitioners rate themselves below average in terms of awareness of / exposure to most Industry 4.0 technologies, and Industry 4.0 technologies are perceived as having the potential to contribute to resolving the OH challenges experienced in construction. Conclusions include: A different approach is necessary to mitigate the persistent OH challenges; current technology is not capable of resolving the OH challenges; an integrated digital effort is required to resolve the OH challenges, and artificial intelligence, blockchain technology, digitalisation in general, drones, the internet of things, robots, and virtual reality are perceived as having the potential to contribute to resolving the 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 OH 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 and OH-related modules, and continuing professional development (CPD) OH should address Industry 4.0.

Keywords: Industry 4.0, Occupational Health, performance

INTRODUCTION

The Construction Industry Development Board (CIDB) (2009) report 'Construction Health and Safety Status and Recommendations' highlighted the considerable number of accidents, fatalities, and other injuries that occur in the South African construction industry. The CIDB (2009) contends the high-level of non-compliance with H&S legislative requirements is indicative of a deficiency of effective management and

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supervision of H&S on construction sites, as well as planning from the inception / conception of projects within the context of project management.

According to The Council for Scientific and Industrial Research (CSIR) (2018), the rapid rise and convergence of emerging technologies is driving the Fourth Industrial Revolution (FIR), also known as Industry 4.0. FIR is a collective term for technologies and value chain organisation which draw together cyber-physical systems, the Internet of Things (IoT) and the Internet of Services (IoS), together with other emerging technologies such as cloud technology, big data, predictive analysis, artificial intelligence, augmented reality, agile and collaborative robots, and additive manufacturing. According to Autodesk and the Chartered Institute of Building (CIOB) (2019), digital technologies are transforming every industry, and construction is no exception. Infinite computing, robotics, machine learning, drones, the Internet of Things (IoT), augmented reality, gaming engines, and reality capture, to name just a few, are innovating the design, build, and operation of buildings and infrastructure. Considering the numerous challenges experienced in construction, especially the delivery of projects, it is inevitable that Industry 4.0 is considered to overcome these.

Given the continuing poor OH and H&S performance in South African construction, and the cited benefits of implementing Industry 4.0 technologies, an exploratory study was conducted to determine the:

- Frequency that phenomena are experienced on projects;
- Extent of the need for performance improvement on projects;
- Respondents' awareness of / exposure to eleven Industry 4.0 technologies, and
- Perceived potential of Industry 4.0 technologies to reduce the occurrence of phenomena.

LITERATURE REVIEW

Occupational Health in Construction

OH is defined by the World Health Organization (WHO) (1994) as the promotion and maintenance of the highest degree of physical, mental and social well-being of workers in all occupations. The principles of OH are embedded in the 'health for all (HFA)' concept adopted and published as a declaration by the WHO. The HFA states that H&S at work is an important matter, and the general health and well-being of workers should be given due consideration at multiple levels. Despite the aforementioned, there is a paucity of literature pertaining to South African OH interventions, and little is known regarding OH in the South African construction industry.

Ill health kills and ruins lives in the construction industry. A construction worker is at least 100 times more likely to die from a disease that has been caused or exacerbated by their work, than from a fatal accident (Snashall, 2012; National Institute of Occupational Health (NIOH), 2018). Construction work itself is known as dirty, tough and hazardous, highly manual, and transient in nature. The NIOH (2018) further cites the construction industry as one of three industries with the highest rate of work-related injury risks. Hazards that workers are exposed to include chemical, biological, poor ergonomics, and psychosocial hazards, and extended exposure to such risks results in occupational and work-related diseases (NIOH, 2018).

Construction workers are exposed to many forms of hazards that cause target organ damage that is considered as an occupational disease (OD). For example, crystalline silica, as a dust, affects the respiratory system, mainly the lungs (the target organ), causing silicosis (an occupational disease). Exposure to asbestos also affects mainly the lungs and causes severe damage and fibrosis of the lung tissue and is diagnosed as asbestosis. Exposure to different forms of work exposes workers to a range of risks: fumes from welding and soldering; a range of dusts from cutting, drilling stone and various materials; gasses, and waste products. Several natural hazards are a further risk to which workers are exposed, such as biological hazards (legionella, zoonoses), temperatures and weather, spores, and sunlight (Institute of Occupational Safety and Health (Iosh, 2016).

The Role of Industry 4.0 Technologies

The traditional approach to monitoring and measuring H&S-related issues are largely manual in nature, and 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 (Awolusi *et al.,* 2018). A study conducted by Gheisari and Esmaeili (2016) 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.

According to Ananthanarayan and Siek (2010), 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. The HSE (2019) in turn state that there is growing evidence that wearable devices can significantly benefit H&S in the workplace through positioning and sensor technologies. A study conducted by Nath *et al. (*2017) determined that wearable technology was able to prevent work related injuries and fatalities by ergonomically designing the work environment based on previous data collected.

In recent years visualisation technologies such as virtual reality (VR) and augmented reality (AR) have been developed and used to improve construction productivity, H&S, and quality (Le *et al.,* 2015). A study conducted by Sacks *et al. (*2013) determined that VR-based training was more effective than traditional H&S training methods, which made use of classrooms and slide presentations. According to Park *et al. (*2013), AR based applications and systems have been developed to improve on-site tasks such as: data visualisation; work inspection and checking for omissions. Furthermore, they have improved on-site H&S performance to some extent.

Global Construction Review (2019) reports on an American construction robotics company which unveiled its concept for an autonomous machine that can lift, carry, and place rebar on bridges and other horizontal reinforced concrete applications. This is in response to a backbreaking task for workers and addresses the shortage of skilled labour.

RESEARCH

Research Method and Sample Stratum

A 14-question questionnaire was circulated per e-mail to 92 Professional (Pr) Construction Health and Safety Agents (CHSAs), 139 Candidate (Can) CHSAs, and 562 Construction Health and Safety Managers (CHSMs) registered with the South African Council for the Project and Construction Management Professions

(SACPCMP). 39 CHSM e-mails could not be delivered, which resulted in a net sample of 754. 7 of the questions were demographic related, 6 were closed-ended and Likert Scale type questions, and one was open-ended. 58 Responses, courtesy of 16 Pr CHSAs, 16 Can CHSAs, and 26 CHSMs, which equates to a response rate of 7.7%. The analysis of the data entailed the computation of frequencies, and a measure of central tendency in the form of a mean score (MS).

Research findings

Table 1 indicates the frequency at which nineteen OH-related phenomena are experienced on projects in terms of percentage responses to a scale of never to constantly, and MSs ranging between 1.00 and 5.00. It is notable that 16 / 19 (84.2%) of the 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.

Table 1: Frequency at which OH-related phenomena are experienced on projects

Phenomenon	Response (%)							
	Unsure	Never	Rarely	Some-times	Often	Con-stantly	MS	Rank
Under-pricing	0.0	0.0	1.8	8.8	42.1	47.4	4.35	1
Late information	0.0	0.0	0.0	21.4	35.7	42.9	4.21	2
Similar or alike errors are repeated	0.0	0.0	3.5	17.5	50.9	28.1	4.04	3
Information anomalies / ambiguities	0.0	0.0	1.8	21.1	52.6	24.6	4.00	4
Inadequate coordination of subcontractors	0.0	0.0	7.0	21.1	38.6	33.3	3.98	5
Data / Statistics is / are not available	0.0	0.0	7.0	21.1	42.1	29.8	3.95	6
Management information is not available	1.8	0.0	7.1	26.8	39.3	25.0	3.84	7
Non-compliance	0.0	0.0	5.3	31.6	50.9	12.3	3.70	8
Unauthorised people fulfil functions	1.8	1.8	8.8	28.1	43.9	15.8	3.64	9
Unhealthy / Unsafe plant and equipment	0.0	0.0	14.0	26.3	47.4	12.3	3.58	10
Materials containing hazardous chemical substances	0.0	0.0	15.8	31.6	36.8	15.8	3.53	11
Injuries	0.0	1.8	17.9	26.8	37.5	16.1	3.48	12
Fatigue among workers	1.8	0.0	16.4	34.5	36.4	10.9	3.43	13
Sprains and strains among workers	0.0	1.8	12.3	43.9	33.3	8.8	3.35	14
Difficulty monitoring the process and activities of construction (in terms of OH)	1.8	1.8	17.9	35.7	33.9	8.9	3.31	15
Accidents	0.0	0.0	17.5	42.1	35.1	5.3	3.28	16
Heat stress among workers	0.0	7.1	25.0	41.1	21.4	5.4	2.93	17
Fatalities	1.8	7.0	43.9	35.1	12.3	0.0	2.54	18
Occupational disease	8.9	14.3	28.6	35.7	10.7	1.8	2.53	19

Only 2 / 19 (10.5%) of the phenomena have MSs > 4.20 ≤ 5.00, which indicates the frequency is between often to constantly / constantly - under-pricing, and late information.

11 / 19 (57.9%) of the MSs are > 3.40 ≤ 4.20, which indicates the frequency is between sometimes to often / often. 5 / 11 (45.5%) MSs of similar or alike errors are repeated, information anomalies / ambiguities, inadequate coordination of subcontractors, data / statistics is / are not available, and management information is not available are > 3.80 ≤ 4.20 - the upper part of the range. The remaining 6 / 11 (54.6%) MSs are > 3.40 ≤ 3.80 - non-compliance, unauthorised people fulfil functions, unhealthy / unsafe plant and equipment, materials containing hazardous chemical substances, injuries, and fatigue among workers.

5 / 19 (26.3%) MSs are > 2.60 ≤ 3.40, which indicates the frequency is between rarely to sometimes / sometimes - sprains and strains among workers, difficulty monitoring the process and activities of construction (in terms of OH), accidents, and heat stress among workers.

The MSs of the last ranked phenomena, namely fatalities, and occupational disease, are > 1.80 ≤ 2.60, which indicates they are experienced between never to rarely / rarely. However, it should be noted that both MSs are within 0.07 of the upper point of the range.

Many of these phenomena are frequently referred to in the literature (HSE, 2017; Autodesk and CIOB, 2019; HSE, 2019a; HSE, 2019b), and furthermore, Industry 4.0 technologies have been identified as being able to reduce the occurrence of phenomena as per the literature (Autodesk and CIOB, 2019).

Table 2 indicates the extent of the need for performance improvement on projects in terms of percentage responses to a scale of 1 (minor) to 5 (major), and MSs 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 need for improvements to be major as opposed to minor.

It is notable that 6 / 17 (35.3%) MSs are > 4.20 ≤ 5.00, which indicates the respondents perceive the need for improvement to be between near major to major / major - improved planning and control of activities on site, improved communication, workers with technical skills, link processes across the stages of projects, integration of information (construction), and integration of information (procurement).

The remaining 11 / 17 (64.7%) MSs are > 3.40 ≤ 4.20, which indicates the respondents perceive the need to be between some improvement to a near major / near major improvement - integration of information (design), healthier and safer plant and equipment, digitalisation of information, improved security, workers with technology skills, improved materials management, identification of hazardous materials, deployment of technology, simulation of activities, and automation of activities on site. 9 / 11 (81.8%) MSs are > 3.80 ≤ 4.20 - the upper part of the range.

These needs are varied; however, the empirical findings reflect the findings of the literature in terms of the implied need for performance improvement (Autodesk and CIOB, 2019; CIDB, 2016). Furthermore, they can be responded to by Industry 4.0 technologies (Autodesk and CIOB, 2019).

Table 3 indicates the respondents' self-rating of their awareness of / exposure to eleven Industry 4.0 technologies in terms of percentage responses to a scale of 1

(limited) to 5 (extensive), and a MS ranging between 1.00 and 5.00. It is notable that only 3 / 11 (27.3%) of the MSs are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to rate themselves as above average, as opposed to below average - Internet of Things, drones, and digitalisation of information. However, it should be noted that smart sensors have a MS of 2.96.

Table 2: Extent of the need for performance improvement on projects

Need	Response (%)						MS	R
	U	Minor…… Major						
		1	2	3	4	5		
Improved planning and control of activities on site	0.0	0.0	3.6	9.1	30.9	56.4	4.40	1
Improved communication	0.0	0.0	7.0	8.8	29.8	54.4	4.32	2
Workers with technical skills	0.0	0.0	3.6	19.6	23.2	53.6	4.27	3
Link processes across the stages of projects	1.8	0.0	12.3	8.8	22.8	54.4	4.21	4
Integration of information (construction)	0.0	1.8	8.9	8.9	26.8	53.6	4.21	5
Integration of information (procurement)	0.0	0.0	8.8	14.0	24.6	52.6	4.21	6
Integration of information (design)	0.0	1.8	7.0	8.8	38.6	43.9	4.16	7
Healthier and safer plant and equipment	0.0	0.0	7.0	21.1	28.1	43.9	4.09	8
Digitalisation of information	0.0	0.0	1.8	25.0	39.3	33.9	4.05	9
Improved security	0.0	0.0	8.8	19.3	31.6	40.4	4.04	10
Workers with technology skills	0.0	0.0	1.8	30.9	34.5	32.7	3.98	11
Improved materials management	0.0	0.0	3.5	29.8	35.1	31.6	3.95	12
Identification of hazardous materials	1.8	1.8	7.0	21.1	33.3	35.1	3.95	13
Deployment of technology	3.5	0.0	8.8	19.3	45.6	22.8	3.85	14
Simulation of activities	0.0	0.0	14.0	21.1	35.1	29.8	3.81	15
Automation of activities on site	0.0	3.6	14.3	26.8	39.3	16.1	3.50	16
Workers with IT skills	0.0	5.4	16.1	25.0	35.7	17.9	3.45	17

It is notable that no technology is rated above average to extensive / extensive (MSs > 4.20 ≤ 5.00). Only 1 / 11 (9.1%) MSs is > 3.40 ≤ 4.20, which indicates a rating of average to above average / above average - Internet of Things. However, it should be noted that drones have a MS of 3.40.

Only 6 / 11 (54.5%) MSs are > 2.60 ≤ 3.40, which indicates a rating of below average to average / average - drones, digitalisation of information, smart sensors, 3-D printing, blockchain, and Artificial Intelligence (AI) / Machine Learning.

The remaining 4 / 11 MSs are > 1.80 ≤ 2.60, which indicates a rating of limited to below average / below average. Virtual Reality, robotics / exoskeletons, and Augmented Reality fall within the upper half of this MS range, whereas nanotechnology falls within the lower half.

Table 3: Respondents' awareness of / exposure to eleven Industry 4.0 technologies

Need	Response (%)						MS	R
	U	Limited…… Extensive						
		1	2	3	4	5		
Internet of Things	1.8	10.9	7.3	18.2	29.1	32.7	3.67	1
Drones	3.6	9.1	16.4	18.2	32.7	20.0	3.40	2
Digitalisation of information	3.6	10.9	12.7	27.3	30.9	14.5	3.26	3
Smart sensors	7.3	16.4	20.0	23.6	16.4	16.4	2.96	4
3-D printing	1.8	21.8	21.8	29.1	18.2	7.3	2.67	5
Blockchain	20.4	16.7	20.4	22.2	14.8	5.6	2.65	6
Artificial Intelligence (AI) / Machine Learning	3.8	18.9	30.2	22.6	18.9	5.7	2.61	7
Virtual Reality	5.5	32.7	16.4	20.0	18.2	7.3	2.48	8
Robotics / Exoskeletons	9.1	29.1	27.3	16.4	9.1	9.1	2.36	9
Augmented Reality	12.7	40.0	14.5	14.5	9.1	9.1	2.23	10
Nanotechnology	10.9	32.7	27.3	16.4	7.3	5.5	2.16	11

Table 4 indicates the potential of Industry 4.0 technologies referred to in Table 3 to reduce the occurrence of nineteen phenomena in terms of percentage responses to a scale of 1 (minor) to 5 (major), and MSs 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 major as opposed to minor.

It is notable that no MS is $> 4.20 \leq 5.00$ - near major to major / major potential.

13 / 19 (68.4%) MSs are $> 3.40 \leq 4.20$, which indicates between potential to near major / near major potential - 6 / 13 (46.1%) the MSs, namely information anomalies / ambiguities, under-pricing, late information, OH data / statistics is / are not available, similar or alike errors are repeated, and management information is not available fall within the upper half of this range, namely $> 3.80 \leq 4.20$. The phenomena whose MSs are $> 3.40 \leq 3.80$ include difficulty monitoring the process and activities of construction (ito of OH), non-compliance, inadequate coordination of subcontractors, unauthorised people fulfil functions, unhealthy / unsafe plant and equipment, accidents, and fatigue among workers.

6 / 19 (31.6%) of the MSs are $> 2.60 \leq 3.40$, which indicates between near minor potential to potential / potential - materials containing hazardous chemical substances, injuries, sprains and strains among workers, fatalities, occupational disease, and heat stress among workers.

Despite the respondents' generally low self-rating of their awareness of / exposure to the eleven Industry 4.0 technologies, they recognise the potential of Industry 4.0 technologies to reduce the occurrence of the phenomena as per the literature (Autodesk and CIOB, 2019).

Table 4: Potential of Industry 4.0 technologies to reduce the occurrence of phenomena

Phenomenon	Response (%)						MS	R
	U	Minor…… Major						
		1	2	3	4	5		
Information anomalies / ambiguities	5.5	3.6	1.8	14.5	38.2	36.4	4.08	1
Under-pricing	5.5	1.8	3.6	16.4	38.2	34.5	4.06	2
Late information	3.6	3.6	3.6	12.7	40.0	36.4	4.06	3
OH data / statistics is / are not available	5.4	3.6	1.8	21.4	37.5	30.4	3.94	4
Similar or alike errors are repeated	5.4	0.0	3.6	28.6	42.9	19.6	3.83	5
Management information is not available	3.6	1.8	12.7	14.5	40.0	27.3	3.81	6
Difficulty monitoring the process and activities of construction (ito of OH)	3.6	3.6	7.1	23.2	41.1	21.4	3.72	7
Non-compliance	3.6	1.8	8.9	23.2	44.6	17.9	3.70	8
Inadequate coordination of subcontractors	3.6	3.6	12.5	21.4	30.4	28.6	3.70	9
Unauthorised people fulfil functions	7.3	9.1	9.1	20.0	23.6	30.9	3.63	10
Unhealthy / Unsafe plant and equipment	3.6	7.1	8.9	23.2	37.5	19.6	3.56	11
Accidents	3.6	5.4	12.5	26.8	37.5	14.3	3.44	12
Fatigue among workers	5.4	3.6	12.5	33.9	28.6	16.1	3.43	13
Materials containing hazardous chemical substances	3.6	8.9	16.1	17.9	37.5	16.1	3.37	14
Injuries	3.6	7.1	16.1	23.2	35.7	14.3	3.35	15
Sprains and strains among workers	3.6	7.1	16.1	25.0	35.7	12.5	3.31	16
Fatalities	3.6	12.5	14.3	23.2	30.4	16.1	3.24	17
Occupational disease	7.3	12.7	12.7	20.0	36.4	10.9	3.22	18
Heat stress among workers	5.4	10.7	17.9	25.0	28.6	12.5	3.15	19

DISCUSSION

The findings indicate that nineteen OH-related phenomena are experienced on projects, and in the case of 84.2%, frequently as opposed to infrequently, which indicates that in general OH challenges exist, and persist. Under-pricing, late information, similar or alike errors are repeated, information anomalies / ambiguities, inadequate coordination of subcontractors, data / statistics is / are not available, and management information is not available predominate. The deployment of Industry 4.0 technologies is perceived as having the potential to mitigate all the challenges.

The extent of the need for performance improvement on projects relative to aspects or interventions that could improve OH is between some improvement to a near major / near major improvement. Improved planning and control of activities on site, improved communication, workers with technical skills, link processes across the stages of projects, integration of information (construction), and integration of information (procurement) predominate, which primarily amplifies the need for information, and the management including integration thereof.

The respondents rated themselves above average in terms of their self-rating of their awareness of / exposure to eleven Industry 4.0 technologies in only 3 / 11 (27.3%)

cases - Internet of Things, drones, and digitalisation of information. However, despite this, they perceive Industry 4.0 technologies to have the potential to reduce the occurrence of the phenomena.

Eleven (100%) Industry 4.0 technologies are perceived as having more major than minor potential to reduce the occurrence of nineteen OH-related phenomena. The predominating phenomena are information anomalies / ambiguities, under-pricing, late information, OH data / statistics is / are not available, similar or alike errors are repeated, and management information is not available.

CONCLUSION

Given the frequency that phenomena are experienced on projects and the extent of the need for performance improvement on projects, it can be concluded that the respondents' OH perceptions reflect the general research findings relative to OH performance in South African construction, and that there is a need for improvement, potential to improve, and a need to process test Industry 4.0 technologies to determine whether they contribute to a quantifiable improvement in OH performance or not.

Given the respondents' below average self-rating of their awareness of / exposure to eleven Industry 4.0 technologies, it can be concluded that there is a need for interventions to raise the level of awareness, and to integrate such technologies into built environment / construction / construction OH / H&S education and training.

Given the perceived potential of Industry 4.0 technologies to reduce the occurrence of nineteen construction resource-related H&S phenomena, the perceived need for the implementation of Industry 4.0 in construction is amplified.

RECOMMENDATIONS

Built environment stakeholders, which includes construction project managers, designers, quantity surveyors, contractors, and construction H&S consultants should process test Industry 4.0 technologies to determine whether they contribute to a quantifiable improvement in OH performance or not.

Built environment, especially construction management, and construction H&S-related tertiary education, and construction OH / H&S-related training should include, or rather embed Industry 4.0 in their programmes.

Construction employer associations, and built environment associations and statutory councils should promote, and preferably provide Industry 4.0-related OH / H&S 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.

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