



Construction Ergonomics: Can the Challenges Be Overcome?

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Abstract. Historical H&S challenges, in terms of a range of issues, continue to be experienced, namely not following procedures, unsafe acts, unsafe conditions, non-compliance, untrained workers undertaking work, commencement of activities without conducting hazard identification and risk assessment (HIRA), data gathering and recording, monitoring, and ultimately the experience of injuries. Given the abovementioned, and the advent of Industry 4.0, an exploratory quantitative study, which entailed a self-administered questionnaire, was conducted among registered professional (Pr) Construction H&S Agents to determine the H&S challenges experienced, H&S performance, and the 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 H&S performance, continue to be experienced in construction, and that Industry 4.0 technologies can contribute to resolving the H&S challenges experienced in construction. Conclusions include that Industry 4.0 technologies have 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 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.

Keywords: Construction · Health and safety · Industry 4.0 · Performance

1 Introduction

The considerable number of accidents, fatalities, and other injuries that occur in the South African construction industry were highlighted in the Construction Industry Development Board (cidb) report ‘Construction Health & Safety Status & Recommendations’ [1]. The disabling injury incidence rate (DIIR) of 0.98, which equates to 0.98 disabling injuries per 100 workers, the all-industry average being 0.78, is also noted in the report. The unfavourable DIIR is underscored by a fatality rate (FR) of 25.5 per 100 000 workers, which does not compare favourably with international rates, the Australian construction industry FR for 2019 was 2.2 [2], and for the United Kingdom (UK), was 1.74 in 2019/2020 [3]. Furthermore, based upon the value of construction work completed in

South Africa, the total cost of accidents (COA) could have been between 4.3% and 5.4% [1].

The cidb [1] contends the high-level of non-compliance with H&S legislative requirements is indicative of a deficiency of effective management and supervision of H&S on construction sites, as well as planning from the inception/conception of projects within the context of project management. However, the contention that the traditional approach to monitoring and measuring H&S-related issues is largely manual in nature, which has its limitations, whereas automated H&S monitoring is considered one of the most promising methods for accurate and continuous monitoring of H&S performance on construction sites, provides insight in terms of a likely response [4]. The contention is underscored by Nath et al. [5] that construction work is physically demanding, and workers can exceed their physical capacity, the challenge being to mitigate same i.e. the ability to monitor activities that entail such exposure.

According to Autodesk & the Chartered Institute of Building (CIOB) [6], digital technologies are transforming every industry, and construction is no exception. Infinite computing, robotics, machine learning, drones, the 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 H&S, Industry 4.0 technologies should be considered in terms of responding to and mitigating these.

Given the continuing poor 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, and
- Potential of Industry 4.0 technologies to reduce the occurrence of phenomena.

2 Review of the Literature

Gheisari and Esmaeili [7] state that using unmanned aerial systems (UASs) commonly referred to as 'drones', provide an effective solution to carry out real-time monitoring and improve H&S monitoring and control practices on site. Furthermore, UAS technology can enable H&S managers to identify hazards at different stages of the project and develop suitable mitigation strategies [8].

During recent years visualisation technologies such as virtual reality (VR) and augmented reality (AR) have been evolved and used to improve construction productivity, H&S, and quality [9]. Both AR and VR have the potential to improve on site construction processes [9]. 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 [10].

According to the Health & Safety Executive (HSE) [11], there is growing evidence that wearable devices can significantly benefit H&S in the workplace through positioning and sensor technologies. Cousins [12] in turn highlights that wearable devices can detect

fatigue risk, high heart rates, and stress. A study conducted by Nath et al. [5] determined that wearable technology was able to prevent work related injuries and fatalities by ergonomically designing the work environment based on previous data collected.

3 Research

A 14-question questionnaire was administered to delegates attending a two-day construction H&S summit in Durban, South Africa, prior to the commencement of the proceedings to avoid influencing the delegates' responses through any presentations as the theme of the summit was 'The role of Industry 4.0 in construction H&S'. The sample is best described as a convenience sample. Seven of the questions were demographic related, six were closed-ended and Likert Scale type questions, and one was open-ended. 28 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).

Table 1 indicates the frequency at which nineteen 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 17/19 (89.5%) 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.

It is notable that no phenomena are experienced between often to constantly/constantly (MSs $> 4.20 \leq 5.00$).

16/19 (84.2%) of the MSs are $> 3.40 \leq 4.20$, which indicates the frequency is between sometimes to often/often. The MSs of non-compliance similar or alike errors are repeated, late information, data/statistics is/are not available, fatigue among workers, underpricing, and inadequate coordination of subcontractors are $> 3.80 \leq 4.20$ – the upper part of the range. The remaining 9/16 (56.3%) MSs are $> 3.40 \leq 3.80$ - materials containing hazardous chemical substances, information anomalies/ambiguities, unhealthy/unsafe plant and equipment, difficulty monitoring the process and activities of construction (in terms of H&S), sprains and strains among workers, management information is not available, heat stress among workers, unauthorised people fulfil functions, and injuries.

2/19 (10.5%) MSs are $> 2.60 \leq 3.40$, which indicates the frequency is between rarely to sometimes/sometimes – accidents, and fatalities. The MS of the last ranked phenomenon, namely occupational disease, is $> 1.80 \leq 2.60$, which indicates it is experienced between never to rarely/rarely.

Many of these phenomena are frequently referred to in the literature [6; 11], and furthermore, Industry 4.0 technologies have been identified as being able to reduce the occurrence of phenomena as per the literature [6].

Table 1. Frequency at which nineteen phenomena are experienced on projects.

Phenomenon	Response (%)						MS	Rank
	Unsure	Never	Rarely	Sometimes	Often	Always		
Non-compliance	0.0	0.0	0.0	21.4	46.4	32.1	4.11	1
Similar or alike errors are repeated	3.7	0.0	0.0	25.0	39.3	32.1	4.07	2
Late information	0.0	0.0	0.0	18.5	55.6	25.9	4.07	3
Data/Statistics is/are not available	0.0	0.0	0.0	25.9	51.9	22.2	3.96	4
Fatigue among workers	0.0	0.0	3.7	25.9	40.7	29.6	3.96	5
Underpricing	12.5	3.7	0.0	14.8	51.9	18.5	3.92	6
Inadequate coordination of subcontractors	0.0	0.0	0.0	33.3	51.9	14.8	3.81	7
Materials containing hazardous chemical substances	0.0	0.0	7.4	33.3	33.3	25.9	3.78	8
Information anomalies/ambiguities	3.8	0.0	0.0	33.3	55.6	7.4	3.73	9
Unhealthy/Unsafe plant and equipment	0.0	0.0	11.1	25.9	48.1	14.8	3.67	10
Difficulty monitoring the process and activities of construction (in terms of H&S)	0.0	3.7	11.1	25.9	37.0	22.2	3.63	11
Sprains and strains among workers	0.0	0.0	11.1	33.3	40.7	14.8	3.59	12
Management information is not available	0.0	0.0	10.7	35.7	39.3	14.3	3.57	13
Heat stress among workers	0.0	0.0	7.4	48.1	25.9	18.5	3.56	14
Unauthorised people fulfill functions	0.0	3.7	3.7	40.7	37.0	14.8	3.56	15
Injuries	0.0	0.0	11.1	44.4	33.3	11.1	3.44	16
Accidents	0.0	0.0	18.5	44.4	33.3	3.7	3.22	17
Fatalities	0.0	11.1	33.3	37.0	18.5	0.0	2.63	18
Occupational disease	3.8	0.0	48.1	40.7	7.4	0.0	2.58	19

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 10/17 (58.8%) MSs are $> 4.20 \leq 5.00$, which indicates the respondents perceive the need for improvement to be between near major to major/major - integration of information (design), link processes across the stages of projects, integration of information (procurement), healthier and safer plant and equipment, workers with technical skills, improved communication, integration of information (construction), improved planning & control of activities on site, identification of hazardous materials, and workers with technology skills.

The seven (41.2%) needs ranked eleventh to seventeenth have MSs $> 3.40 \leq 4.20$, which indicates the respondents perceive the need to be between some improvement to a near major/near major improvement - deployment of technology, improved security, digitalisation of information, improved materials management, simulation of activities, automation of activities on site, and workers with IT skills. It should be noted that deployment of technology, and improved security have MSs of 4.19, which means they fall below the upper range by 0.02.

These needs are varied, however, the empirical findings reflect the findings of the literature in terms of the implied need for performance improvement [6]. Furthermore, they can be responded to by Industry 4.0 technologies [6].

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

Need	Response (%)						MS	R
	Unsure	Minor.....Major						
		1	2	3	4	5		
Integration of information (design)	3.8	0.0	0.0	11.1	22.2	63.0	4.54	1
Link processes across the stages of projects	0.0	0.0	0.0	3.8	42.3	53.8	4.50	2
Integration of information (procurement)	4.0	0.0	0.0	7.7	34.6	53.8	4.48	3
Healthier and safer plant and equipment	0.0	0.0	0.0	11.1	33.3	55.6	4.44	4
Workers with technical skills	0.0	0.0	0.0	11.1	33.3	55.6	4.44	5
Improved communication	0.0	0.0	0.0	11.1	40.7	48.1	4.37	6
Integration of information (construction)	0.0	0.0	3.7	11.1	33.3	51.9	4.33	7
Improved planning & control of activities on site	0.0	0.0	0.0	18.5	33.3	48.1	4.30	8
Identification of hazardous materials	0.0	0.0	0.0	18.5	33.3	48.1	4.30	9
Workers with technology skills	0.0	0.0	3.7	11.1	40.7	44.4	4.26	10
Deployment of technology	0.0	0.0	3.8	19.2	30.8	46.2	4.19	11
Improved security	0.0	0.0	0.0	22.2	37.0	40.7	4.19	12
Digitalisation of information	0.0	0.0	0.0	33.3	25.9	40.7	4.07	13
Improved materials management	0.0	0.0	0.0	23.1	50.0	26.9	4.04	14
Simulation of activities	4.0	0.0	3.8	26.9	30.8	34.6	4.00	15
Automation of activities on site	0.0	0.0	7.4	29.6	40.7	22.2	3.78	16
Workers with IT skills	0.0	0.0	7.4	37.0	33.3	22.2	3.70	17

Table 3 indicates the potential of Industry 4.0 technologies 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 above average.

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

17/19 (89.5%) MSs are $> 3.40 \leq 4.20$, which indicates between potential to near major/near major potential – the MSs of data/statistics is/are not available, late information, and similar or alike errors are repeated fall within the upper half of this range, namely

Table 3. Potential of Industry 4.0 technologies to reduce the occurrence of phenomena.

Phenomenon	Response (%)						MS	R
	Unsure	Minor.....Major						
		1	2	3	4	5		
Data / Statistics is / are not available	0.0	0.0	3.6	28.6	35.7	28.6	3.93	1
Late information	0.0	0.0	3.8	26.9	42.3	26.9	3.92	2
Similar or alike errors are repeated	0.0	0.0	3.8	34.6	34.6	26.9	3.85	3
Non-compliance	0.0	0.0	11.1	22.2	44.4	22.2	3.78	4
Unhealthy / Unsafe plant and equipment	3.7	3.7	7.4	18.5	51.9	18.5	3.74	5
Management information is not available	3.8	3.7	3.7	29.6	37.0	22.2	3.73	6
Accidents	0.0	0.0	7.4	25.9	55.6	11.1	3.70	7
Information anomalies / ambiguities	0.0	0.0	3.7	40.7	37.0	18.5	3.70	8
Materials containing hazardous chemical substances	0.0	0.0	14.8	22.2	48.1	14.8	3.63	9
Difficulty monitoring the process and activities of construction (in terms of H&S)	0.0	0.0	14.8	29.6	33.3	22.2	3.63	10
Inadequate coordination of subcontractors	3.7	3.7	7.4	29.6	40.7	18.5	3.63	11
Injuries	0.0	0.0	10.7	35.7	35.7	17.9	3.61	12
Fatigue among workers	0.0	0.0	14.8	40.7	22.2	22.2	3.52	13
Heat stress among workers	3.7	3.7	11.1	37.0	29.6	18.5	3.48	14
Sprains and strains among workers	3.7	3.7	14.8	33.3	25.9	22.2	3.48	15
Fatalities	3.6	3.6	10.7	32.1	42.9	10.7	3.46	16
Underpricing	3.7	3.6	17.9	25.0	32.1	17.9	3.44	17
Occupational disease	3.8	3.7	7.4	48.1	25.9	11.1	3.35	18
Unauthorised people fulfill functions	7.7	7.4	3.7	44.4	29.6	11.1	3.35	19

$> 3.80 \leq 4.20$. The phenomena whose MSs are $> 3.40 \leq 3.80$ include non-compliance, unhealthy/unsafe plant and equipment, management information is not available, accidents, information anomalies/ambiguities, materials containing hazardous chemical substances, difficulty monitoring the process and activities of construction (in terms of H&S), inadequate coordination of subcontractors, injuries, fatigue among workers, heat stress among workers, sprains and strains among workers, fatalities, and underpricing.

Only 2/19 (10.5%) of the MSs are $> 2.60 \leq 3.40$, which indicates between near minor potential to potential/potential - occupational disease, and unauthorised people fulfill functions.

The empirical findings reflect the findings of the literature in terms of the potential of Industry 4.0 technologies to reduce the occurrence of the phenomena as per the literature [6].

4 Conclusions

Given the frequency that phenomena are experienced on projects, it can be concluded that the respondents' H&S perceptions reflect the general research findings relative to H&S performance in South African construction, and that there is a need for improvement, potential to improve, and a need for the implementation of Industry 4.0 technologies.

Given the extent of the need for performance improvement on projects, it can be concluded that the respondents' perceptions reflect the general research findings relative to H&S performance in South African construction, and that there is a need for the implementation of Industry 4.0 technologies.

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

5 Recommendations

Construction management, and construction H&S-related tertiary education, and construction H&S-related training must include, or rather embed Industry 4.0 in their programmes.

Construction employer associations, and built environment associations and statutory councils must promote, and preferably provide Industry 4.0-related 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.

References

1. Construction Industry Development Board (cidb): Construction health & safety in South Africa status & recommendations. CIDB, Pretoria (2009)
2. Safe Work Australia (SWA): Work-related Traumatic Injury Fatalities, Australia 2019. SWA, Canberra (2020)

3. Health & Safety Executive (HSE): Workplace fatal injuries in Great Britain, 2020. HSE (2020)
4. Awolusi, I., Marks, E., Hallowell, M.: Wearable technology for personalized construction safety monitoring and trending: review of applicable devices. *Autom. Constr.* **85**, 96–106 (2018)
5. Nath, N.D., Akhavian, R., Behzadan, A.H.: Ergonomic analysis of construction worker's body postures using wearable mobile sensors. *Appl. Ergon.* **62**, 107–117 (2017)
6. Autodesk and Chartered Institute of Building (CIOB): discussion paper reimagining construction: the vision for digital transformation, and a roadmap for how to get there. CIOB, London (2019)
7. Gheisari, M., Esmaeili, B.: Unmanned aerial systems (UAS) for construction safety applications. In: *Construction Research Congress 2016: Old and New Construction Technologies Converge in Historic San Juan*, pp. 2642–2650. American Society of Civil Engineers (ASCE), San Juan (2016)
8. Alizadehsalehi, S., Asnafi, M., Yitmen, I., Celik, T.: UAS-BIM based real-time hazard identification and safety monitoring of construction projects. In: *9th Nordic Conference on Construction Economics and Organization*, pp. 22–32. Polyteknisk Forlag, Lyngby (2017)
9. Le, Q.T., Pedro, A., Lim, C.R., Park, H.T., Park, C.S., Kim, H.K.: A framework for using mobile based virtual reality and augmented reality for experiential construction safety education. *Int. J. Eng. Educ.* **31**, 713–725 (2015)
10. Park, C.S., Lee, D.Y., Kwon, O.S., Wang, X.: A framework for proactive construction defect management using BIM, augmented reality and ontology-based data collection template. *Autom. Constr.* **33**, 61–71 (2013)
11. Health & Safety Executive (HSE): Shared Research Project Wearables in the Workplace. HSE, London (2019)
12. Cousins, S.: Workplace monitoring: Orwell's world of work (2018). <https://www.healthandsafetyatwork.com/feature/orwells-world-of-work>