Industry 4.0 in Construction: Practitioners' Perceptions

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Abstract

Construction continues to experience challenges in terms of a range of issues, namely, following processes, certification, data gathering and recording, monitoring, availability of skilled labour, late payment of contractors, and a declining interest in pursuing careers in the industry. Then, challenges are experienced in terms of performance relative to the project parameters of cost, environment, health and safety, productivity, quality, and time.

Given the abovementioned, and the advent of Industry 4.0, an exploratory quantitative study was conducted to determine the challenges experienced, performance relative to the project parameters, and the potential of Industry 4.0 to contribute to resolving the former cited challenges.

The salient findings are: most project parameter-related phenomena, and construction resource-related phenomena are experienced frequently; there is a need for performance improvement relative to a range of resources and aspects; respondents rate themselves below average in terms of awareness of / exposure to most Industry 4.0 technologies, and Industry 4.0 technologies have the potential to reduce the occurrence of project parameter-related phenomena, and construction resource-related phenomena on projects. Conclusions include that that there is: a need for improvement in performance in construction; potential to improve; a need for the implementation of Industry 4.0, and a need for interventions to raise the level of awareness, and to integrate such technologies into built environment / construction education and training.

Recommendations include: employer associations, professional associations, and statutory councils should raise the level of awareness relative to the potential implementation of Industry 4.0 in construction; case studies should be documented and the findings shared; tertiary built environment education programmes should integrate Industry 4.0 into all possible modules, and continuing professional development (CPD) should address Industry 4.0.

Keywords: Construction, Industry 4.0, Performance

1. Introduction

Just a quarter of construction projects undertaken in the last three years were completed within 10% of their original deadlines (McKinsey in Autodesk & CIOB, 2019). Pryke, Managing Director, BAM Design, United Kingdom (UK) contends that "In some cases buildings are still being delivered 50% late and 50% over budget and there are still defects on site. Productivity has only increased by 1% in the last 20 years, so the industry is ripe for takeover." (Autodesk & CIOB, 2019). Drastically improving productivity and profitability remains one of construction's biggest challenges, which two factors are inextricably linked. For example, if the workforce is 10% less efficient than expected, profits are currently reduced by a minimum of 5% (The Construction Professional in Autodesk & CIOB, 2019). Furthermore, average UK construction project margins reduced to just 1% in 2017 (EY in Autodesk & CIOB, 2019).

Within the context of South Africa, the Construction Industry Development Board (cidb) (2016) highlighted a range of performance issues: clients were neutral or dissatisfied with the performance of contractors on 18% of the projects surveyed; clients were neutral or dissatisfied with the construction schedule performance of contractors on 26% of the projects; approximately 13% of the projects surveyed had levels of defects which are regarded as inappropriate; there was a noticeable increase in the levels of defects over the period 2012 to 2015; contractors were neutral or dissatisfied with the performance of clients on 18% of the projects surveyed; contractors were neutral or dissatisfied with the quality of tender documents and specifications obtained from clients on approximately 17% of the projects surveyed; contractors were neutral or dissatisfied with the management of variation orders on 24% of the projects surveyed; 60% of payments to contractors were delayed for longer than 30 days after invoicing; the recommendations of the tender committee were overruled in the award of approximately 9% of public sector projects, and H&S on construction sites as well as transportation to the sites remains a concern.

The Council for Scientific and Industrial Research (CSIR) (2018) states that 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.

Considering the numerous challenges experienced in construction, especially the delivery of projects, it is inevitable that the FIR is considered to overcome these. According to Autodesk & CIOB (2019), 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.

Furthermore, Schwab (2018) states that the world is volatile, uncertain, complex, and ambiguous, and therefore, for organisations to function in this fast-changing market they need to develop and incorporate smart digital ways to maintain their competitive advantage. The FIR, a combination of cyber physical systems, is driven by the increasing availability and interaction of a new set of extraordinary technologies, building on three previous technological revolutions. Much more than linking computers and creating higher levels of automation, the signature of the Third Industrial Revolution, it is more about how we learn from what we are doing by collecting state-of-the-art information on our methods, systems and processes and then using that through human or artificial intelligence to do things smarter.

Considering the numerous challenges experienced in construction, especially the delivery of projects, it is inevitable that the FIR is considered in terms of potential to overcome these. Furthermore, recent studies have highlighted that 26% of construction workers say they are frustrated by the lack of tools they need to do their jobs better (Autodesk & CIOB, 2019).

Industry 4.0 is only possible because of digitalisation, thus the approach to planning, decision making, organising, and operating in this age will in many ways be different from the current approach due to the greater amounts of information and learning systems available to assist. More autonomous and individual decisions are going to be made, which requires live and up-to-date information from various sources. This will not just be decision making at a management level but will encapsulate the principles enshrined in the 'Toyota' way, whereby individuals on the 'production line' can stop the process based on information available to them (Liker, 2004). This will see a skill shift with new formal, and informal competencies needed by these individuals, including enhanced communication skills. Manyika & Bughin (2018) contend that approximately half of current work activities (not jobs) are technically automatable.

Given the continuing poor 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 project parameter-related phenomena are experienced on projects;
- Frequency that eighteen-construction resource-related phenomena are experienced on projects;
- Extent of the need for performance improvement on projects;
- Respondents' self-rating of their awareness of / exposure to ten Industry 4.0 technologies;
- Potential of Industry 4.0 technologies to reduce the occurrence of seven project parameter-related phenomena, and
- Potential of Industry 4.0 technologies to reduce the occurrence of eighteen construction resource-related phenomena.

2. Review of the Literature

2.1 The Fourth Industrial Revolution

Schwab (2018) states that the publication of The Fourth Industrial Revolution in January 2016 established the need to take collective responsibility "for a future where innovation and technology are centred on humanity and the need to serve the public interest." However, Schwab (2018) stresses the importance of developing a mindset that considers system-level effects, the impact on individuals, which remains future oriented and is aligned with common values across diverse stakeholder groups.

Furthermore, Schwab (2018) advocates that the following four principles should be kept in mind when considering how technologies can create impact: systems not technologies; empowering, not determining; by design, not by default, and values as a feature, not a bug. Cousins (2018) echoes a similar sentiment and states if staff are not onboard with the journey, it's possible that 'Big Brother syndrome' could result in distrust towards management, and create an additional source of workplace stress and low morale.

2.2 Data

Data is a powerful means of driving improvements across the global construction industry, but the built environment has not yet developed the capability to use data in a genuinely meaningful way (van Rooyen, 2015). Unmanageable volumes and complexity of 'big data' have driven the need for machine learning, which is difficult for humans to interpret using traditional analytical methods. The Health & Safety Executive (HSE) (2017) states that artificial intelligence (AI) is "the science of making machines smart", and is a field that is advancing at an exponential rate. Machine learning in turn, is a tool for constructing AI systems, involving extraction of knowledge and 'learning' from data.

Within the context of construction and the management of projects, worker health and safety (H&S) is an area which still needs much improvement. Ideally, 'big data' should enable people to determine what is transpiring, and how to intervene to improve a system such as an H&S management system. Much of the recent excitement with respect to AI has been the result of advances in the field known as deep learning, a set of techniques to implement machine learning based on artificial neural networks (Manyika & Bughin, 2018).

Then, the 'Internet of Things' (IoT) is one of the major up-and-coming new technologies that will play a role in reshaping work, which can most simply be described as "a technological development where everyday machines, devices and appliances are connected and able to send and receive data over the Internet." (HSE, 2017)

2.3 Benefits of Industry 4.0

McKinsey in Autodesk & CIOB (2019) reports that moving to a manufacturing-style production system could boost productivity in the construction sector by up to 10 times. Kranz (2017) in turn cites the payback relative to IoT as reduced labour, lower costs, increased productivity, improved quality, and enhanced decision making. Reduced labour due to IoT performing a task that a person would have had to do. Lower costs due to devices connecting and communicating to automate a process. Increased productivity due to such automation. Improved quality due to intelligent devices connecting and communicating through the IoT thus reducing errors and rework. Enhanced decision making, intelligent devices connecting and communicating through the IoT, especially if analytics or predictive analytics are included into the equation.

Recent advances in access technologies such as unmanned aerial vehicles (UAVs) or drones and Remotely Operated Vehicles (ROVs) coupled with imaging technology, have enabled increasing replacement of the human element in terms of visual inspection. This is beneficial in terms of avoidance of high-risk manned interventions such as in confined spaces, working at height, or in hazardous environments (HSE, 2019a). Cousins (2018) cites the real-time surveillance of job sites courtesy of drones, and adds that they are increasingly being deployed to oversee H&S systems over large work areas.

According to the HSE (2019b), there is growing evidence that wearable devices can significantly benefit H&S in the workplace through positioning and sensor technologies. To this end, the priority areas for a pending research project are monitoring occupational personal exposure to hazardous substances and physical hazards on construction sites, and musculoskeletal disorders (MSDs) in workers identified at greater risk. Cousins (2018) in turn highlights that wearable devices can detect fatigue risk, high heart rates, and stress.

From a macro perspective, the findings of research conducted by the World Economic Forum (WEF) predicts that 10 years of full-scale digitalisation of the construction industry will lead to huge annual global cost savings. Savings in the design, engineering and construction phases in the non-residential construction sector are expected to increase from \$0.7 trillion to \$1.2 trillion, and in the operations phase, from \$0.3 trillion to \$0.5 trillion (WEF in Autodesk & CIOB, 2019).

3. Research

3.1 Research Method and Sample Stratum

The exploratory study entailed a self-administered questionnaire survey delivered via e-mail. The sample strata included alumni (graduates) of the Department of Construction Management, Nelson Mandela University, Construction H&S Agents, and Master Builders Association (MBA) Kwazulu-Natal H&S competition award winners. The questionnaire consisted of fourteen questions – thirteen closed ended, and one open-ended. Seven of the close ended questions were Likert scale type questions, and six were demographics related. 46 Responses were received, which equates to a response rate of 16.1%. The analysis of the data 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.

3.2 Results and Discussion

Table 1 indicates the frequency at which seven project parameter-related phenomena are experienced on projects in terms of percentage responses to a scale of never to constantly, and a MS ranging between 1.00 and 5.00. It is notable that only 5 / 7 (71.4%) 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 ≤ 5.00). 5 / 7 (71.4%) of the MSs are > 3.40 ≤ 4.20, which indicates the frequency is between sometimes to often / often – delays, poor productivity, late completion, quality non-conformances, and costs exceed value, which are inter-related in that they impact upon each other. Damage to the environment has a MS > 2.60 ≤ 3.40 – between rarely to sometimes / sometimes. The MS of accidents is marginally below the lower limit of the upper MS range. The pervasiveness of these phenomena are frequently referred to in the literature (cidb, 2016; Autodesk & CIOB, 2019).

Table 1: Frequency at which project parameter-related phenomena are experienced on projects.

Phenomenon	**Response (%)**						**MS**	**Rank**
	Unsure	**Never**	**Rarely**	**Some-times**	**Often**	**Constantly**		
Delays	0.0	0.0	7.0	16.3	46.5	30.2	4.00	1
Poor productivity	0.0	2.3	9.3	27.9	37.2	23.3	3.70	2
Late completion	2.3	2.3	14.0	25.6	32.6	23.3	3.62	3
Quality non-conformances	0.0	0.0	9.3	39.5	34.9	16.3	3.58	4

Costs exceed value	2.3	0.0	9.3	41.9	34.9	11.6	3.50	5
Damage to the environment	0.0	4.7	41.9	34.9	9.3	9.3	2.77	6
Accidents	0.0	0.0	62.8	23.3	7.0	7.0	2.58	7

Table 2 indicates the frequency at which eighteen construction resource-related phenomena are experienced on projects in terms of percentage responses to a scale of never to constantly, and a MS ranging between 1.00 and 5.00. It is notable that 13 / 18 (72.2%) 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. However, the MSs of four phenomena are on the cut-point, namely 3.00. It is notable that no phenomena are experienced between often to constantly / constantly (MSs > 4.20 ≤ 5.00). 6 / 18 (33.3%) of the MSs are > 3.40 ≤ 4.20, which indicates the frequency is between sometimes to often / often – late information, a shortage of workers with the necessary skills, information anomalies / ambiguities, rework occurs, inadequate coordination of subcontractors, and similar or alike errors are repeated. It is notable that 2 / 6 (33.3%) are information-related. The MS (3.40) of data / statistics is / are not available, ranked seventh, which is information-related, is on the lower point of the upper MS range. The remaining twelve (66.7%) phenomena have MSs > 2.60 ≤ 3.40 – between rarely to sometimes / sometimes. It is notable that three (25.0%) phenomena are information-related, ‘difficulty monitoring the process and activities of construction’ included. 5 / 12 (41.6%) are in the upper half of the range, namely > 3.10 ≤ 3.40 - data / statistics is / are not available, underpricing, management information is not available, materials are not available when required, and difficulty monitoring the process and activities of construction. The MSs of a further two are 3.10, namely fatigue among workers, and materials are lost / stolen. These are followed by unauthorised people fulfill functions, workers are regularly absent, poor plant and equipment utilisation, materials are damaged, and sprains and strains among workers. Many of these are frequently referred to in the literature (HSE, 2017; 2016; Autodesk & CIOB, 2019; HSE, 2019a; HSE, 2019b).

Table 2: Frequency at which construction resource-related phenomena are experienced on projects.

Phenomenon	**Response (%)**						**MS**	**Rank**
	Unsure	**Never**	**Rarely**	**Some-times**	**Often**	**Constantly**		
Late information	0.0	0.0	4.7	20.9	46.5	27.9	3.98	1
A shortage of workers with the necessary skills	4.7	2.3	7.0	23.3	34.9	27.9	3.83	2
Information anomalies / ambiguities	4.7	2.3	4.7	30.2	41.9	16.3	3.68	3
Rework occurs	2.4	0.0	9.5	45.2	33.3	9.5	3.44	4
Inadequate coordination of subcontractors	0.0	0.0	20.9	27.9	32.6	18.6	3.49	5
Similar or alike errors are repeated	2.3	0.0	11.6	41.9	30.2	14.0	3.48	6
Data / Statistics is / are not available	7.0	2.3	18.6	20.9	41.9	9.3	3.40	7
Underpricing	7.0	2.3	11.6	37.2	32.6	9.3	3.38	8
Management information is not	7.1	0.0	19.0	31.0	33.3	9.5	3.36	9

available								
Materials are not available when required	7.0	0.0	23.3	39.5	20.9	9.3	3.18	10
Difficulty monitoring the process and activities of construction	4.7	2.3	25.6	27.9	37.2	2.3	3.12	11
Fatigue among workers	9.3	4.7	18.6	34.9	27.9	4.7	3.10	12
Materials are lost / stolen	2.3	2.3	18.6	51.2	18.6	7.0	3.10	13
Unauthorised people fulfill functions	9.3	11.6	18.6	30.2	18.6	11.6	3.00	14
Workers are regularly absent	7.0	2.3	30.2	32.6	20.9	7.0	3.00	15
Poor plant and equipment utilisation	7.0	4.7	23.3	39.5	18.6	7.0	3.00	16
Materials are damaged	4.7	2.3	18.6	53.5	18.6	2.3	3.00	17
Sprains and strains among workers	4.7	0.0	41.9	30.2	16.3	7.0	2.88	18

Table 3 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 a MS ranging between 1.00 and 5.00. It is notable that the MSs are all 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 only 4 / 17 (23.5%) MSs are > 4.20 ≤ 5.00, which indicates the respondents perceive the need for improvement to be between near major to major / major - improved communication, workers with technical skills, integration of information (construction), and integration of information (design). One need is communication-related, and two are integration of communication-related. These needs, including workers with technical skills, can be responded to by Industry 4.0 technologies. Improved planning & control of activities on site, ranked fifth, has a MS of 4.19, which is marginally below the lower point of the upper MS range. The 12 (66.7%) needs ranked fifth to sixteenth have MSs > 3.40 ≤ 4.20, which indicates the respondents perceive the need to be between some improvement to a near major / major improvement. 8 / 12 (66.7%) of these needs fall in the upper half of the range, namely > 3.8 ≤ 4.20 - improved planning & control of activities on site, integration of information (procurement), link processes across the stages of projects, reduced occurrence of H&S incidents / accidents, digitalisation of information, workers with technology skills, deployment of technology, and improved security. These needs are varied, however, they can be responded to by Industry 4.0 technologies. The needs in the lower half of the range, namely improved materials management, modern plant and equipment, simulation of activities, and automation of activities on site, can be responded to by Industry 4.0 technologies. Workers with IT skills, has a MS marginally below the lower point of the upper MS range, and thus falls within the range > 2.60 ≤ 3.40, which indicates a near minor need to some need / some need. Yet again, the empirical findings reflect the findings of the literature in terms of the implied need for performance improvement (Autodesk & CIOB, 2019; cidb, 2016).

Table 3: Extent of the need for performance improvement on projects.

Need	**Response (%)**						**MS**	**Rank**
	Un-sure	**Minor ……………………………Major**						
		1	**2**	**3**	**4**	**5**		
Improved communication	0.0	0.0	2.3	4.7	44.2	48.8	4.40	1

Workers with technical skills	2.3	0.0	0.0	11.6	34.9	51.2	4.40	2
Integration of information (construction)	0.0	0.0	0.0	16.3	39.5	44.2	4.28	3
Integration of information (design)	0.0	0.0	0.0	18.6	41.9	39.5	4.21	4
Improved planning & control of activities on site	0.0	0.0	2.3	23.3	27.9	46.5	4.19	5
Integration of information (procurement)	0.0	2.3	2.3	16.3	37.2	41.9	4.14	6
Link processes across the stages of projects	2.3	0.0	0.0	23.3	41.9	32.6	4.10	7
Reduced occurrence of H&S incidents / accidents	0.0	2.3	9.3	14.0	27.9	46.5	4.07	8
Digitalisation of information	4.7	0.0	7.0	16.3	34.9	37.2	4.07	9
Workers with technology skills	4.7	2.3	2.3	20.9	39.5	30.2	3.98	10
Deployment of technology	2.3	0.0	4.7	27.9	37.2	27.9	3.90	11
Improved security	0.0	2.4	7.1	31.0	16.7	42.9	3.90	12
Improved materials management	0.0	2.3	7.0	25.6	41.9	23.3	3.77	13
Modern plant and equipment	0.0	0.0	7.0	39.5	27.9	25.6	3.72	14
Simulation of activities	9.3	2.3	9.3	27.9	25.6	25.6	3.69	15
Automation of activities on site	7.1	2.4	7.1	26.2	40.5	16.7	3.67	16
Workers with IT skills	4.7	7.0	11.6	32.6	25.6	18.6	3.39	17

Table 4 indicates the respondents' self-rating of their awareness of / exposure to ten 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 / 10 (30.0%) 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. It is notable that no technology is rated above average to extensive / extensive (MSs > 4.20 ≤ 5.00). Only 1 / 10 (10.0%) MSs is > 3.40 ≤ 4.20, which indicates a rating of average to above average / above average - Internet of Things. Only 2 / 10 (20.0%) MSs are > 2.60 ≤ 3.40, which indicates a rating of below average to average / average - digitalisation of information, and drones. The remaining 7 / 10 MSs are > 1.80 ≤ 2.60, which indicates a rating of limited to below average / below average. Virtual reality, and 3-D printing fall within the upper half of this MS range, whereas blockchain, augmented reality, artificial intelligence (AI) / machine learning, robotics / exoskeletons, and nanotechnology fall within the lower half.

Table 4: Respondents' self-rating of their awareness of / exposure to ten Industry 4.0 technologies.

Technology	Response (%)						MS	Rank
	Un-sure	Limited ………………………..Extensive						
		1	2	3	4	5		
Internet of Things	7.1	7.1	2.4	23.8	35.7	23.8	3.72	1
Digitalisation of information	0.0	16.7	11.9	16.7	33.3	21.4	3.31	2
Drones	0.0	18.6	9.3	30.2	27.9	14.0	3.09	3
Virtual Reality	0.0	32.6	16.3	25.6	14.0	11.6	2.56	4
3-D printing	2.3	39.5	20.9	14.0	16.3	7.0	2.29	5
Blockchain	11.6	32.6	27.9	18.6	4.7	4.7	2.11	6
Augmented Reality	7.0	48.8	11.6	14.0	14.0	4.7	2.08	7
Artificial Intelligence (AI) / Machine Learning	2.3	41.9	25.6	18.6	9.3	2.3	2.02	8
Robotics / Exoskeletons	2.3	48.8	18.6	20.9	4.7	4.7	1.95	9
Nanotechnology	4.8	47.6	23.8	16.7	2.4	4.8	1.88	10

Table 5 indicates the potential of Industry 4.0 technologies to reduce the occurrence of seven parameter-related phenomena 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 MSs are all 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 ≤ 5.00 – near major to major / major potential. All 7 MSs are > 3.40 ≤ 4.20, which indicates between potential to near major / near major potential. The top three ranked phenomena, namely late completion, quality non-conformances, and delays are clustered. Despite the respondents' generally low self-rating of their awareness of / exposure to ten Industry 4.0 technologies, they recognise the potential of Industry 4.0 technologies to reduce the occurrence of the parameter-related phenomena as per the literature (Autodesk & CIOB, 2019).

Table 5: Potential of Industry 4.0 technologies to reduce the occurrence of project parameter-related phenomena.

Phenomenon	**Response (%)**						**MS**	**Rank**
	Un-sure	**Minor ……………………………Major**						
		1	**2**	**3**	**4**	**5**		
Late completion	11.9	0.0	9.5	23.8	26.2	28.6	3.84	1
Quality non-conformances	11.6	0.0	7.0	23.3	37.2	20.9	3.82	2
Delays	11.6	2.3	7.0	16.3	41.9	20.9	3.82	3
Poor productivity	9.3	2.3	11.6	20.9	27.9	27.9	3.74	4
Costs exceed value	14.0	2.3	11.6	18.6	30.2	23.3	3.70	5
Damage to the environment	14.0	2.3	14.0	25.6	20.9	23.3	3.57	6
Accidents	11.9	2.4	14.3	23.8	28.6	19.0	3.54	7

Table 6 indicates the potential of Industry 4.0 technologies to reduce the occurrence of eighteen construction resource-related phenomena 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 except for one MS all the other MSs (94.4%) 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 ≤ 5.00 – near major to major / major potential. 12 / 18 (66.7%) MSs are > 3.40 ≤ 4.20, which indicates between potential to near major / near major potential. 6 / 12 (50.0%) of these phenomena fall in the upper half of the range, namely > 3.80 ≤ 4.20 - information anomalies / ambiguities, difficulty monitoring the process and activities of construction, similar or alike errors are repeated, management information is not available, data / statistics is / are not available, and rework occurs. The other six phenomena fall in the lower half of the range, namely late information, inadequate coordination of subcontractors, underpricing, poor plant and equipment utilization, unauthorised people fulfill functions, and materials are not available when required. The phenomena ranked thirteenth to seventeenth have MSs > 2.60 ≤ 3.40, which indicates between near minor to potential / potential, namely materials are damaged, sprains and strains among workers, materials are lost / stolen, fatigue among workers, and a shortage of workers with the necessary skills. The MS (2.59) of workers are regularly absent is marginally below the lower point of the upper MS range. However, the potential is nevertheless between minor to near minor / near minor. As is the case of the parameter-related phenomena, despite the respondents' generally low self-rating of their awareness of / exposure to ten Industry 4.0 technologies, they recognise the potential of Industry 4.0 technologies to reduce the occurrence of the resource-related phenomena as per the literature (Autodesk & CIOB, 2019).

Table 6: Potential of Industry 4.0 technologies to reduce the occurrence of construction resource-related phenomena.

Phenomenon	**Response (%)**						**MS**	**Rank**
	Un-sure	**Minor ……………………………Major**						
		1	**2**	**3**	**4**	**5**		
Information anomalies / ambiguities	7.0	2.3	4.7	11.6	37.2	37.2	4.10	1
Difficulty monitoring the process and activities of construction	4.7	2.3	2.3	18.6	39.5	32.6	4.02	2
Similar or alike errors are repeated	4.8	2.4	4.8	26.2	26.2	35.7	3.93	3

Management information is not available	7.0	4.7	4.7	23.3	25.6	34.9	3.88	4
Data / Statistics is / are not available	7.0	7.0	9.3	16.3	18.6	41.9	3.85	5
Rework occurs	7.0	2.3	2.3	32.6	25.6	30.2	3.85	6
Late information	4.7	4.7	4.7	27.9	27.9	30.2	3.78	7
Inadequate coordination of subcontractors	4.7	2.3	9.3	23.3	37.2	23.3	3.73	8
Underpricing	7.0	7.0	9.3	11.6	39.5	25.6	3.73	9
Poor plant and equipment utilisation	7.0	2.3	7.0	30.2	32.6	20.9	3.68	10
Unauthorised people fulfill functions	9.3	4.7	16.3	14.0	32.6	23.3	3.59	11
Materials are not available when required	9.5	7.1	11.9	16.7	31.0	23.8	3.58	12
Materials are damaged	9.3	7.0	16.3	34.9	18.6	14.0	3.18	13
Sprains and strains among workers	7.1	11.9	16.7	23.8	23.8	16.7	3.18	14
Materials are lost / stolen	9.3	18.6	11.6	18.6	20.9	20.9	3.15	15
Fatigue among workers	4.8	9.5	19.0	28.6	26.2	11.9	3.13	16
A shortage of workers with the necessary skills	11.9	14.3	14.3	23.8	21.4	14.3	3.08	17
Workers are regularly absent	7.1	26.2	23.8	19.0	9.5	14.3	2.59	18

4. Conclusions

Given the frequency that project parameter-related phenomena are experienced on projects by respondents, it can be concluded that the respondents' experience reflects the general research findings relative to project 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.

Given the frequency that eighteen construction resource-related phenomena are experienced on projects by respondents, it can be concluded that the respondents' experience reflects the general research findings relative to project 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. The frequency, and thus the need and potential are notable relative to information, however, also applicable to the other resources such as labour, materials, and plant.

Given the extent of the need for performance improvement on projects in terms of integration, linkages, mitigation of errors, automation, digitalisation, simulation, security, and technology, it can be concluded that the respondents' experience reflects the general research findings relative to project performance in South African construction, and that there is a need for the implementation of Industry 4.0.

Given the respondents' below average self-rating of their awareness of / exposure to ten 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 education and training. However, this should be expedited in a contextual manner.

Given the potential of Industry 4.0 technologies to reduce the occurrence of seven project parameter-related phenomena, and eighteen construction resource-related phenomena on projects, the need for the implementation of Industry 4.0 in construction is amplified.

Recommendations

Built environment-related tertiary education 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 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 Industry 4.0 case studies to record the benefits of implementing Industry 4.0 technologies.

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