Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AF07.20260038
Published: May 13, 2026

Assessing Construction 4.0 Awareness, Adoption Barriers, and Benefits in the Eswatini Construction Sector

Fisokuhle Ndlangamandla and Khaled Aboalez
Postgraduate School of Engineering Management
Faculty of Engineering and the Built Environment
University of Johannesburg
Johannesburg, South Africa
215082290@student.uj.ac.za, khaleda@uj.ac.za

Abstract

Significant technological advancements over the past two decades have made technology an integral part of our everyday lives. These technological advancements have resulted in a substantial shift towards digitisation for industries, including the construction sector, which calls this shift Construction 4.0. Construction companies need to understand the Construction 4.0 concept and adopt and benefit from it. Comprehensive knowledge of Construction 4.0, however, remains limited, especially in developing countries. This research adopts a questionnaire survey distributed to construction industry players in Eswatini to assess Construction 4.0 awareness and usage levels, adoption barriers, and benefits. Results reveal moderate awareness but low usage of most Construction 4.0 technologies, with AI, IoT, and cloud computing well known and widely used, while blockchain and robotics were the least known and used. This observation holds across company sizes; however, less experienced respondents had higher awareness than their more experienced counterparts. Prevailing Construction 4.0 adoption barriers included high implementation costs, technological challenges, resistance to change, and complex implementation. At the same time, the top five benefits were increased productivity, improved quality, improved resource planning, reduced manual labor, and improved collaboration. This paper will assist construction organizations in making informed decisions about which technologies to implement, which barriers to avoid, and the perceived benefits of adopting Construction 4.0.

Keywords
Construction 4.0, Digitisation in Construction, Technology Adoption Barriers, Eswatini Construction Industry, Productivity and Quality Improvement.

1. Introduction
Eswatini is one of the developing countries in southern Africa. It is therefore imperative that the country thrive and catch up with the world in construction, innovation, and technology. Construction 4.0 promises vast opportunities through innovative technologies that will shape how construction activities are executed, improving safety and enabling efficient operations that reduce construction costs (Sherratt et al., 2020). Olatunde et al. (2023) reported moderate levels of awareness, while Osunsanmi et al. (2020) reported low levels of Construction 4.0 adoption in studies conducted in developing countries, Nigeria and South Africa, respectively. Wang et al. (2024) noted that Industry 4.0 is powerful and impactful but identified significant barriers to its adoption in construction. Consequently, the opportunities presented by these technologies may not be appreciated, leading to delayed adoption and delayed benefits. The construction sector in Eswatini is no exception. To the authors' knowledge, no previous studies have been conducted on Construction 4.0 in Eswatini; as a result, the country's awareness and usage levels, adoption barriers, and potential benefits remain unknown. This study will therefore create a knowledge pool on awareness and usage levels, adoption barriers, and benefits of Construction 4.0 in Eswatini. This will benefit the country's

construction stakeholders who may want to implement or aid Construction 4.0 to improve construction project performance.

1.1 Objectives

This study explores the Eswatini construction sector's readiness to embrace Construction 4.0, with the following objectives:

1- To assess the current levels of awareness and utilisation of Construction 4.0 technologies within the Eswatini construction industry.
2- To identify the key challenges hindering Construction 4.0 adoption and the opportunities its implementation presents for the sector.

2. Literature Review

Unlike the manufacturing sector, the construction sector has lagged in adopting technology in its processes. (Newman et al., 2021)**.** However, some efforts have been made to adopt Industry 4.0 technologies, leading to the emergence of a new concept, "Construction 4.0," within the construction industry. (Maria et al., 2021). Being a new concept, the Construction 4.0 definition has evolved over the years, with its early definition primarily based on the application of Industry 4.0 concepts in the construction sector. (Dallasega et al., 2018). In their book, Sawhney et al. (2020) suggest that Construction 4.0 is a transformative framework in which three transformations take place: industrial production and construction, cyber-physical systems, and digital technologies. Industrial production and construction enable the industrialisation of construction processes by automating them through cyber-physical systems. Digital technologies are advanced information and communication technologies that will allow the capture, storage, processing, display, communication, integration, and collaboration with information. They will enable the digitisation of the construction industry through digital data management, leveraging the internet and software. (Maria et al., 2021). Both industrialization of construction processes and digitalization of the construction industry are Construction 4.0 pillars that enable improved construction efficiency and productivity. (Forcael et al., 2020). The following sections review literature on Construction 4.0 technologies, awareness, adoption barriers, and benefits in both developed and developing countries. The literature on Construction 4.0 in Eswatini is limited, and studies from a neighboring country and other developing countries were used.

2.1 Construction 4.0 technologies

Construction 4.0 is charecterised by several Industry 4.0 technologies applied in the construction sector. A bibliometric analysis of articles dated between 2014 and 2019 from China, the USA, the UK, and Australia identified 3D printing, big data, virtual reality, and the Internet of Things (IoT) as essential technologies that identify Construction 4.0 (Forcael et al., 2020). In another study, Statsenko et al. (2023) conducted a systematic literature review, including bibliographic coupling, of 170 articles from the top 22 construction journals in the Scopus database between 2013 and 2021 to identify 9 Construction 4.0 technologies. These technologies included cloud computing, vertical and horizontal integration, simulation, augmented/ virtual reality, autonomous robotics, and cybersecurity, in addition to the four identified by Forcael et al. (. Brozovsky et al. (2024) categorized Construction 4.0 technologies into two main technology categories namely dominant and emerging technologies where dominant technologies were found to be 3D modelling, artificial intelligence (AI) and machine learning (ML), BIM, Computer Aided Drafting (CAD), cloud, prefabrication, robots, sensors, and virtual/ augmented/ mixed reality (VR/AR/MR) and emerging technologies being 3D printing, big data, blockchain, data analytics, digital twin, and drones. In a recent study, Dhamak et al. (2025) conducted a review of 379 research papers published between 2013 and 2023 from referred international journals to identify 13 Industry 4.0 technologies with a major impact on the construction sector. These technologies included IoT, artificial intelligence (AI) and machine learning (ML), Autonomous robots, augmented reality (AR), 3D printing, cloud computing, cybersecurity, simulation, drones, big data analytics, smart sensors, building information modelling (BIM), and digital twin. The number of Construction 4.0 technologies has increased in recent studies, as noted by Forcael et al. (2020), who identified only 4 technologies, whereas Dhamak et al. (2025) reported 13. The recent studies include technologies covered in previous studies making the reviewed literature concur and a summary of the major Construction 4.0 technologies follows simulation, augmented reality, big data, blockchain, laser scanner, robotics and automation (using sensors and actuators), internet of things (IoT), additive manufacturing (3D printing), cyber security, artificial intelligence, BIM and cloud computing.

2.2 Construction 4.0 awareness
Understanding the level of Construction 4.0 awareness in Eswatini is important for the successful adoption of Construction 4.0. Numerous studies in developing and developed countries have been conducted to assess Construction 4.0 awareness. Osunsanmi et al. (2020) used a questionnaire survey on construction professionals within the Gauteng province to examine their willingness to adopt Construction 4.0, and part of the study was to assess awareness of Construction 4.0 by ranking the importance of Construction 4.0 technologies. Construction professionals ranked IoT, robotics, human-computer interaction, and cyber-physical systems poorly; this was attributed to their lack of awareness, whereas drone technology was highly ranked, indicating awareness. Similar results were obtained in a different questionnaire survey study in Malaysia, where Alaloul et al. (2020) investigated Construction 4.0 technology awareness by professionals within the construction industry. Only 47% of construction industry practitioners were aware of Construction 4.0, with BIM having the highest level of awareness, while prefabrication, IoT, digitisation, and automation had lower levels. A study in Nigeria found improved awareness of Construction 4.0. The overall level of awareness was moderate, with BIM, 3D printing, IoT, AI, and cybersecurity technologies having a moderate level of awareness, while AR, blockchain, cyber-physical systems, big data, robotics, and cloud computing having the least level of awareness (Olatunde et al., 2023). A recent questionnaire survey by Menegon Lopes and Silva Filho (2024) on construction professionals in Brazil indicated that 6% knew and used Construction 4.0 technology, 37% knew and had basic knowledge, 44% knew but had limited knowledge, and 13% had never heard of the technology. Also, Cloud computing, simulation and modelling, and BIM were found to be the most used, with high signaling awareness, while prefabrication, automation, VR, AR, robotics, drones, big data, IoT, sensors, cyber-physical systems, and 3D printing were the least used, indicating low awareness. The reviewed literature shows a slight increase in Construction 4.0 awareness, from low to moderate, between 2020 and 2024. Also, the literature review exercise identifies BIM, 3D printing, IoT, cybersecurity, cloud computing, simulation, prefabrication, and modelling as the Construction 4.0 technologies that construction professionals are aware of.

2. 3 Construction 4.0 adoption barriers
Barriers to the adoption of Construction 4.0 are a global problem. Numerous studies have been conducted to assess the major barriers to Construction 4.0 in both developing and developed nations. Newman et al. (2021) carried out a mixed methods study approach where a literature review was done to identify documented enablers and barriers to Construction 4.0 technology adoption in the UK. It was found that a combination of high implementation costs and limited technological knowledge is the main barrier. Demirkesen and Tezel (2022) Concur with their identification of major challenges for Industry 4.0 adoption among construction companies in the USA: resistance to change, unclear benefits or gains, and the cost of implementation. Cost, cybersecurity, and lack of training were the top three major challenges to Construction 4.0 adoption in Australia, according to (Chaaya et al., 2025). (Osunsanmi et al., 2020) found nature of construction, Poor understanding of Modern technologies, and the Cost of Construction 4.0 technologies to hinder the adoption of Construction 4.0 in South Africa. A study in Nigeria indicated that lack of standardisation, lack of investment in research and development (R&D), cost of implementation, and resistance to change were the most important challenges for Construction 4.0 adoption (Olatunde et al., 2023). A recent study by Menegon Lopes and Silva Filho (2024) identified high implementation cost, resistance to change, and lack of qualified personnel to be the most important barriers, while lack of information/ knowledge, difficulty to implement, unclear benefits, lack of demand from clients, insufficient infrastructure were of moderate importance, and lack of regulations and standards, reduction in jobs, and risk of information security were the least important. Interestingly, there are similarities in the barriers observed in developing and developed countries; however, developing countries face more barriers than developed ones, including technological constraints, limited R&D, unclear benefits, and fear of job losses. Cost of technology, Lack of tech-savvy labor force, resistance to change, Lack of standards, and Cybersecurity issues are common barriers in both developed and developing countries, making them significant.

2. 4 Construction 4.0 adoption benefits
Construction 4.0 offers several opportunities in the construction sector. Knowledge of these opportunities is important for decision makers to understand and motivate Construction 4.0 implementation. Sawhney et al. (2020) and Alaloul et al. (2020) agree that Construction 4.0 benefits include creating an enabling and innovative environment, improving sustainability, improving the image of the industry, cost savings, time savings, enhancing safety, better time and cost predictability, improving quality, improving collaboration and communication, and a customer and end-user centric world view. Twenty-three (23) Construction 4.0 opportunities were identified in Nigeria; these were further grouped into six clusters: improved operational framework, improved innovativeness, improved safety practices, improved competitive edge, greater accuracy, and increased productivity (Aliu and Oke, 2023). Menegon Lopes and Silva Filho (2024) identified product benefits, operational benefits, and side benefits as opportunities in Construction 4.0 in Brazil.

3. Methods

This research employed a quantitative method, with primary data collected from participants via a questionnaire. The study aimed to gain insights into the status of Construction 4.0 in Eswatini by asking 'what' questions to assess the level of Construction 4.0 awareness and identify barriers and opportunities. This required the study to be descriptive (Leavy, 2023). Leavy (2023) mention that survey research is suitable for cross-sectional studies, which focus on a phenomenon at a particular time. This study was time-constrained and needed to focus on the then-current knowledge and status of the construction industry in Eswatini, further reinforcing the need for survey research.

4. Data Collection

Data collection techniques vary and are dependent on the research method, according to Saunders et al. (2019)Quantitative studies are conducted using questionnaire-based survey strategies. This study sourced data using a structured questionnaire survey that was created using Google Forms and distributed to seventy-six (76) Eswatini construction industry participants via LinkedIn. These were sampled using Krejcie and Morgan's table, with a population (N) of 95 LinkedIn connections. Thirty-seven (37) responses were achieved online, while fourteen (14) requested hard copies, resulting in a 67% response rate.

The questionnaire survey questions were divided into four sections: Section 1: general/background information; Construction 4.0 awareness; Construction 4.0 adoption barriers; and Construction 4.0 opportunities/benefits. The first section: general/ background information, extracted general participant information such as education, work experience, and company demographics using a list and categorical questions. The second section: Construction 4.0 awareness, assessed Construction 4.0 awareness and usage using various question types, including list, category, and five-point Likert scale questions. The third section, Construction 4.0 adoption barriers, evaluated these barriers using various question types, such as ranking and five-point Likert scales. Finally, the fourth section: Construction 4.0 adoption opportunities/benefits, evaluated the adoption benefits/opportunities using various question types, such as ranking and five-point Likert scales. The questionnaire survey questions were coded for quantitative analysis: list and categorical questions were assigned numbers, and five-point Likert scales were assigned values from 1 to 5 to facilitate analysis using IBM SPSS Statistics. Descriptive analysis was used across all four questionnaire sections, with tables, graphs, and charts used to report response counts, percentages, mean values, and standard deviations. Descriptive statistics were further compared for participants to understand the influence of company size on Construction 4.0 awareness and usage. The demographics section was analysed using counts and percentages, which were presented graphically in tables and charts. Construction 4.0 awareness and usage section was analysed using the mean where the extent of construction technology awareness and ranking was done according to the criterion: not aware/ never (1<=mean<1.5), slightly aware/ yearly (1.5<=mean<2.5), somewhat aware/ monthly (2.5<=mean<3.5), moderately aware/ weekly (3.5<=mean<4.5), and very aware/ daily (4.5>=mean). Construction 4.0 adoption barriers and benefits sections were also analysed using the mean where the extent of Construction 4.0 adoption barriers and benefits were categorised according to the criterion: strongly disagree (1<=mean<1.5), disagree (1.5<=mean<2.5), neither agree/ disagree (2.5<=mean<3.5), agree (3.5<=mean<4.5), and strongly agree (4.5>=mean). Additionally, the reliability of all Likert scale questions was assessed using Cronbach's Alpha coefficient, and all questions were consistent with coefficients greater than 0.7, as seen in Table 1.

Table 1. Reliability statistics for Likert scale questions

Construction 4.0 technology awareness		**Construction 4.0 technology usage**		**Construction 4.0 adoption barriers**		**Construction 4.0 adoption benefits**	
Cronbach's Alpha	No. of items	Cronbach's Alpha	No. of items	Cronbach's Alpha	No. of items	Cronbach's Alpha	No. of items
0.890	14	0.859	14	0.745	10	0.907	12

5. Results and Discussion

5.1 Numerical Results

5.1.1 Research participants and company profile

Table 2 shows a summary of the research participants and their company profiles. The most common qualification among participants was a diploma at 37%, followed by a bachelor's degree at 31%, an honors degree at 14%, a master's degree at 12%, and an associate degree at 6%. The leading job titles of the respondents were technicians

(31%) and engineers (22%), followed by quantity surveyors at 16%, other (i.e., Treatment plant operator) at 10%, project managers and architects at 6%, principal managers and land surveyors at 4%, and executive managers at 2%. The prevailing participants sector was Civil/ structural engineering firm (22%), followed by civil works contractor (18%), architectural firm (12%), building works contractor (10%), project management and quantity surveying firms each at (8%), MEP (6%), and land surveying firm (2%). Registration status analysis indicated 49% of the participants were not professionally registered, 35% were candidates, 14% were professionals, and 2% were registered outside the local regulatory council. 41% of participants had less than 4 years of work experience, 20% had 6 to 10 years, and 14% had 11 to 15 years. 10% of the participants reported 4 to 5 years of experience, 8% 16 to 20 years, and 8% more than 20 years. Most participants worked in HHohho (57%), followed by Manzini (22%), Lubombo (16%), and Shiselweni (6%). The company profile analysis indicates that most companies were long established with most having been operational for more than 20 years (33%), followed by those having been around for 6-10 years (20%), 11-15 years and 16-20 years each at 14%, 4-5 years (12%) and lastly those having been operational for less than 4 years (8%). The least response of 8% was captured from participants working in medium size companies of 100 to 199 people, the second least response of 10 % was from participants working in large companies of more than 199 people, the responses from participants working in micro size companies of less than 10 employees had similar responses to those of small companies of 10 to 99 employees each at 41%.

Table 2. Participants and company profile

Variable	Category	Count	%	Variable	Category	Count	%
Job tittle	Technician	16	31	Sector	Civil/ structural firm	11	22
	Engineer	11	22		Civil works contractor	9	18
	Quantity Surveyor	8	16		Other	8	16
	Other	5	10		Architectural firm	6	12
	Architect	3	6		Building Contractor	5	10
	Project manager	3	6		Quantity Surveying firm	4	8
	Land Surveyor	2	4		Project Management firm	4	8
	Principal manager	2	4		MEP	3	6
	Executive manager	1	2		Land surveying firm	1	2
Qualification (degree)	Diploma	19	37	Registration status	Unregistered	25	49
	Bachelors	16	31		Candidate	18	35
	Honor's	7	14		Professional	7	14
	Masters	6	12		Other	1	2
	Associate	3	6				
Work experience	<4 years	21	41	Years company operating	>20 years	17	33
	6-10 years	10	20		6-10 years	10	20
	11-15 years	7	14		11-15 years	7	14
	4-5 years	5	10		16-20 years	7	14
	16-20 years	4	8		4-5 years	6	12
	>20 years	4	8		<4 years	4	8
The region where most work is conducted	Hhohho	29	57	People employed	<10	21	41
	Manzini	11	22		10-99	21	41
	Lubombo	8	16		>199	5	10
	Shiselweni	3	6		100-199	4	8

5.1.2 Construction 4.0 awareness and usage

The results presented in Table 3 indicate that the overall Construction 4.0 awareness in Eswatini was at a moderate level with a mean score of 3.5. Similar awareness levels were observed by (Alaloul et al., 2020, Olatunde et al., 2023). Only three out of fourteen technologies had mean scores below average (2.31<=mean<=2.88). Participants had a high level of awareness of AI with a mean score of 4.51. Drones, 3D printing, robotics, cybersecurity, BIM, Prefabrication, IoT, and Cloud computing had mean scores between 3.5 and 4.5, which meant participants were moderately aware of them. Simulation, AR/VR, big data, and laser had mean scores between 2.5 and 3.5, which meant participants were somewhat aware of them. Finally, participants had a mean score of 2.31, indicating they were slightly aware of blockchain.

Table 3. Technology awareness

Technology	N	Mean	Std. Deviation	Awareness ranking
AI	51	4,51	0,834	1
Drones	51	4,25	0,796	2
3D printing	51	3,98	1,086	3
Robotics	51	3,96	0,999	4
Cybersecurity	51	3,82	1,053	5
BIM	51	3,73	1,313	6
Prefabrication	51	3,69	1,319	7
IoT	51	3,65	1,412	8
Cloud computing	51	3,53	1,391	9
Simulation	51	3,37	1,326	10
AR/ VR	51	3,18	1,396	11
Big data	51	2,88	1,306	12
Laser	51	2,80	1,371	13
Blockchain	51	2,31	1,334	14
Overall mean		3,55		

Table 4 The cross-tabulation analysis indicated that less experienced participants (<4 years) were more familiar with the terminology (Construction 4.0 = 18, Industry 4.0 in construction = 9, and 4IR = 12) than experienced participants. This may be due to experienced participants being older and not eager to embrace technology, as previously indicated by (Demirkesen and Tezel, 2022)This is evident from the two (2) experienced participants (one with 11-15 years and the other with >20 years' experience) who indicated that they were not familiar with any terminology.

Table 4. Construction 4.0 awareness according to work experience

Familiar Construction 4.0 terminology	Work experience in years					
	<4	4-5	6-10	11-15	16-20	>20
Construction 4.0	18	4	7	3	3	2
Industry 4.0 in construction	5	3	1	3	0	1
Fourth Industrial Revolution (4IR)	12	4	7	6	2	2
None	0	0	0	1	0	1

Analysis of familiar Construction 4.0 terminology by company size indicates that smaller companies were more familiar with it, as shown in Table 5. This observation is strongly influenced by the significant number of micro (41%) and small companies (41%) which make up the study population. Further analysis indicates that all participants in the medium- and large-company groups were familiar with the Construction 4.0 terminology. From this observation, it can be inferred that the company size does not influence Construction 4.0 awareness, as observed by (Menegon Lopes and Silva Filho, 2024).

Table 5. Construction 4.0 awareness according to company size

Familiar Construction 4.0 terminology	**Organisation size (no. of employees)**			
	<10	10-99	100-199	>199
Construction 4.0	18	14	2	3
Industry 4.0 in construction	9	3	1	0
Fourth Industrial Revolution (4IR)	13	13	2	5
None	1	1	0	0

Table 6 shows that the overall Construction 4.0 technology usage in Eswatini was at a low level, with a mean score of 2.08, which meant technologies were used yearly, (Menegon Lopes and Silva Filho, 2024) Also reported low technology usage. 93% of the technologies had mean scores below average (1.33<=mean<=2.96). Participants had a moderate level of usage for AI, with a mean score of 3.9, which meant the technology was used weekly. IoT and Cloud computing had mean scores of 2.5-3.5, indicating participants used them monthly. Simulation, BIM, cybersecurity, big data, AR/VR, Prefabrication, Drones, laser, and 3D printing had mean scores between 1.5 and 2.5, which meant participants used them yearly. Finally, robotics and blockchain had a mean score of less than 1. which meant most participants never used them.

Table 6. Technology usage

Technology	N	Mean	Std. Deviation	Usage ranking
AI	51	3,90	1,171	1
IoT	51	2,96	1,523	2
Cloud computing	51	2,94	1,515	3
Simulation	51	2,29	1,238	4
BIM	51	2,29	1,285	5
Cybersecurity	51	2,04	1,148	6
Big data	51	1,82	1,072	7
AR/ VR	51	1,71	1,026	8
Prefabrication	51	1,71	0,901	9
Drones	51	1,65	0,996	10
Laser	51	1,63	1,019	11
3D printing	51	1,53	1,007	12
Robotics	51	1,41	0,853	13

Technology	N	Mean	Std. Deviation	Usage ranking
Blockchain	51	1,24	0,551	14
Overall mean		2,08		

5.1.3 Construction 4.0 adoption barriers

Ten barriers were analysed, based on the mean score per barrier in Table 7**.** The overall mean of 3.47 suggests that participants perceive the Construction 4.0 adoption barriers as moderate. However, the analysis of each barrier indicates that the most significant barriers were high cost of technology, technological (connectivity, high computing requirements), resistance to change, and difficult implementation, with mean scores between 3.5 and 4.5. The least significant barriers were cybersecurity issues, lack of standards, lack of a tech-savvy labor force, threat of job losses, lack of R&D, and unclear benefits, with a mean of 2.5-3.5. (Olatunde et al., 2023, Menegon Lopes and Silva Filho, 2024) had similar observations, however, (Menegon Lopes and Silva Filho, 2024) found technological, cybersecurity issues, the threat of job losses, and the lack of standards to be less significant.

Table 7. Construction 4.0 technology adoption barriers mean scores and ranking

Barrier	**N**	**Mean**	**Std. Deviation**	**Barrier ranking**
High cost of technology	51	4,14	1,470	1
Technological	51	3,84	1,065	2
Resistance to change	51	3,76	1,012	3
Difficult to implement	51	3,63	1,019	4
Cybersecurity issues	51	3,43	1,315	5
Lack of standards	51	3,41	1,117	6
Lack of tech-savvy labor force	51	3,41	1,252	7
Threat of job losses	51	3,20	1,200	8
Lack of R&D	51	3,18	1,337	9
Unclear benefits	51	2,65	1,180	10
Overall mean		3,47		

5.1.4 Construction 4.0 adoption benefits

Twelve benefits were analysed, based on the mean score per benefit in Table 8. All but one of the benefits were significant, with mean scores ranging from 3.5 to 4.5, indicating that participants agreed they were benefits. Participants neither agreed nor disagreed that improved energy use was a Construction 4.0 adoption benefit, with a mean score of 3.06; this suggests participants associated Construction 4.0 with increased technology use that consumed more energy. The overall analysis of the benefits indicates they were perceived as significant, with a mean score of 3.72. Similar findings were observed by (Aliu and Oke, 2023, Alaloul et al., 2020) However, improved energy use was a moderate benefit.

Table 8. Construction 4.0 technology benefits mean scores and ranking

Benefit/ opportunity	N	Mean	Std. Deviation	Benefit ranking
Increased productivity	51	4,37	1,264	1
Improved quality	51	4,08	1,246	2
Improved resource planning	51	3,82	1,014	3
Reduced manual labor	51	3,78	1,172	4
Improved collaboration	51	3,78	1,026	5
Reduced project duration	51	3,71	1,082	6
Improved maintenance planning	51	3,69	1,049	7
New jobs to support computer scientists	51	3,67	1,108	8
Reduced redoing work	51	3,59	1,099	9
Cost savings	51	3,57	1,136	10
Increased safety	51	3,53	1,222	11
Improved energy use	51	3,06	1,121	12
Overall mean		3,72		

5.2 Graphical Results

This section presents graphical results on familiar Construction 4.0 terminologies to assess Construction 4.0 awareness. Also, the sources from which familiar terminologies were heard are presented in a bar chart. This strengthened the results for Construction 4.0 awareness.

5.2.1 Familiar Construction 4.0 terminologies

Participants were requested to select all terminologies they were familiar with; these included Construction 4.0, Industry 4.0 in construction, Fourth Industrial Revolution (4IR), and the non-optional. Figure 1 shows that 37 of the participants were aware of Construction 4.0, while 33 were aware of the fourth industrial revolution. The term with the least awareness was Industry 4.0 in construction, with a frequency of 13. Two (2) participants were unaware of any of the terminology. This shows that a significant portion of the respondents were familiar with Construction 4.0 and could give valuable insights into the topic, further strengthening the high level of awareness discussed in section 5.1.2.

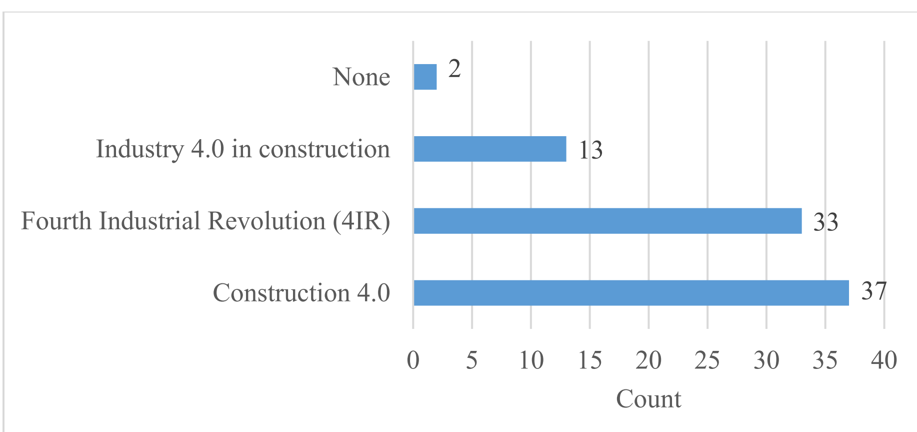

Figure 1. Familiar terminologies

5.2.2 Where have you heard of Construction 4.0 terminologies?

Participants were asked to select all options relevant to the terminologies they were familiar with, as reported by the source they heard about them. Participants were given 10 options, including one in which they had to specify other sources. A significant portion of the participants indicated that they were made aware of Construction 4.0 terminologies by the internet, followed by formal education and workplace, television and seminars, books, newspapers, magazines, radio, and other as demonstrated in Figure 2 showing the response frequencies where each participant was allowed to select more than one option.

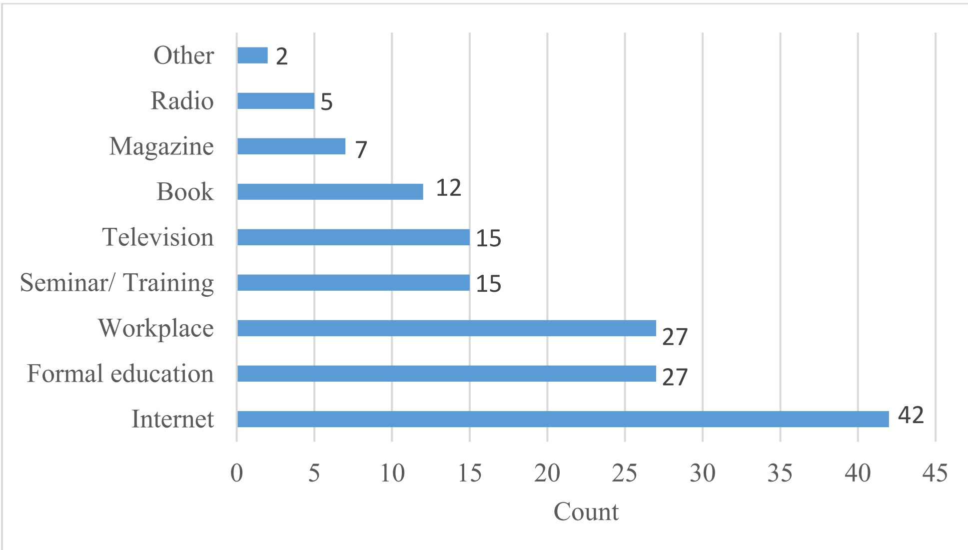

Figure 2. Sources of familiar terminology

5.3 Proposed Improvements

The research used a closed-ended questionnaire survey to source data from fifty-one (51) construction industry participants, who were LinkedIn connections. A high level of Construction 4.0 awareness but low usage was observed. Significant, moderate, and least significant barriers to the adoption of Construction 4.0 were identified. Lastly, the major benefits of Construction 4.0 adoption were identified. Future studies may improve results by increasing sample size and ensuring a representative sample of all construction industry players and regions, as this study included most participants from the consulting sector in the Hhohho and Manzini regions. Also, mixed methods approaches and open-ended interviews may yield more accurate results and reveal additional Construction 4.0 themes.

5.4 Validation

Validity is about the research's ability to produce relevant results by measuring what is intended to be measured, while reliability is about the research's ability to produce consistent results in similar conditions with the same or comparable population (Sreejesh et al., 2014). Validity was achieved by ensuring survey questions were derived from the reviewed literature. Reliability was ensured through pilot testing the questionnaire with five participants, who provided feedback on whether the questionnaire design was user-friendly, whether the questions were easily understood, and whether they were comfortable answering. Also, as Saunders et al. (2019) suggest, internal consistency of questions was measured using Cronbach's alpha, which assessed the consistency of responses to scaled questions. The alpha coefficient for each scaled question was reported; values between 0.7 and 1 indicated acceptable internal consistency, whereas values below 0.7 indicated inconsistent results and should be rejected or not used in the study.

6. Conclusion

The study aimed to assess the level of Construction 4.0 awareness, adoption barriers, and adoption benefits in Eswatini, a developing country in Southern Africa. Construction 4.0 awareness and usage levels were determined, and it was concluded that Eswatini construction participants were moderately aware of Construction 4.0; however, its usage was low. The low level of usage is attributed to the prevailing Construction 4.0 adoption barriers, including the high cost of implementation, technological challenges, resistance to change, and difficult implementation. It was also concluded that the most significant benefits of Construction 4.0 adoption were increased productivity, improved quality, improved resource planning, reduced manual labor, and improved collaboration. Less experienced participants were more aware of Construction 4.0 than their more experienced counterparts, while company size did not influence awareness of Construction 4.0. It can be concluded that younger construction participants are more knowledgeable about Construction 4.0 and more inclined to embrace it than older participants; moreover, the adoption of Construction 4.0 has equal potential across all company sizes. These findings are limited to the study area of Eswatini, specifically the Hhohho and Manzini regions, where most participants practiced. Generalizing the findings to other regions of the country or to other developing countries should be done with caution.

References

Alaloul, W. S., Liew, M. S., Zawawi, N. A. W. A. and Kennedy, I. B., industrial revolution 4.0 in the construction industry: challenges and opportunities for stakeholders, *Ain Shams Engineering Journal*, vol. 11, pp. 225–230, 2020. DOI: https://doi.org/10.1016/j.asej.2019.08.010

Aliu, J. and Oke, A. E., construction in the digital age: exploring the benefits of digital technologies, *Built Environment Project and Asset Management*, vol. 13, pp. 412–429, 2023. DOI: https://doi.org/10.1108/BEPAM-11-2022-0186

Brozovsky, J., Labonnote, N. and Vigren, O., digital technologies in architecture, engineering, and construction, *Automation in Construction*, vol. 158, article 105212, 2024. DOI: https://doi.org/10.1016/j.autcon.2023.105212

Chaaya, M. L., Sarkis, L. M. and Faham, T., integration of emerging technologies with construction practices in Australia, *Buildings*, vol. 15, p. 396, 2025. DOI: https://doi.org/10.3390/buildings15030396

Dallasega, P., Rauch, E. and Linder, C., industry 4.0 as an enabler of proximity for construction supply chains: a systematic literature review, *Computers in Industry*, vol. 99, pp. 205–225, 2018. DOI: https://doi.org/10.1016/j.compind.2018.02.004

Demirkesen, S. and Tezel, A., investigating major challenges for industry 4.0 adoption among construction companies, *Engineering, Construction and Architectural Management*, vol. 29, pp. 1470–1503, 2022. DOI: 10.1108/ECAM-12-2020-1059

Dhamak, P., Aital, P. and Daftardar, A., a comprehensive overview of construction 4.0 technologies and their implementation in the construction industry, *Journal of Science and Technology Policy Management*, 2025. DOI: https://doi.org/10.1108/JSTPM-02-2023-0025

Forcael, E., Ferrari, I., Opazo-Vega, A. and Pulido-Arcas, J. A., construction 4.0: a literature review, *Sustainability*, vol. 12, p. 9755, 2020. DOI: https://doi.org/10.3390/su12229755

Leavy, P. A., *research design: quantitative, qualitative, mixed methods, arts-based, and community-based participatory research approaches*, New York: The Guilford Press, 2023.

Maria, K., Daria, K. and Zuzana, S., impact of industry 4.0 platform on the formation of construction 4.0 concept: a literature review, *Sustainability*, vol. 13, p. 2683, 2021. DOI: https://doi.org/10.3390/su13052683

Menegon Lopes, J. and Silva Filho, L. C. P. D., adoption of fourth industrial revolution technologies in the construction sector: evidence from a questionnaire survey, *Buildings*, vol. 14, p. 2132, 2024. DOI: https://doi.org/10.3390/buildings14072132

Newman, C., Edwards, D., Martek, I., Lai, J., Thwala, W. D. and Rillie, I., industry 4.0 deployment in the construction industry: a bibliometric literature review and UK-based case study, *Smart and Sustainable Built Environment*, vol. 10, pp. 557–580, 2021. DOI: https://doi.org/10.1108/SASBE-02-2020-0016

Olatunde, N. A., Gento, A. M., Okorie, V. N., Oyewo, O. W., Mewomo, M. C. and Awodele, I. A., construction 4.0 technologies in a developing economy: awareness, adoption readiness and challenges, *Frontiers in Engineering and Built Environment*, vol. 3, pp. 108–121, 2023. DOI: https://doi.org/10.1108/FEBE-08-2022-0037

Osunsanmi, T. O., Aigbavboa, C. O., Emmanuel Oke, A. and Liphadzi, M., appraisal of stakeholders' willingness to adopt construction 4.0 technologies for construction projects, *Built Environment Project and Asset Management*, vol. 10, pp. 547–565, 2020. DOI: 10.1108/BEPAM-12-2018-0159

Saunders, M. N. K., Lewis, P., and Thornhill, A., *research methods for business students*, Pearson Education, New York, 2019.

Sawhney, A., Riley, M. and Irizarry, J., *construction 4.0: an innovation platform for the built environment*, Routledge, Abingdon, 2020.

Sherratt, F., Dowsett, R. and Sherratt, S., construction 4.0 and its potential impact on people working in the construction industry, *Proceedings of the ICE – Management, Procurement and Law*, vol. 173, pp. 145–152, 2020. DOI: 10.1680/jmapl.19.00053

Sreejesh, S., Mohapatra, S. and Anusree, M. R., *business research methods: an applied orientation*, Springer, Cham, 2014. DOI: https://doi.org/10.1007/978-3-319-00539-3

Statsenko, L., Samaraweera, A., Bakhshi, J. and Chileshe, N., construction 4.0 technologies and applications: a systematic literature review of trends and potential areas for development, *Construction Innovation*, vol. 23, pp. 961–993, 2023. DOI: https://doi.org/10.1108/CI-07-2021-0135

Wang, K., Guo, F., Zhang, C. and Schaefer, D., from industry 4.0 to construction 4.0: barriers to the digital transformation of engineering and construction sectors, *Engineering, Construction and Architectural Management*, vol. 31, pp. 136–158, 2024. DOI: 10.1108/ECAM-05-2022-0383

Biographies

Fisokuhle Ndlangamandla is a student enrolled in the Master of Engineering in Engineering Management program at the University of Johannesburg. He is a Civil and Structural Engineer from Eswatini with experience in industrial, commercial, and residential structural design. He holds a BEng (Hons) in Civil Engineering from the University of Johannesburg and works across structural analysis, detailing, and steel fabrication. He is proficient in Prokon, Tekla Structural Designer, AutoCAD, Revit, and Advance Steel, and has growing expertise in structural assessment and construction supervision.

Khaled Aboalez has been an NRF-C3-rated researcher since January 2020. He received his PhD degree from Mansoura University, Egypt, in 2011. He is a Professional Electrical Engineer (Pr.Eng.) registered with the Engineering Council of South Africa (ECSA). He has been an Associate Professor in the Postgraduate School of Engineering Management at the University of Johannesburg (UJ) since March 2024. He was a post-doc fellow at the National Hub for Energy Efficiency and Demand Side Management and the Center of New Energy Systems (CNES) at the University of Pretoria, South Africa (Mar. 2012 - Feb. 2013). He was also a postdoctoral fellow at the Center for Substation Automation and Energy Management Systems (CSAEMS) at the Cape Peninsula University of Technology (CPUT), South Africa (Mar. 2015 - Oct. 2016). Khaled was a senior lecturer at CPUT from January 2017 to September 2021. From October 2021 to February 2024, he was an Associate Professor of Electrical Power Systems and the head of the Center for Research in Power Systems at CPUT.