Construction Economics and Building

Vol. 25, No. 3/4
December 2025

Citation: Pittri, H., Agyekum, K., Salgin, B., Dompey, A. M. A., Gasue, R., Anderson, S. A. 2025. The Fourth Industrial Revolution Technologies and the Construction Industry in Ghana. *Construction Economics and Building*, 25:3/4, 231–253. https://doi.org/10.5130/AJCEB.v25i3/4.9408

ISSN 2204-9029 | Published by UTS ePRESS | https://epress.lib.uts.edu.au/journals/index.php/AJCEB

RESEARCH ARTICLE

The Fourth Industrial Revolution Technologies and the Construction Industry in Ghana

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DOI: https://doi.org/10.5130/AJCEB.v25i3/4.9408
Article History: Received 22/10/2024; Revised 30/05/2025; Accepted 03/07/2025; Published 05/12/2025

Abstract

Given the Ghanaian construction industry's continued reliance on conventional practices, understanding its readiness for digital transformation is essential to enhance productivity, efficiency, and competitiveness. This study investigates the level of awareness and extent of utilization of Industry 4.0 technologies within the Ghanaian construction industry (GCI). A quantitative approach was adopted using a structured questionnaire administered to 100 built environment professionals through convenience and snowball sampling. Descriptive and inferential statistical tools, including one-sample *t*-tests, independent samples *t*-tests, and analysis of variance (ANOVA), were used to analyze the data. The results revealed low overall awareness and utilization of Industry 4.0 technologies across the GCI. Drone technology showed the highest awareness and usage, while technologies such as 3D printing, artificial intelligence, and big data analytics recorded the lowest. Significant differences were observed in utilization based on respondents' awareness, profession, and years of experience. This study fills a critical gap by providing baseline data necessary for understanding the sector's digital maturity. The findings offer valuable insights for policymakers, industry stakeholders, and educators aiming to promote digital innovation. The study concludes that enhancing awareness through training, curriculum reforms, and supportive policies is vital for driving the digital transformation of the GCI.

DECLARATION OF CONFLICTING INTEREST The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. **FUNDING** The author(s) received no financial support for the research, authorship, and/or publication of this article.

Keywords

Industry 4.0 Technologies; Internet of Things; Building Information Modeling; Artificial Intelligence; Construction 4.0

Introduction

The fourth industrial revolution (4IR), also known as Industry 4.0, represents a paradigm shift in the integration of human, physical, and digital systems, unifying people, products, data, and machines to create smart, interconnected production environments. Unlike previous industrial revolutions, the pace of technological advancement under Industry 4.0 is unprecedented, reshaping everyday life and redefining how businesses operate across sectors (Bakar et al., 2024). From intelligent automation to real-time data analytics, this transformation is driving efficiency, customization, and innovation on a global scale (Aryal et al., 2023; Bakar et al., 2024).

The notion of "Construction 4.0" epitomizes the adoption of Industry 4.0 technologies in the construction industry, where information and digital technologies are revolutionizing decision-making and management processes. This transformation is primarily driven by the potential for improving project performance and management (Perrier et al., 2020). Embracing advanced manufacturing and digital technologies not only enhances construction quality but also increases productivity and safety. It has been established that Construction 4.0 plays a pivotal role in streamlining operations within the construction industry (Aryal et al., 2023). A wide range of Construction 4.0 technologies—such as augmented reality, laser scanning, Building Information Modeling (BIM), the Internet of Things (IoT), wearable sensors, and automated equipment—are transforming the construction industry (Forcael et al., 2020). For instance, IoT-based safety systems have been shown to reduce on-site safety costs by up to 78% compared to conventional methods (Chung et al., 2020), while additive manufacturing enhances both energy efficiency and occupant comfort in buildings (Pessoa et al., 2021). Despite these advantages, only 6% of architecture, engineering, and construction firms currently adopt these technologies in most developing countries, largely due to entrenched reliance on traditional practices (You and Feng, 2020; Begic and Galic, 2021).

Maisiri and Van Dyk (2019) postulated that although noticeable progress has been made in the use of Industry 4.0 technologies, systems, and processes in developed countries, there is uncertainty about the preparedness of businesses and industries in developing countries to adopt Industry 4.0, and Ghana is not an exception. Given that emerging markets like Ghana's can ill afford the inefficiencies often associated with traditional construction methods, leveraging Industry 4.0 technologies could usher in substantial improvements in both project quality and safety standards. Emerging research in nearby contexts, such as Nigeria, has shown that the awareness and implementation of Construction 4.0 technologies can significantly expedite construction processes and reduce costs, indicating a fruitful path for investigating similar technologies in Ghana (Opawole et al., 2022). Knowledge gained from examining successful case studies of technology utilization can be instrumental in breaking down the barriers identified in the Ghanaian construction industry (GCI), such as financial constraints and limited technological infrastructure (Bakar et al., 2024).

Oke et al. (2022) postulated that many construction practitioners are familiar with certain Industry 4.0 technologies but have not engaged with them effectively, which makes the evaluation of the level of awareness and understanding of such technologies among industry professionals crucial. This gap in utilization suggests a pressing need for further education and training tailored to Construction 4.0 technologies, which could potentially improve project outcomes in the GCI. Dosumu and Uwayo (2023) indicated that a lack of understanding regarding the impact of Construction 4.0 technologies, such as IoT, on construction processes significantly hampers their adoption in developing economies. Hence, assessing the level of awareness and utilization of Industry 4.0 tools can illuminate the critical factors that influence their uptake, thereby facilitating targeted interventions to overcome identified barriers (Ibrahim et al., 2024). The socio-economic implications of embracing Construction 4.0 technologies extend beyond the construction industry; they hold the potential to impact the broader economic growth of the nation. The integration of advanced technological systems contributes to the country's development goals by enhancing job creation, improving service delivery, and fostering innovation (Isayev, 2023). Thus, a comprehensive study on the awareness and utilization of these technologies is vital, as it can inform policymakers and industry leaders about the necessary steps to support the digital transition and ensure sustainable construction practices aligned with global standards.

The application of Industry 4.0 has not been adopted in many countries, especially developing economies; thus, studies on these technologies are narrow (Agyekum et al., 2018; Anitah et al., 2019; Manda and Dhaou, 2019). Despite the growing relevance of Industry 4.0, no empirical study has assessed the awareness and extent of its adoption within the GCI. Establishing baseline knowledge and utilization levels is essential for identifying critical gaps and informing targeted strategies to drive digital transformation. This study investigates the awareness and utilization of Construction 4.0 technologies within the GCI, offering insights to inform policy, research, and industry strategies for improved global competitiveness. Specifically, it addresses the following questions:

1. What is the level of awareness of Construction 4.0 technologies among construction professionals in the GCI?
2. To what extent are these technologies being utilized?

Literature review

INDUSTRY 4.0 TECHNOLOGIES AND THE CONSTRUCTION INDUSTRY

Since its inception in 2011, Industry 4.0 has garnered increasing scholarly attention, with research highlighting its transformative potential across industries (Liao et al., 2017; Culot et al., 2020). The construction sector, characterized by its complexity and socio-economic significance (Williams et al., 2020; Paliwal et al., 2021), faces persistent challenges in meeting infrastructure demands while addressing inefficiencies tied to conventional practices (Li et al., 2019). Industry 4.0 technologies, collectively termed Construction 4.0, offer solutions by enhancing design, safety, automation, and sustainability (Bai et al., 2020; Begic and Galic, 2021). The United Nations Environment Programme underscores its role in mitigating environmental impacts through reduced waste and optimized workflows (IEA, 2018). Schönbeck et al. (2020) classified Construction 4.0 technologies into three domains: information and communication (e.g., BIM, IoT, cloud computing, and mixed reality), automation [e.g., artificial intelligence (AI), drones, sensors, and radio-frequency identification (RFID)], and industrialization (e.g., robotics and 3D printing). The benefits of integrating these tools in construction processes and practices are well-documented. BIM combined with IoT creates digital twins for operational optimization (Shahzad et al., 2022), while AI and machine learning enhance scheduling, risk management, and data-driven decisions (Forcael et al., 2020; Abioye et al., 2021). Technologies like 3D printing and robotic systems offer automation, cost reduction, and safety improvements (Krupík, 2020; Tankova and da Silva, 2020). Augmented reality (AR) supports immersive safety training (Delgado et al., 2020; Babalola et al., 2023), and cloud computing facilitates scalable IT infrastructure with real-time data access, reducing costs and improving coordination (Lu and Cecil, 2016; Maqbool et al., 2023).

Similarly, IoT enables real-time communication between devices, enhancing operational efficiency through machine-to-machine and human-to-machine interactions (Patel and Patel, 2016; Rghioui and Oumnad, 2017). Autonomous robots accelerate processes, reduce errors, and improve collaboration (Jayani

Rajapathirana and Hui, 2018), while big data analytics enhances decision-making and performance by leveraging vast datasets from multiple construction inputs (Erboz, 2017; Wang and Hajli, 2017). RFID systems further optimize material tracking and supply chain logistics (Anitah et al., 2019).

Despite these opportunities, adoption remains limited in the construction sector due to cultural resistance, high costs, lack of expertise, and fragmented implementation strategies. A summary of some of the key Industry 4.0 technologies identified from the literature is presented in Table 1.

Table 1. Summary of Industry 4.0 technologies

No.	Industry 4.0 technologies	Source(s)
1	Big data analytics	Sisinni et al., 2018; Anitah et al., 2019; Culot et al., 2020; Dawood et al., 2022; Suleiman et al., 2022
2	Cloud computing	Sisinni et al., 2018; Culot et al., 2020; Schönbeck et al., 2020; Xu et al., 2021; Dawood et al., 2022; Suleiman et al., 2022
3	Augmented reality (AR)	Culot et al., 2020; Delgado et al., 2020; Schönbeck et al., 2020; Kazemzadeh et al., 2021; Xu et al., 2021; Dawood et al., 2022; Suleiman et al., 2022
4	Artificial intelligence (AI)	Dalenogare et al., 2018; Sisinni et al., 2018; Bai et al., 2020; Schönbeck et al., 2020
5	Building Information Modeling (BIM)	Maskuriy et al., 2019; Forcael et al., 2020; Schönbeck et al., 2020; Dawood et al., 2022
6	Robotics	Dalenogare et al., 2018; Bai et al., 2020; Xu et al., 2021
7	3D printing/additive manufacturing	Dalenogare et al., 2018; Bai et al., 2020; Krupík, 2020; Xu et al., 2021
8	Drone technologies	Dalenogare et al., 2018; Bai et al., 2020; Suleiman et al., 2022
9	Radio-frequency identification (RFID)	Dalenogare et al., 2018; Bai et al., 2020; Schönbeck et al., 2020
10	Internet of Things (IoT)	Culot et al., 2020; Forcael et al., 2020; Xu et al., 2021; Dawood et al., 2022; Suleiman et al., 2022

Source: Table created by authors.

AWARENESS OF INDUSTRY 4.0 TECHNOLOGIES IN THE CONSTRUCTION INDUSTRY

Research has linked numerous environmental and operational inefficiencies, such as global warming, pollution, excessive waste, project underperformance, and low labor productivity, to the persistent use of traditional construction methods (You and Feng, 2020; Pittri et al., 2025). These challenges have heightened global interest in digital solutions, thereby increasing awareness of Industry 4.0 technologies across various industrial sectors. Industry 4.0 has demonstrated transformative potential in enhancing operations in manufacturing, agriculture, international trade, and the built environment, including construction (Schwab and Davis, 2018; Bongomin et al., 2020). While sectors such as manufacturing and banking have integrated these technologies into their core operations (Oesterreich and Teuteberg, 2016), the construction industry is often characterized by slow technological uptake (Brous et al., 2020).

However, growing interest among construction professionals in adopting digital innovations suggests that a paradigm shift is underway (Kozlovska et al., 2021). Studies from countries such as Denmark, France, and South Korea have highlighted the practical applications of AI, additive manufacturing, and IoT in construction (Attoue et al., 2018; Jo et al., 2019; Tankova and da Silva, 2020). A comparative study in Malaysia identified weak Industry 4.0 exposure among recent graduates and uneven familiarity among practitioners, underscoring the urgent need for enhanced education and training (Adepoju and Aigbavboa, 2021; Zabidin et al., 2024). These deficiencies often stem from limited practical experience, which hampers the transition to digital construction practices and slows innovation (Zabidin et al., 2024). Opawole et al. (2022) emphasized that awareness of 4IR technologies in Nigeria remains low, with limited practical engagement. In Ghana, efforts to integrate BIM–AR and simulation tools are emerging (Addy et al., 2023; Koranteng et al., 2023), although awareness remains low compared to developed regions (Newman et al., 2021; Pittri et al., 2025). Agyekum et al. (2022a) concluded that the awareness of 4IR technologies for health and safety management remains low, even though professionals are aware of the benefits they present. Pittri et al. (2024a) added that 4IR, such as drone technologies, have proven benefits for health and safety management, but their awareness and adoption remain low in the GCI, underscoring the need for educational reforms, capacity building, and training to align with the demands of a rapidly evolving construction ecosystem.

UTILIZATION OF INDUSTRY 4.0 TECHNOLOGIES IN THE CONSTRUCTION INDUSTRY

Although awareness of 4IR is gradually improving, actual utilization in the construction industry, particularly in developing contexts, remains minimal. Despite growing recognition of the need for innovation, the actual utilization of Industry 4.0 technologies in the construction industry, such as BIM, IoT, and automation, remains limited (Ribeiro et al., 2022). This is largely due to entrenched reliance on traditional methods, high initial investment costs, lack of technical expertise, and resistance to change (Ribeiro et al., 2022). While the potential benefits of these technologies are well acknowledged, their operational application continues to lag, particularly in areas that could significantly improve project delivery, like IoT and data analytics (Zabidin et al., 2024). Moreover, skepticism over return on investment and the inertia of conventional practices persist, often undermining government-led digitalization initiatives and placing firms at a disadvantage in an increasingly competitive, tech-driven construction environment (Venter et al., 2021). Research has indicated that developed countries have made significant strides in implementing technologies such as robotics, AI, big data analytics, and cloud computing (Maisiri and Van Dyk, 2019; Dhamija, 2022). In contrast, many developing economies—including Ghana, Nigeria, South Africa, and Kenya—struggle with issues such as technological readiness, infrastructure, and workforce capability, which limit full-scale adoption (Müller et al., 2018; Anitah et al., 2019).

Case studies from Kenya have shown that the application of Industry 4.0 technologies improves demand forecasting and decision-making, yet adoption rates remain low due to limited awareness (Anitah et al., 2019). Similarly, in the GCI, the actual deployment of technologies like IoT, drones, and 3D printing is still in its infancy, hindered by financial constraints, limited technical skills, and resistance to change (Agyekum et al., 2022a; Pittri et al., 2024a). Gbolagade et al. (2022) emphasized that entrepreneurs who have embraced these technologies report significant performance improvements, reinforcing the need for broader industry-wide digital transition. To bridge the gap between awareness and practical application, stakeholders must invest in implementation frameworks, workforce upskilling, and supportive policy instruments to accelerate the integration of Industry 4.0 in construction (Maskuriy et al., 2019; Pittri et al., 2024a).

Methodology

SURVEY STRATEGY/APPROACH

This study examined the awareness and utilization of Construction 4.0 technologies within the GCI using a quantitative research approach. This methodology was appropriate, as it facilitated the use of structured questionnaires and statistical tools such as descriptive analysis and hypothesis testing to assess the relationships between key variables (Agyekum et al., 2022a). The questionnaire survey offered a systematic and efficient means of collecting data from a broad sample of construction professionals, enabling a comprehensive analysis of perceptions and practices. Furthermore, the structured nature of the survey supported the empirical testing of the study's hypotheses, as presented in the subsequent section.

SURVEY DESIGN AND ADMINISTRATION

Following a review of the pertinent literature, a questionnaire was prepared to gather data from construction professionals in the GCI. Prior to data collection, a two-stage pilot testing process was undertaken to ensure the validity and reliability of the questionnaire. Validity in this context refers to the extent to which the instrument accurately captures the constructs it is designed to measure (Agyekum et al., 2023a). This process was essential for enhancing the accuracy of the study's findings and the robustness of the conclusions drawn (Agyekum et al., 2022b). In the first stage, the questionnaire was reviewed by an expert in Industry 4.0 research to assess its content relevance and clarity. Following this, a pilot test was conducted with 10 purposively selected construction professionals from diverse built environment disciplines who possessed experience with Industry 4.0 technologies. Their feedback was instrumental in confirming the feasibility and comprehensibility of the questionnaire items, ensuring that the instrument was appropriately aligned with the study's objectives. After a few clarifications and grammatical corrections, both phases of piloting were approved. The respondents were given the final version of the questionnaires online using Google Forms. This form of data collection was deemed sufficient since, unlike other methods like face-to-face communication, it guarantees respondents' anonymity, and the respondents can complete the form at their convenience, reducing the need for scheduling meetings or face-to-face interviews. It is also more cost-effective and often comes with built-in data analysis tools that can help one quickly and easily generate reports and insights from the collected data (Agyekum et al., 2022a; Botchway et al., 2023a).

Respondents were required to reveal their background information in the first section of the questionnaire. This included their profession, years of experience, and the highest level of education. From the literature review and questionnaire piloting, 10 technologies under Industry 4.0 were revealed to be utilized in the GCI. In the second part of the survey, respondents were asked to rate their familiarity with these technologies on a 5-point Likert scale (1 = highly unaware, 2 = not aware, 3 = moderately aware, 4 = aware, and 5 = highly aware). Subsequently, the third section sought information on utilizing Industry 4.0 technologies in the GCI. Respondents were required to indicate their level of usage of the technologies on a 5-point Likert scale (1 = not used, 2 = least used, 3 = moderately used, 4 = used, and 5 = highly used).

The study's population was construction professionals working in various built environment organizations in Ghana, irrespective of their familiarity with Industry 4.0 technologies. Even though there was a recognized sampling frame for some of the construction professionals, such as architects and engineers, a sampling frame for construction managers and quantity surveyors was difficult to produce due to a lack of a database for these professionals (Kumah et al., 2022; Botchway et al., 2023b; Pittri et al., 2024b). Given the challenge of determining the actual sampling frame, compounded by their diverse occupational profiles, geographic dispersion, and time constraints, the sample size was determined using Cochran's formula, a method widely applied in research involving large or indeterminate populations. This approach has been adopted in similar regional studies (Oduro et al., 2024; Pittri et al., 2024a) to ensure statistical validity.

Based on a 95% confidence level, 10% margin of error, and a conservative population proportion of 0.5, the minimum required sample size was calculated to be approximately 96 using Equation 1:

$$n_0 = \frac{Z^2 . p . (1 - p)}{e^2} \qquad \text{Equation 1}$$

where n_0 is the minimum required sample size. Z is the Z-score, which corresponds to the desired confidence level. For a 95% confidence level, the Z-score is 1.96. P is the estimated proportion of the population that has the attribute of interest (usually set to 0.5, as this maximizes the sample size). 'e' is the margin of error set at 10% to ensure higher accuracy of the survey and study results.

A total of 100 responses were collected using convenience and snowball sampling techniques. Convenience sampling enabled access through established networks, while snowball sampling extended outreach to harder-to-reach professionals, mitigating coverage bias. Although these approaches may introduce selection bias, safeguards such as targeting a cross-section of roles (e.g., architects, engineers, and contractors), achieving geographic spread, and applying eligibility screening (minimum 1 year of experience) helped enhance representativeness and data quality. The large sample size further offsets limitations by capturing broader perspectives across the industry. Exploratory studies in the same jurisdiction have used a similar approach, as it is nearly impossible to list the actual number of participants in this population (Kissi et al., 2023; Oduro et al., 2024; Pittri et al., 2024a).

ANALYSES OF DATA

Following a thorough data assessment and verification for completeness in Microsoft Excel, the data were entered into IBM SPSS version 26 for statistical analysis. The data were retrieved, sorted, and coded systematically in preparation for analysis. The study employed a combination of descriptive and inferential statistical techniques to interpret the data. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarize the central tendencies and distribution of the responses. Mean score ranking provided insight into the awareness of the variables under investigation, while the standard deviation assessed the extent of variability in the responses. Inferential statistics, including one-sample *t*-tests, independent samples *t*-tests, and one-way ANOVA, were applied to examine differences in perceptions and usage levels of Industry 4.0 technologies among different respondent groups, thereby enabling robust statistical inferences.

The data's reliability (i.e., consistency of responses) from the filled-out questionnaires was assessed using Cronbach's alpha. The alpha values for the GCI's experts' knowledge of Industry 4.0 technologies and the level of usage of these technologies were 0.936 and 0.931, respectively, suggesting the reliability of the data for the analysis.

The one-sample *t*-test is a statistical hypothesis test used to determine whether the mean of a single sample significantly differs from a predefined reference value. In this study, the one-sample *t*-test was employed to evaluate whether the mean scores for the usage of various Industry 4.0 technologies differed significantly from a test value of 3.50, which was selected to represent the threshold for moderate usage on a 5-point Likert scale. This analysis aimed to determine whether the technologies were being used above, below, or at an average level by construction professionals. The hypotheses for the test were formulated as follows: the null hypothesis (H_{01}) posited that the sample mean is equal to the reference value (i.e., $\mu = 3.50$), indicating no significant difference in usage. The alternative hypothesis (H_1) suggested that the sample mean differs from 3.50, indicating a statistically significant deviation. The test was conducted at a 95% confidence level, with statistical significance established at $p < 0.05$. If the p-value was less than 0.05, H_0 was rejected in favor of H_1, indicating that the level of usage of a given technology was significantly different from the reference point. This analysis was crucial in identifying which Industry 4.0 technologies are underutilized or well-integrated in the GCI.

To assess differences in perceptions and usage patterns among groups of construction professionals, this study employed two key inferential statistical tools: the independent samples *t*-test and the one-way ANOVA. The independent samples *t*-test is used to compare the means of two independent groups to determine if a significant difference exists between them (Pittri et al., 2024b; Kotei-Martin et al., 2025). It was used in this study to evaluate whether there was a statistically significant difference in the level of Industry 4.0 technology utilization between respondents who reported awareness of the concept and those who did not (H_{02}: there is no significant difference in the utilization of Industry 4.0 technologies between professionals who are aware and those who are not aware of the concept).

The one-way ANOVA, in contrast, is a statistical technique used to compare the means of two or more independent groups to determine whether there are statistically significant differences among them (Agyekum et al., 2023b; Kent State University, 2024). In the context of this study, the one-way ANOVA was applied to examine whether respondents' professional background and years of experience significantly influenced their reported frequency of using Industry 4.0 technologies. This helped to identify whether particular demographic subgroups were more inclined to adopt these technologies, which has practical implications for training and policy targeting. Two hypotheses were set. (1) H_{03}: There is no significant difference in the utilization of Industry 4.0 technologies based on respondents' professional roles. (2) H_{04}: There is no significant difference in the utilization of Industry 4.0 technologies based on years of experience. Both tests were conducted at a 95% confidence level, with statistical significance determined at $p < 0.05$. These analyses were essential in uncovering the underlying factors influencing the uptake of Industry 4.0 technologies across different categories of construction professionals.

Results

DEMOGRAPHIC BACKGROUND

This section presents the demographic information of the respondents (Table 2). This section was expedient because the respondents' demographic frequency analysis clarifies the background history of the study's participants and formed the basis for the independent samples *t*-test and the one-way ANOVA. The respondents performed various professional roles, such as contractors (12%), construction managers (40%), quantity surveyors (36%), architects (4%), and engineers (8%). The qualifications of these professionals were in the order of Master of Philosophy (MPhil) (4%), Master of Science/Architecture (MSc/MArch) (64%), bachelor's degree holders (24%), and, lastly, Higher National Diploma (HND) holders (8%) in related disciplines. The work experience revealed that 28% of the professionals had between 1 and 5 years of work experience in their respective professions. 24% of the professionals had between 6 and 10 years of work experience, 4% had between 11 and 15 years of work experience, and 44% had more than 15 years of work experience in their respective professions.

AWARENESS LEVELS OF INDUSTRY 4.0 TECHNOLOGIES IN THE GHANAIAN CONSTRUCTION INDUSTRY

This objective aimed to assess respondents' level of awareness regarding the concept of Construction 4.0 and its technologies. Descriptive frequency analysis was conducted to determine the extent to which participants were familiar with the concept. The results, presented in Figure 1, revealed that only 40% of the respondents indicated awareness of the concept, while the majority—60%—reported no prior knowledge. These findings highlight a significant knowledge gap within the GCI, suggesting the need for increased sensitization and education on Construction 4.0 concept and its technologies.

Table 2. Demographic information

Demographic	Frequency	Percentage (%)
Profession		
Contractor	12	12
Construction manager	40	40
Quantity surveyor	36	36
Architect	4	4
Engineer	8	8
Total	100	100
Years of professional experience		
1–5 years	28	28
6–10 years	24	24
11–15 years	4	4
Over 15 years	44	44
Total	100	100
Educational level		
HND	8	8
BSc	24	24
MSc/MArch	64	64
MPhil	4	4
Total	100	100

Note(s): HND, Higher National Diploma.

Source: Table created by authors.

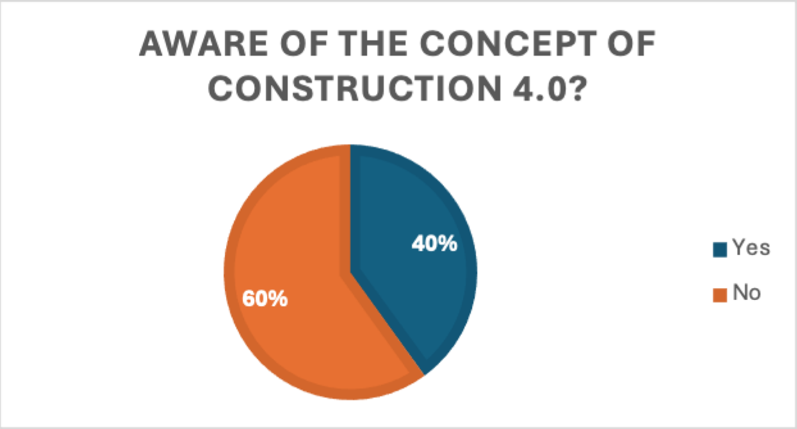

Figure 1. Awareness of the concept of Construction 4.0.

Source: Figure created by authors.

To further examine the level of awareness of the 10 Construction 4.0 technologies among professionals, a mean score ranking and a one-sample *t*-test were conducted. As shown in Table 3, drone technology emerged as the most familiar to respondents, with a mean score (MS) of 3.80 and a standard deviation (SD) of 1.449, indicating statistical significance ($p = 0.041$). This suggests that drone applications have gained some traction within the GCI, likely due to their increasing visibility in site surveying and monitoring. IoT and BIM followed, each with a mean score of 3.36, but statistically not significantly different from the stated mean of 3.5. While these results suggest moderate awareness, the mean values indicate that knowledge of these technologies is not yet widespread or deeply embedded in practice.

Table 3. Summary analyses of the awareness of Industry 4.0 technologies (mean score ranking and one-sample *t*-test)

Industry 4.0 technologies	T	Mean	Std. deviation	Rank	*p*-Value	Statically significant
Drone technologies	2.070	3.8000	1.44949	1	0.041[a]	Yes
IoT	−1.053	3.3600	1.32969	2	0.295	No
BIM	−1.008	3.3600	1.38914	3	0.316	No
Robotics	−2.360	3.1600	1.44054	4	0.020[a]	Yes
RFID	−2.895	3.1200	1.31257	5	0.005[a]	Yes
Cloud computing	−4.936	2.8400	1.32360	6	0.000[a]	Yes
AI	−5.804	2.8000	1.20605	7	0.000[a]	Yes
AR	−5.515	2.7600	1.34179	8	0.000[a]	Yes
3D printing/additive manufacturing	−6.853	2.6800	1.19663	9	0.000[a]	Yes
Big data	−6.190	2.6800	1.32482	10	0.000[a]	Yes

Note(s): IoT, Internet of Things; BIM, Building Information Modeling; RFID, radio-frequency identification; AI, artificial intelligence; AR, augmented reality.

[a] One-sample *t*-test result is significant at 0.05 significance level, *p*-value < 0.05 (two-tailed); Cronbach's alpha = 0.936, test value = 3.50.

Source: Table created by authors.

All other technologies assessed, including AI, big data, augmented reality, and robotics, recorded mean scores below 3.5, signifying limited awareness among construction professionals. This underscores a critical knowledge gap and the need for deliberate capacity-building initiatives, including continuous professional development, targeted training programs, and curriculum enhancements (Agyekum et al., 2022a; Kissi et al., 2023; Pittri et al., 2024a). The findings reveal a fragmented understanding of Construction 4.0 technologies, which may hinder their broader adoption and integration. Therefore, increasing industry-wide sensitization and strategic policy interventions are essential for accelerating digital transformation in the GCI (Agyekum et al., 2022a; Kissi et al., 2023; Pittri et al., 2025).

This finding aligns with those of Osunsanmi et al. (2018), who observed that awareness levels among construction professionals on emerging technologies remain suboptimal, largely due to limited understanding of the Industry 4.0 paradigm and insufficient investment in technological research and development (R&D). Similarly, Brous et al. (2020) emphasized that the potential benefits of emerging technologies are often under-communicated within the construction sector, leaving many professionals unaware of their practical applications for improving performance. Dalenogare et al. (2018) further argued that the sector's low innovation culture and inadequate R&D expenditure contribute significantly to professionals' limited knowledge of Construction 4.0 technologies. The absence of structured exposure to digital advancements hinders the industry's ability to adapt to evolving demands. As Maskuriy et al. (2019) contended, effective technology adoption is closely linked to iterative training and institutional support. Without targeted upskilling and knowledge dissemination, the transformative potential of Construction 4.0 technologies will remain largely unrealized, especially in resource-constrained construction environments such as Ghana.

UTILIZATION OF INDUSTRY 4.0 TECHNOLOGIES IN THE GHANAIAN CONSTRUCTION INDUSTRY

This section presents the results of the mean score ranking (MSR) and the one-sample *t*-test of the level of utilization of the Construction 4.0 technologies. As shown in Table 4, all technologies recorded negative *t*-values, indicating that their mean scores were significantly below the hypothesized benchmark of 3.5. This suggests that, overall, these technologies are infrequently used within the GCI. Drone technology (MS = 2.92, SD = 1.203, $p = 0.00$), the Internet of Things (MS = 2.88, SD = 1.513), and Building Information Modeling (MS = 2.64, SD = 1.202) emerged as the most utilized, albeit still under the threshold for moderate usage. Conversely, technologies such as RFID, artificial intelligence, big data analytics, cloud computing, robotics, and 3D printing recorded even lower mean scores, highlighting their minimal integration in practice in the GCI.

Table 4. Summary analyses of the utilization of Industry 4.0 technologies (mean score ranking and one-sample *t*-test)

Industry 4.0 technologies	T	Mean	Std. deviation	Rank	*p*-Value	Statically significant
Drone technologies	−4.820	2.92	1.203	1	0.000[a]	Yes
IoT	−4.098	2.88	1.513	2	0.000[a]	Yes
BIM	−7.155	2.64	1.202	3	0.000[a]	Yes
RFID	−7.447	2.40	1.477	4	0.000[a]	Yes
AI	−11.339	2.24	1.111	5	0.000[a]	Yes
Big data	−12.745	2.16	1.051	6	0.000[a]	Yes
Cloud computing	−15.116	2.08	0.939	7	0.000[a]	Yes
Robotics	−11.515	2.00	1.303	8	0.000[a]	Yes
AR	−14.755	1.96	1.043	9	0.000[a]	Yes
3D printing/additive manufacturing	−14.389	1.92	1.098	10	0.000[a]	Yes

Note(s): IoT, Internet of Things; BIM, Building Information Modeling; RFID, radio-frequency identification; AI, artificial intelligence; AR, augmented reality.

[a] One-sample *t*-test result is significant at 0.05 significance level, *p*-value < 0.05 (two-tailed); Cronbach's alpha = 0.931, test value = 3.50.

Source: Table created by authors.

These findings are consistent with those of Nnaji and Karakhan (2020), who argued that although Industry 4.0 technologies have garnered growing attention in construction discourse, their practical implementation remains at a nascent stage. Originally introduced to enhance efficiency, reduce costs, and improve quality in construction processes, these technologies have yet to be fully integrated into mainstream operations. Despite this, certain technologies such as drones, BIM, and IoT are beginning to gain traction in specific applications such as site surveying, design simulation, and basic data collection (Suleiman et al., 2022). However, their use remains fragmented and largely superficial, reinforcing the need for strategic efforts to improve awareness, provide hands-on training, and embed digital tools within core project workflows.

Maqbool et al. (2023) highlighted that despite the growing importance of smart technologies like IoT and BIM, their implementation in Ghana remains minimal due to inadequate skills, limited awareness, and resistance to change. Similarly, Kissi et al. (2023) noted that construction stakeholders in Ghana often encounter barriers such as high costs, lack of training, and poor infrastructure, which constrain the effective deployment of digital solutions like robotics, 3D printing, and cloud computing.

Pittri et al. (2024a) and Mustapha et al. (2024) added that Construction 4.0 technologies, such as unmanned aerial vehicles (UAVs), are still significantly underused for safety management and monitoring in Ghana, primarily due to technical limitations, lack of policy support, and insufficient industry training. The findings of this study highlight a higher awareness level of UAVs, indicating that although the awareness of UAVs/drones may be growing, practical implementation across firms remains fragmented.

Similarly, in Nigeria, Opawole et al. (2022) found low adoption of 3D printing, attributing it to high initial investment, limited practical exposure, and a weak innovation culture—barriers equally relevant to the GCI. Overall, the low utilization rates confirm a pressing need for strategic investment in skills development, regulatory frameworks, and infrastructure to facilitate meaningful adoption of Construction 4.0 technologies in Ghana.

INDEPENDENT SAMPLES *T*-TEST FOR THE LEVEL OF UTILIZATION OF INDUSTRY 4.0 TECHNOLOGIES

Statistical differences in the utilization of Construction 4.0 technologies based on respondents' awareness were examined using the independent samples t-test. As shown in Table 5, significant differences ($p < 0.05$) were found in the usage of nine out of the 10 technologies, indicating that low utilization of Construction 4.0 technologies in the GCI is largely driven by limited awareness. Robotics was the only exception, suggesting that its low adoption may be attributed to other barriers such as high costs and technical complexity. These findings support the assertions of Newman et al. (2021) and Müller et al. (2018), who noted that while Construction 4.0 research is emerging, its practical application in developing contexts remains limited. The results underscore the critical role of awareness in driving adoption and highlight the need for strategic interventions, such as curriculum reforms, targeted training, and innovation-friendly environments, to foster technological readiness in the GCI (Maskuriy et al., 2019).

ONE-WAY ANOVA FOR THE LEVEL OF UTILIZATION OF INDUSTRY 4.0 TECHNOLOGIES

Statistically significant differences in the means of the level of utilization of the Industry 4.0 technologies in the GCI were assessed under this section based on the profession (categorized as contractors, construction managers, architects, quantity surveyors, and engineers) and experience (i.e., 1–5, 6–10, 11–15, and over 15 years) of the respondents. This was carried out using one-way ANOVA statistics as presented in Tables 6 and 7. The results based on both the profession and experience of respondents revealed that there were significant differences in the views of the construction professionals. All the Industry 4.0 technologies emerged as significantly different among the groups [p (two-tailed) ≤ 0.05]. This indicates that the

Table 5. Independent samples *t*-test for differences in utilization of Industry 4.0 technologies based on awareness

					Independent samples t-test						
										95% confidence interval of the difference	
Industry 4.0 technologies	Awareness of IR 4.0 technologies	N	Mean	Std. dev.	*t*	df	*p* (two-tailed)	Mean difference	Std. error difference	Lower	Upper
Big data	Yes	40	2.700	1.114	4.601	98	0.000*	0.900	0.195	0.51181	1.28819
	No	60	1.800	0.840							
Cloud computing	Yes	40	2.700	0.911	6.378	98	0.000*	1.033	0.162	0.71183	1.35484
	No	60	1.667	0.705							
AR	Yes	40	2.600	1.033	5.764	98	0.000*	1.067	0.185	0.69946	1.43388
	No	60	1.533	0.812							
AI	Yes	40	2.700	1.114	3.576	98	0.001*	0.767	0.214	0.34116	1.19217
	No	60	1.933	1.006							
BIM	Yes	40	3.300	1.114	4.996	98	0.000*	1.100	0.220	0.66310	1.53690
	No	60	2.200	1.054							
Robotics	Yes	40	2.200	1.181	1.257	98	0.212	0.333	0.265	−0.19281	.85948
	No	60	1.867	1.371							
3D printing/ additive manufacturing	Yes	40	2.200	1.091	2.118	98	0.037*	0.467	0.220	0.02952	.90382
	No	60	1.733	1.071							
Drone technologies	Yes	40	3.500	1.132	4.263	98	0.000*	0.967	0.227	0.51668	1.41665
	No	60	2.533	1.096							
RFID	Yes	40	2.800	1.488	2.256	98	0.026*	.0667	0.295	0.08032	1.25301
	No	60	2.133	1.420							
IoT	Yes	40	3.500	1.450	3.535	98	0.001*	1.033	0.292	0.45330	1.61336
	No	60	2.467	1.420							

Note(s): AR, augmented reality; AI, artificial intelligence; BIM, Building Information Modeling; RFID, radio-frequency identification; IoT, Internet of Things.

*Independent samples *t*-test result is significant at 0.05 significance level, *p*-value < 0.05 (two-tailed).

Source: Table created by authors.

professional roles and experience of the respondents influence the utilization of Industry 4.0 technologies in the GCI.

Studies have shown that professionals, such as architects and engineers, who typically possess specialized training and technological competence, are more likely to integrate digital tools into their workflows (Nnadi and Akabudike, 2024). Nguyen et al. (2023) emphasized that practitioner expertise directly impacts risk perception and willingness to adopt innovation. While experience can enhance decision-making, it does not always equate to proficiency with emerging technologies, particularly in contexts where digital tools are still

Table 6. One-way ANOVA test for the profession of respondents

Industry 4.0 technologies	Comparison	Sum of squares	df	Mean square	F	Sig.
Big data	Between groups	65.173	4	16.293	34.967	0.000
	Within groups	44.267	95	0.466		
	Total	109.440	99			
Cloud computing	Between groups	34.471	4	8.618	15.479	0.000
	Within groups	52.889	95	0.557		
	Total	87.360	99			
AR	Between groups	55.218	4	13.804	24.921	0.000
	Within groups	52.622	95	0.554		
	Total	107.840	99			
AI	Between groups	40.640	4	10.160	11.828	0.000
	Within groups	81.600	95	0.859		
	Total	122.240	99			
BIM	Between groups	50.551	4	12.638	12.981	0.000
	Within groups	92.489	95	0.974		
	Total	143.040	99			
Robotics	Between groups	116.933	4	29.233	54.383	0.000
	Within groups	51.067	95	0.538		
	Total	168.000	99			
3D printing/ additive manufacturing	Between groups	68.960	4	17.240	32.496	0.000
	Within groups	50.400	95	0.531		
	Total	119.360	99			
Drone technologies	Between groups	27.093	4	6.773	5.534	0.000
	Within groups	116.267	95	1.224		
	Total	143.360	99			
RFID	Between groups	67.378	4	16.844	10.767	0.000
	Within groups	148.622	95	1.564		
	Total	216.000	99			
IoT	Between groups	97.271	4	24.318	17.868	0.000
	Within groups	129.289	95	1.361		
	Total	226.560	99			

Note(s): AR, augmented reality; AI, artificial intelligence; BIM, Building Information Modeling; RFID, radio-frequency identification; IoT, Internet of Things.

Source: Table created by authors.

Table 7. One-way ANOVA test for years of experience in the role

Industry 4.0 technologies	Comparison	Sum of squares	df	Mean square	F	Sig.
Big data	Between groups	12.470	3	4.157	4.115	0.009
	Within groups	96.970	96	1.010		
	Total	109.440	99			
Cloud computing	Between groups	7.767	3	2.589	3.123	0.029
	Within groups	79.593	96	0.829		
	Total	87.360	99			
AR	Between groups	13.113	3	4.371	4.430	0.006
	Within groups	94.727	96	0.987		
	Total	107.840	99			
AI	Between groups	20.413	3	6.804	6.415	0.001
	Within groups	101.827	96	1.061		
	Total	122.240	99			
BIM	Between groups	39.066	3	13.022	12.023	0.000
	Within groups	103.974	96	1.083		
	Total	143.040	99			
Robotics	Between groups	16.485	3	5.495	3.482	0.019
	Within groups	151.515	96	1.578		
	Total	168.000	99			
3D printing/ additive manufacturing	Between groups	19.689	3	6.563	6.321	0.001
	Within groups	99.671	96	1.038		
	Total	119.360	99			
Drone technologies	Between groups	27.750	3	9.250	7.681	0.000
	Within groups	115.610	96	1.204		
	Total	143.360	99			
RFID	Between groups	24.511	3	8.170	4.096	0.009
	Within groups	191.489	96	1.995		
	Total	216.000	99			
IoT	Between groups	38.785	3	12.928	6.610	0.000
	Within groups	187.775	96	1.956		
	Total	226.560	99			

Note(s): AR, augmented reality; AI, artificial intelligence; BIM, Building Information Modeling; RFID, radio-frequency identification; IoT, Internet of Things.

Source: Table created by authors.

evolving (Nguyen et al., 2023). Gong et al. (2024) further highlighted that organizational size and employee experience levels are critical to technology uptake, especially for complex systems like big data. Additionally, professionals aligned with sustainability goals tend to adopt innovative tools more readily, whereas resistance often stems from rigid traditional practices (Wafai and Aouad, 2023).

Conclusions

This study aimed to assess the awareness and utilization of Industry 4.0 technologies within the GCI, focusing on how professional role, experience, and awareness levels influence adoption. Drawing on data from 100 construction professionals, the findings revealed a generally low level of awareness and utilization, with drone technology emerging as the most recognized and moderately used tool, while technologies such as AR, robotics, and 3D printing showed the least usage. One-sample *t*-tests confirmed that the mean utilization scores for all technologies fell significantly below the expected threshold. Furthermore, independent samples *t*-tests and one-way ANOVA demonstrated that awareness, profession, and experience significantly influenced usage patterns. These results suggest that adoption remains limited, not due to a lack of access alone but because of gaps in the training, exposure, and role-specific applicability of these technologies within the GCI. Table 8 provides a summary of the study's hypotheses, the statistical tests employed, and the corresponding decisions regarding their acceptance or rejection based on the analysis results.

Table 8. Summary of hypotheses and their acceptance/rejection

Hypothesis	Statistical test	Result	Decision
H_{01}: The mean level of utilization of each Industry 4.0 technology is equal to the hypothesized mean value (3.5)	One-sample *t*-test	$p < 0.05$ for 8 out of 10 technologies	**Reject H_{01}**
H_{02}: There is no significant difference in the utilization of Industry 4.0 technologies between professionals who are aware and those who are not aware of the concept	Independent samples *t*-test	$p < 0.05$ for 9 out of 10 technologies	**Reject H_{02}**
H_{03}: There is no significant difference in the utilization of Industry 4.0 technologies based on respondents' professional roles	One-way ANOVA	$p < 0.05$ for all technologies	**Reject H_{03}**
H_{04}: There is no significant difference in the utilization of Industry 4.0 technologies based on years of experience	One-way ANOVA	$p < 0.05$ for all technologies	**Reject H_{04}**

Source: Table created by authors.

PRACTICAL IMPLICATIONS

The study highlights an urgent need for targeted interventions to drive digital transformation in the GCI. Industry practitioners should collaborate with academic institutions to develop continuous professional development programs tailored to different roles within the industry. Construction firms must also invest in onboarding and upskilling initiatives to bridge technological gaps, particularly in underutilized areas such as AI, AR, and big data. Policymakers are encouraged to provide incentive frameworks such as tax reliefs or grants to support digital innovation adoption, especially among small and medium-sized enterprise. Furthermore, integrating Construction 4.0 technologies into university curricula will equip future professionals with the skills needed for a tech-driven construction landscape. Construction firms are recommended to improve the integration of Industry 4.0 technologies in their operations by developing a new or updated Industry 4.0 implementation plan and communicating the information to employees to improve their readiness for the change.

THEORETICAL IMPLICATIONS

This study contributes to the growing body of literature on Construction 4.0 by providing empirical evidence from a developing country context. It reinforces the argument that awareness and professional characteristics are critical determinants of technology adoption. The results support further theory-building around technology acceptance and digital readiness frameworks in low-resource settings.

LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

A key limitation of this study is its reliance on non-probabilistic sampling, which may limit the generalizability of the findings. While steps were taken to ensure diversity in roles and regional representation, future studies should consider stratified or random sampling techniques where feasible. Additionally, the study adopted a descriptive and comparative statistical approach using *t*-tests and ANOVA, which, although appropriate for identifying group differences, did not model causal relationships. Future research could employ Structural Equation Modeling (SEM) to examine the structural relationships between awareness, perceived benefits, organizational factors, and technology utilization. Longitudinal studies are also recommended to capture changes in adoption patterns over time as digital infrastructure and training improve in the GCI.

The study relied solely on quantitative data, which, while effective for identifying patterns and group differences, does not capture the nuanced, context-specific barriers and motivations influencing technology adoption. The absence of qualitative insights restricts a deeper understanding of organizational culture, behavioral resistance, and structural limitations. Future research should consider adopting a mixed-methods approach, incorporating interviews or focus groups to explore subjective experiences, perceptions, and institutional barriers to adoption. Expanding the research to other developing countries would also support comparative analysis and strengthen the global discourse on Construction 4.0 adoption in low-resource settings.

Additionally, the study focused on only 10 commonly cited Industry 4.0 technologies, potentially overlooking emerging or context-specific innovations; future research could expand the scope to include a broader and evolving set of technologies relevant to diverse construction environments.

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