
| RESEARCH ARTICLE

Investigation of Efficiency Improvements in Large-scale Infrastructure Projects in Ghana through Construction 4.0 Technologies

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| ABSTRACT

This study investigates the efficiency improvements in large-scale infrastructure projects in Ghana through construction 4.0 technologies. Ghana's construction industry, while crucial for economic development, faces significant hurdles in project efficiency. Traditional practices often result in delays, budget overruns, and subpar outcomes. This research explores how C4.0 technologies, encompassing the Internet of Things (IoT), Building Information Modelling (BIM), augmented reality (AR), and other advanced digital tools, can revolutionize the sector. Employing a mixed-methods approach, the study surveyed 120 participants from government agencies, construction firms, technology providers, and consultants. Data collection involved both structured and semi-structured questionnaires administered via Google Forms. Quantitative data was analysed statistically, while qualitative data underwent thematic analysis. Findings reveal a largely positive perception of C4.0's efficiency-boosting potential, with respondents anticipating significant time savings (21-30%). However, the study also highlights critical areas for improvement, such as inter-stakeholder communication and cost management. The study concludes by recommending that Ghanaian construction firms adopt and integrate C4.0 technologies, supported by pilot projects and collaboration with technology providers. The findings of this study can inform policymakers, industry stakeholders, and other decision-makers on the importance of supporting the integration of Construction 4.0 technologies in the Ghanaian construction sector. This can lead to the development of supportive policies, incentives, and initiatives that facilitate technology adoption and drive sector-wide transformation.

| KEYWORDS

Construction 4.0, Internet of Things, Artificial Intelligence, Virtual Reality, Construction industry.

| ARTICLE INFORMATION

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1. Introduction

The construction industry is constantly evolving, with the emergence of Construction 4.0 technologies changing the way large-scale infrastructure projects are planned, designed, and executed. The term Construction 4.0 (C4.0) is drawn out from the Industry 4.0 (I4.0) concept, which refers to the fourth industrial revolution linked to digitisation and automation of the manufacturing environment (Oesterreich and Teuteberg, 2016). It can also be referred to as Digital construction. Construction 4.0 (C4.0) refers to the next-generation digital transformation of the construction sector using disruptive technologies such as the Internet of Things (IoT), mobile and cloud computing, autonomous equipment, 5D building information modelling (BIM), augmented reality (AR), etc. The integration of these technologies into the construction industry can offer a remarkable benefit. However, according to Maqbool et al.2023, the process of digitizing construction using these innovative technologies is not automatic or guaranteed. Notably, in developing countries or emerging markets, complex issues abound in the unique situations and

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characteristics of large-scale infrastructure projects in such economies. These can act as barriers, thereby complicating the process. Findings indicate that some of the most significant challenges in implementing C4.0 technologies (C4.0Ts) are the lack of confidence in uncertain returns on investments, challenges to the traditional roles and activities of financiers and contractors, and the fact that the low-cost strategy of most contractors often conflicts with labour market regulations. It, therefore, required that some measures be put in place to harness perceived opportunities and address the challenges associated with implementing C4.0 technologies in large-scale infrastructure projects in African countries, particularly Ghana. (Ametepey et al., 2022; Seidu et al.2023).

As Ghana seeks to strengthen its infrastructure to support economic growth and development, it is crucial to assess how these advanced technologies can be effectively integrated into the construction processes. This study will provide an overview of the integration of Construction 4.0 technologies in the context of Ghana. The study will investigate the significance of Construction 4.0 technologies in improving project efficiency in large-scale infrastructure projects. The outcome of this study can shed light on how advanced technologies can enhance project delivery, efficiency, and quality. This, in turn, can contribute to economic growth by reducing project costs, accelerating timelines, and improving overall performance in the construction sector.

2. Literature Review

2.1 Theoretical background

Statsenko et al. 2022 established the fact that Industry 4.0 (I4.0) originated from Germany. The basic focus was on digital manufacturing, digitalisation, and interconnectivity value chains and businesses. This concept I4.0 aged in the manufacturing sector, and it became a de facto foundation of digital innovations that drove the transformation of business models in the comprehensive economy and transformed the delivery of products and services. The basis of I4.0 is moulded by interconnected, self-optimising production systems that can work in real-time (Aichholzer et al.,2015). I4.0 has brought about a new industrial generation driven by the integration of manufacturing and operations with information and communication technologies (ICT) to enable semi-autonomous smart factories with digitised operations and supply chain, the interconnectivity of people, processes, and technology, and decision-making driven by the near real-time data acquisition and transfer (Dalenogare et al.,2018).

The industrial transformation was easy through the adoption of ICT in industrial environments and the affordability of sensors due to the abundance of technologies and data management frameworks (Statsenko et al. 2022). The real-time data collection and processing, together with interconnectivity, empowered the application of artificial intelligence (AI) and rapid decision-making that creates the ability of the operations supply chains to quickly adapt to changes in the external environment (Hecklau et al., 2016). I4.0 technologies promote operational efficiencies, innovations, customisation, and agility (Liao et al., 2017; Statsenko et al., 2022). For example, additive manufacturing or 3D printing enables prototyping and experimenting with designs at lower costs. Smart technologies allow for digital-physical integration, where better and more holistic decisions can be made (Ghobakhloo, 2018).

Several key technology domains have been explored for implementing I4.0 across various industrial contexts (Moosavi et al.,2021). Those include Cyber-Physical Systems (CPS) and Embedded systems; Internet of Things (IoT) and Internet of Services (IoS); Radio-Frequency Identification (RFID); Robotics; Big Data; Cloud Computing; Simulation and Modelling; Smart Factory; Human-Computer-Interaction (HCI); Modularisation; Product-Lifecycle-Management (PLM); AugmentedReality (AR)/Virtual Reality (VR)/Mixed Reality (MR); 3 D-Printing/Additive Manufacturing; Mobile Computing, and Social Media. These key technologies were elaborated in the nine I4.0 technology domains by Alcacer and Cruz-Machado (2019)

Table 1. The definitions of the I4.0 technology domains (Source: Adopted from Statsenko et al. 2022)

S/N	TECHNOLOGY DOMAINS	DEFINITION
1	The Industrial Internet of Things (IIoT) platforms	A “group of infrastructures, interconnecting connected objects and allowing their management, data mining and the access to data they generate” where connected objects are “sensor(s) and/or actuator(s) carrying out a specific function that are able to communicate with other equipment
2	Cloud computing/the cloud	I4.0 technology for companies practicing IT outsourcing resources and (SMEs) can use Cloud Computing with the purpose of pooling resource to obtain flexible, measured on demand self-service
3	Horizontal and vertical system integration	Horizontal integration is referred to as the inter-company integration underpinning collaboration among value chain participating companies around the product lifecycle; whereas vertical integration assumes integration across operational layers within the company and enables collaboration and information exchange within the organisational hierarchy, corporate planning, production, scheduling or management
4	Big Data Analytics and Advanced Algorithms	Described as “large volumes of high velocity, complex and variable data requiring advanced techniques and techniques to enable the capture, storage, distribution, management and analysis of the information” The key value add from Big Data is the analytics. Big Data Analytics allows supporting decision makers to solve operational problems in near real time related to production activities within the entire product lifecycle. Artificial Intelligence (AI) falls into this domain, representing a range of advanced Data Analytics techniques
5	Simulation	An essential technology to model the dynamics of business. This enables the tackling of the system complexity and uncertain problems that cannot be easily resolved by means of analytical and mathematical models and systems
6	Additive manufacturing/3D printing	A technology that allows fabrication of components in a layer wise way from a digital file. Additive manufacturing further represents a set of technologies that enables “3 D printing” of physical objects
7	Augmented reality (AR)	AR is an IoT technology that enables the integration of digital information with the user’s environment in real time. AR increases operator’s reality perception by overlaying digital information over the objects observed by the operator in the surrounding environment
8	Autonomous robotics:	Considered as a paradigm shift from mass production towards product customisation increased the demand for industrial robots as a reconfigurable automation technology. For example, adaptive intelligent robots enable bespoke products manufacturing at low cost
9	Cybersecurity:	IoT enabling interconnected virtual environments, remote access, cloud data storages and software services create manifold vulnerabilities that can be targeted to compromise sensitive information. The role of cybersecurity has increased dramatically. Cybersecurity (CS) is a technology focused on

		protecting, detecting and responding to attacks to ensure a high level of information security. This includes authentication and Fraud Detection.
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2.2 Construction 4.0 technologies

All over the world, the construction industry is an important contributor to economic growth and development (Sanni-Anibire et al., 2022). It is also an important vehicle for translating macroeconomic growth into sustainable poverty reduction in many low and middle-income countries (LMICs). In the words of Mwanza et al., 2023, it is, however, one of the few sections remaining of the economy which has been largely resistant to digitalisation and other forms of economic transformation. A range of literature has linked the reversal of construction productivity to inefficiencies in organizations and the maturation of construction as an industry, which has delayed serious digitization and transformation. In spite of the rising importance and adoption rates of Information and Communication Technologies (ICTs) across different industries, the construction industry lags behind many others in terms of both the adoption of ICT and improving efficiency through digitization and other processes. (Kissi et al., 2023) (Maqbool et al., 2023). In recent years, a range of 4th industrial revolution (4IR) or Industry 4.0 technologies have been identified and, increasingly, are being adopted by construction research communities worldwide to improve efficiency (Sawhney et al.2020).

Lekan et al. 2020, simplified the term Construction 4.0 as the application of technologies, such as social media, mobility, analytics, cloud [SMAC], robotics, artificial intelligence, augmented knowledge, and virtual reality, in expressing construction phenomenon and new areas of practice.

The various digital technologies and their interaction with each other are the key drivers of construction 4.0. Research has identified that both the integration of technologies and concepts from various sectors, as well as specialized industry technologies, serve as significant catalysts for advancement. Building Information Modelling (BIM) occupies a pivotal role and has become essential for the construction industry's transition toward creating digital twins (Boton et al., 2020; Winfield, 2020). Existing literature has examined the application of various technologies, often in conjunction with BIM. Notable examples include Virtual and Augmented Reality, Unmanned Aerial Vehicle (UAV) systems, the Internet of Things (IoT), Blockchain, additive manufacturing, laser scanning technologies, and Radio Frequency Identification (RFID) (Forcael et al., 2020). These technologies have been further enhanced by Artificial Intelligence (AI), Machine Learning (ML), Big Data Analytics, and Cloud Computing. Systematic reviews in the context of Construction 4.0 (Boton et al., 2020; Kozlovskaja et al., 2021) emphasize the foundational role of BIM, which is typically augmented by applications such as AR/VR, RFID, and other digital technologies.

3. Methodology

3.1 Research design

A survey study was deemed appropriate for this research for three reasons: Survey research involves data collection from construction professionals, generalizing the result of the study to envisage the attitude of the population of interest. In that same manner, survey questionnaires were designed to draw information from the population of interest in a systematic and impartial manner; the questionnaires allowed statistical analysis of data and generalisation of the results to a larger population.

3.2 Population

The population for this study comprised stakeholders involved in large-scale infrastructure projects in Ghana. A stakeholder, as defined by the Project Management Institute (2021), is any person, group, or organisation who can be positively or negatively impacted by or cause an impact on the actions or activities proposed. In the construction industry, the checklist for stakeholders is often huge. Each of them, however, can influence the course of the project at some time. Within this context, the participants of this study were namely: government agencies, construction firms, technology providers, and consultants. By the nature of the landscape of the industry, the Population is not known.

3.3 Sample and sampling technique

This study adopted a combination of purposive and stratified sampling techniques. The method of purposive sampling was used to develop the research sample under discussion. According to this method, which belongs to non-probability sampling techniques, sample members are selected based on their knowledge, relationships, and expertise regarding a research subject (Freedman et al., 2007). According to Parker et al. (2019), purposive sampling is closely associated with qualitative research, aiming to gather information about a population by observing a small portion of it. To select a sample, all sampling units must be compiled to create an accurate sample frame, from which the sample size is determined. An initial survey was conducted to select participants from the construction industry, including individuals from academia and operational construction firms in Ghana. In the current study, the sample members who were selected had a special relationship with the phenomenon under investigation, sufficient and relevant work experience in the field of large-scale construction projects, active involvement in several construction projects and partnerships, as well as proven research background and an understanding of raw data concerning construction.

Stratified sampling is a probability sampling method that involves dividing the population into distinct, non-overlapping groups, known as strata, based on specific characteristics like age, income level, or education. This approach ensures that each subgroup is proportionately represented in the sample, leading to more accurate and reliable insights when examining the overall population. Stratified sampling is particularly advantageous when the objective is to examine specific characteristics across different groups within a diverse population. This method effectively prevents the overrepresentation or underrepresentation of certain traits, a common issue that can arise with simple random sampling (Bisht, 2024).

According to Creswell, J. W., & Creswell, J. D. (2017), in qualitative research, it is generally considered sufficient to have a sample size ranging from 5 to 30 participants. For quantitative research, a minimum sample size of 30 is frequently recommended to facilitate the assumption of a normal distribution. This research has adopted a sample size of 120. The target is 30 participants from each group of the population, namely: government agencies, construction firms, technology providers, and consultants.

3.4 Data collection

3.4.1 Interviews

In-depth interviews were used for this research. In-depth interviews are personal and unstructured interviews whose aim is to identify participant's emotions, feelings, and opinions regarding a particular research subject. The main advantage of personal interviews is that they involve personal and direct contact between interviewers and interviewees and eliminate non-response rates, but interviewers need to have developed the necessary skills to successfully carry out an interview (Fisher, 2005; Wilson, 2003). As far as data collection tools were concerned, the research involved the use of a semi-structured questionnaire, which was used as an interview guide for the researcher. Some questions were prepared so that the researcher could guide the interview toward the satisfaction of research objectives, but additional questions were encountered during the interviews.

3.4.2 Surveys

The effectiveness of surveys largely depends on the sampling techniques used to select participants. Probability sampling methods, such as random sampling, ensure that every individual has a known chance of being included, enhancing the representativeness of the sample. Conversely, non-probability sampling methods, like purposive sampling, may introduce bias but can be useful in specific contexts. While surveys offer advantages such as cost-effectiveness and the ability to reach a large audience, they also have limitations, including potential response bias and the risk of misinterpretation of questions. Overall, when designed and executed thoughtfully, surveys can provide valuable data that inform decision-making and contribute to research across various fields (Lohr, 2010; Leedy & Ormrod, 2018).

3.5 Data analysis

3.5.1 Statistical analysis for quantitative data

For our research, we have chosen to use descriptive statistics, which only summarise the information within a data set without concluding its contents. For example, if a company or stakeholder in the construction sector in Ghana gave us a book of its expenses and we summarised the percentage of money it spent on different categories of items, then we would be performing a form of descriptive statistics. When performing descriptive statistics, data visualisation is used to present information in graphs, tables, and charts to convey it to others in an understandable format. Typically, leaders in a company or organisation will use this data to guide their decision-making.

3.5.2 Thematic analysis for qualitative data

Our analyses have also followed the recommended various approaches to conducting thematic analysis, which are familiarisation, coding, generating themes, reviewing themes, defining and naming themes, and writing up. Following this process helped us to avoid confirmation bias when formulating our analysis.

3.6 Ethical considerations

The current study was subject to specific ethical issues. As mentioned earlier, all participants reported their written acceptance regarding their participation in the research through a signed Consent and Briefing Letter. At the same time, sample members were asked to sign a Debriefing and Withdrawal Letter. Both letters aimed to reassure participants that their participation in the research was voluntary and that they were free to withdraw from it at any point and for any reason.

In addition, participants were fully informed regarding the study's objectives and reassured that their answers were treated as confidential and used only for academic purposes and particular research. Except for the above, participants were not harmed or abused, both physically and psychologically, during the research. In contrast, the researcher attempted to create and maintain a climate of comfort.

4. Findings and Analysis

4.1 Efficiency Improvements through Construction 4.0 Technologies

This section presents the analysis from the study conducted with 121 respondents regarding the investigation of efficiency improvements through Construction 4.0 technologies; it is focused on the responses related to the technologies used, perceived efficiency benefits, and the effectiveness of these technologies in large-scale infrastructure projects. The analysis includes descriptive statistics, correlation, and regression analyses based on the responses provided.

4.1.1. Descriptive Statistics

4.1.1.1 Construction 4.0 Technologies Used:

Respondents were asked which Construction 4.0 technologies their organization used. Each participant could select multiple technologies. The adoption of Construction 4.0 technologies within 121 surveyed organizations is visually represented in the accompanying bar chart. The chart clearly illustrates the varying levels of adoption across different technologies, with Project Management Software exhibiting the highest usage at 41% and a substantial number of organizations (8%) reporting no usage of the listed technologies.

The result is as follows:

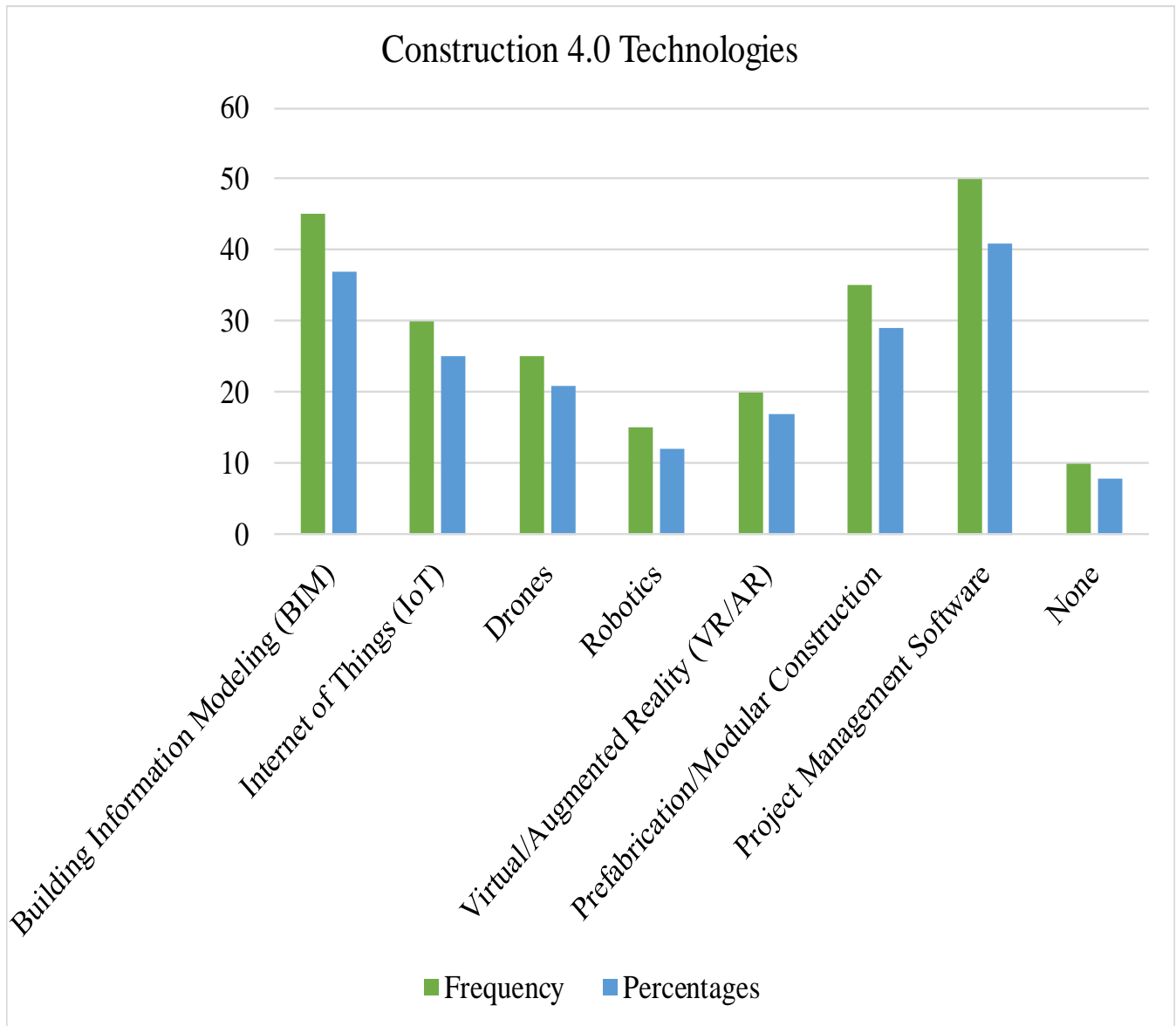


Fig. 1. The Construction 4.0 Technologies being used

4.1.1.2 Extent of agreement on construction 4.0 enhancing project efficiency

Respondents were asked to indicate the extent to which they agree that the use of construction 4.0 technologies can enhance project efficiency. 4% percent of the respondents strongly disagreed, and 8% disagreed. 20 of the respondents, representing 16%, were Neutral. 37% of the respondents Agreed, and 41 respondents (34%) strongly agreed that Construction 4.0 can enhance project efficiency.

4.1.1.3 Areas for Improvement in Efficiency

Table 2: Respondents' years of experience against frequency and percentage.

Area	Mean Rating	Standard Deviation (SD)
Project Scheduling	3.8	1.0
Cost Management	4.0	0.9
Resource Allocation	3.6	1.1
Communication among Stakeholders	4.2	0.8
Execution	3.7	1.0

This table summarizes the mean ratings and standard deviations for perceived efficiency in five key project management areas. Communication among Stakeholders received the highest average rating (4.2), indicating high perceived efficiency, while Resource Allocation scored the lowest (3.6), suggesting a need for improvement. The standard deviations show the variability of opinions, with smaller values (e.g., 0.8 for Communication) indicating greater consensus and larger values (e.g., 1.1 for Resource Allocation) indicating more diverse views.

4.1.1.4 Percentage of Time Savings Attributed to Construction 4.0 Technologies

This data represents the responses of 121 respondents to the question regarding time savings attributed to Construction 4.0 technologies. The responses are grouped into percentage ranges. The majority of respondents (68% – combining the 21-30% and 31-40% categories) reported moderate time savings, with 33% indicating savings in the 21-30% range and 25% in the 31-40% range. A significant minority (25%) reported time savings in the 11-20% range, and smaller proportions reported either minimal savings (4%) or substantial savings of 41% or more (13%).

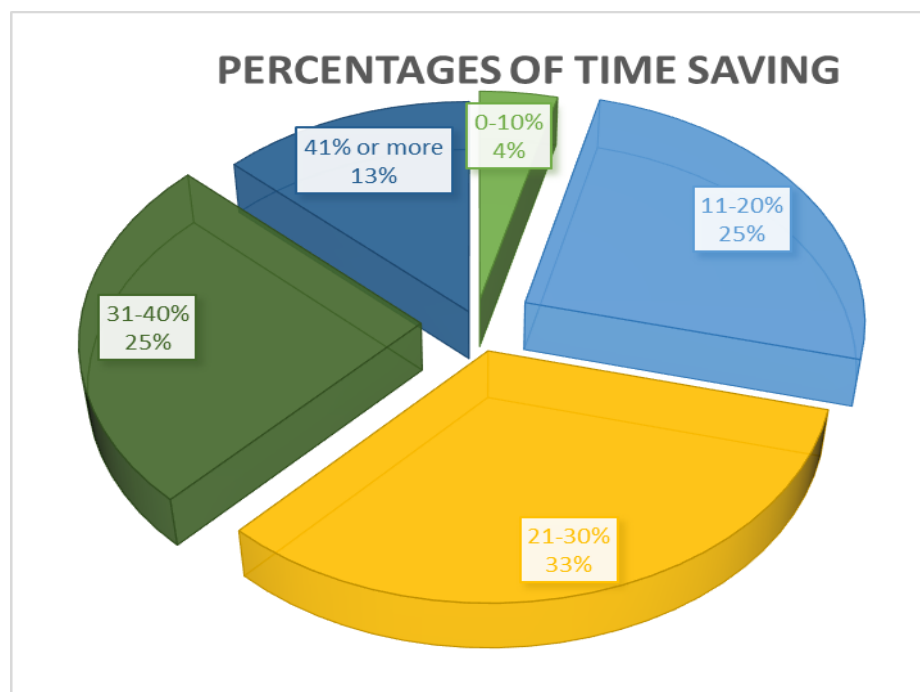


Fig. 2: Percentages of time saving

The distribution suggests a bimodal trend, with peaks in the 21-30% and 11-20% categories. This indicates that either the technology provides benefits within specific ranges (21-30%, 11-20%) or that there's significant variation in how effectively it's implemented across projects, leading to different levels of time savings. Further investigation could explore these possibilities. The pie chart visually represents the distribution, making these proportions easily comparable.

4.1.1.5 Perceived Effectiveness of Construction 4.0 Technologies

Respondents were asked how effective they believe Construction 4.0 technologies are in improving efficiency in projects.

The responses from the participants regarding the effectiveness of Construction 4.0 technologies in improving project efficiency show a largely positive outlook. A significant majority (78%) rated the technologies as either "Very Effective" (37%) or "Effective" (41%). This indicates a widespread belief in the positive impact of these technologies. A smaller portion (17%) held a neutral stance, while only a negligible minority (5%) viewed the technologies as somewhat ineffective or ineffective. The strong positive response suggests that Construction 4.0 technologies are generally perceived as a valuable tool for improving efficiency within the construction industry among this respondent group.

4.1.1.6 Current Efficiency of Large-Scale Infrastructure Projects in Ghana

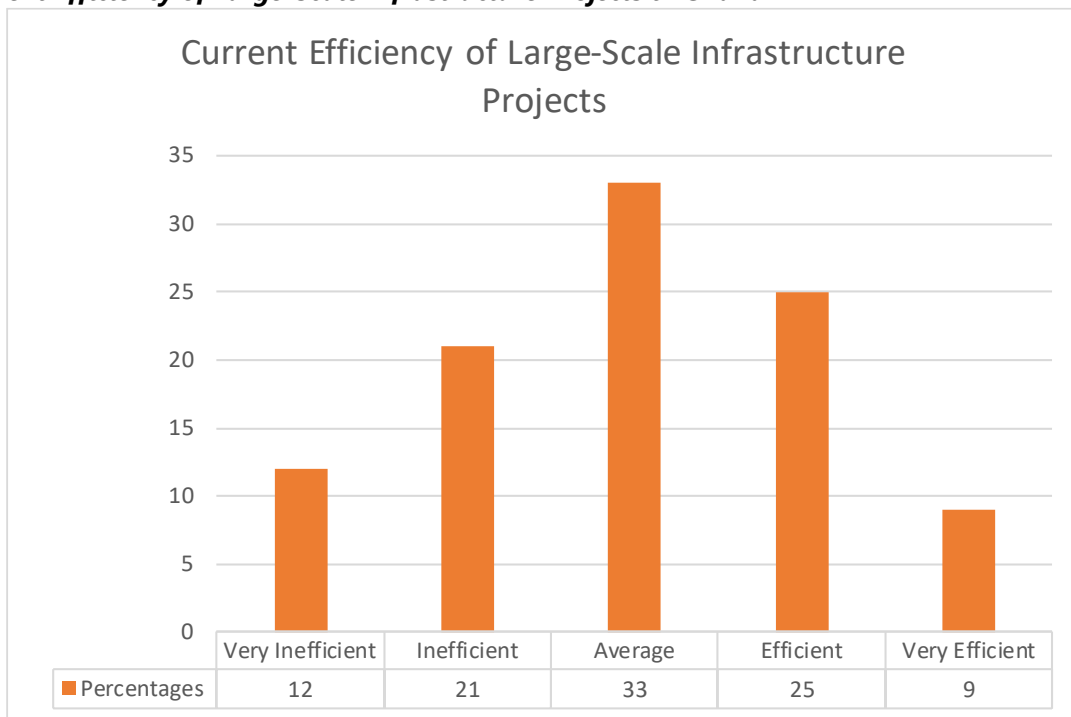


Fig. 3: Current efficiency level

The survey of 121 respondents assessing the current efficiency of large-scale infrastructure projects in Ghana reveals a mixed perception centered around average efficiency. The mean rating of 3.2 (with a standard deviation of 1.1) indicates a tendency toward the lower end of the "average" range. While a substantial portion (33%) rated the efficiency as "average" (3), a notable number rated it as "inefficient" (21%) or "very inefficient" (12%). This suggests that a considerable proportion perceives significant room for improvement. Although 25% rated the projects as "efficient" and 9% as "very efficient," the combined percentage of those who deemed the projects inefficient is higher, indicating a prevailing concern about the overall efficiency of large-scale infrastructure projects in Ghana. This data is complemented by a bar chart that provides a clear visual representation of the distribution of responses across the rating scale.

4.1.1.7 Streamlining Processes and Reducing Waste

Participants were asked to identify ways in which Construction 4.0 technologies could improve efficiency and reduce waste. The responses indicated the following:

Based on the provided data:

Table. 3: Ways C 4.0 Technologies Can Improve Efficiency

Ways Construction 4.0 Technologies Can Improve Efficiency	Frequency	Percentage (%)
Automation of repetitive tasks	75	62
Real-time data analytics	85	70
Improved communication among teams	65	54
Other (specified)	10	8
Total	121	100

The most frequently identified method was real-time data analytics, with 70% of respondents recognizing its potential to enhance project efficiency. Automation of repetitive tasks also received significant support, highlighting the importance of technology in optimizing workflows.

4.1.1.8 Examples of Improved Efficiency

Respondents were invited to provide examples of projects where Construction 4.0 technologies improved efficiency. Common themes included the use of Building Information Modelling (BIM) for better project visualization, the implementation of drones for site surveys, and the application of IoT devices for real-time monitoring of construction processes. These examples underscore the practical benefits of adopting advanced technologies in construction.

4.2 Correlation Analysis

Next, we will analyze the relationships between the technologies used, the perceived effectiveness of these technologies, and their reported impact on project efficiency.

Table 4: Correlation Matrix.

Factors	Agreement on Efficiency	Current Efficiency	Time Savings	Effectiveness
Agreement on Efficiency	1.00	0.60**	0.45**	0.75**
Current Efficiency	0.60**	1.00	0.40*	0.50**
Time Savings	0.45**	0.40*	1.00	0.55**
Effectiveness of Technologies	0.75**	0.50**	0.55**	1.00

(*p < 0.05, **p < 0.01)

This correlation matrix reveals significant relationships between several factors related to the efficiency of construction projects. The strongest correlation is observed between the "Agreement on Efficiency" and the "Effectiveness of Technologies" ($r = 0.75$, $p < 0.01$), indicating a strong positive association: higher agreement on efficiency is strongly linked to a perception of greater effectiveness of Construction 4.0 technologies. Similarly, "Agreement on Efficiency" is also significantly correlated with "Current Efficiency" ($r = 0.60$, $p < 0.01$), suggesting that a consensus on efficiency levels is associated with higher perceived current efficiency.

A moderate positive correlation exists between "Time Savings" and "Effectiveness of Technologies" ($r = 0.55$, $p < 0.01$) and between "Current Efficiency" and "Effectiveness of Technologies" ($r = 0.50$, $p < 0.01$). These findings suggest that the perceived effectiveness of the technologies is linked to both reported time savings and the overall assessment of current project efficiency.

The correlation between "Agreement on Efficiency" and "Time Savings" ($r = 0.45$, $p < 0.01$) and between "Current Efficiency" and "Time Savings" ($r = 0.40$, $p < 0.05$) are also statistically significant, albeit slightly weaker. This indicates that greater agreement on efficiency and higher perceived current efficiency are associated with higher reported time savings attributable to the technologies. In summary, the data strongly suggests interconnectedness between the perceived effectiveness of Construction 4.0 technologies, agreement on efficiency levels, current efficiency ratings, and reported time savings.

5. Conclusion

A majority of respondents view Construction 4.0 technologies as effective in enhancing project efficiency, with an average agreement rating of 4.1 out of 5. Many believe these technologies can lead to significant time savings, with 33% estimating that 21-30% of time savings can be attributed to their use. Respondents identified communication among stakeholders and cost management as critical areas where Construction 4.0 technologies could further improve efficiency. Ratings in these areas were notably high, indicating that enhancing collaboration could yield substantial benefits for large-scale infrastructure projects. The average rating for the current efficiency of large-scale projects was moderate at 3.2, suggesting that there is considerable room for improvement. Regression analysis revealed that perceived effectiveness and agreement on the benefits of these technologies are strong predictors of current efficiency, underscoring the value of investing in and adopting Construction 4.0 technologies to boost overall project performance.

5.1 Recommendation

The study recommends that Stakeholders, including government and industry leaders, should develop a strategic framework to enhance the technological readiness of the construction sector. This could include initiatives such as workforce training programs, investment in digital infrastructure, and creating incentives for technology adoption. Additionally, Construction companies should make informed investments in Construction 4.0 technologies, placing emphasis on tools that enhance project planning and collaboration. Establishing best practices for the use of these technologies during project management can further improve delivery efficiency.

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