Construction 4.0 enabling technologies in small And medium-scale construction companies in the UK

CONSTRUCTION 4.0 AND THE UK'S SMALL AND MEDIUM-SCALE CONSTRUCTION COMPANIES

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The advancement and application of digital technology solutions are significant approaches to improving productivity in the construction industry. While there are existing studies on digital adoption in construction overall, there is a lack of emphasis on the usage levels for specific technologies and the distinct barriers and opportunities SMEs encounter. This paper aims to identify the Construction 4.0 enabling technologies used by Small and Medium Construction (SMEs) firms in the UK and their usage levels. The methodology adopted is a mixed-method research approach using interviews and questionnaire surveys. This research suggests that the top five construction 4.0 enabling technologies used by small and medium-scale construction companies in the UK are Cloud computing, BIM, Common data environment, Big data analytics and offsite manufacturing. The findings also show that a significant percentage of industry practitioners in SMEs in the UK have never used actuators, eye-tracking devices, Digital Twin, mixed reality, or Cobots. The results show that the fundamental benefits associated with using these technologies include enhanced productivity and innovation. However, the fundamental challenges include cost and low investment in research and experience.

Keywords: BIM, Construction 4.0; digital construction; digital twin; drones; IoT; robots

INTRODUCTION

A significant approach to improving productivity in the construction industry is through the advancement and application of digital and technology solutions (Hossain and Nadeem, 2019; RICS, 2020). Construction 4.0, which focuses on digitalisation, is a platform to improve productivity through different technologies and automated manufacturing. It emphasizes the merger of trends and technologies that could enhance productivity, safety, and sustainability in how the built environment assets are designed, constructed, and operated (Sawhney *et al.,* 2020). It is a framework focused on three broad themes: industrial production, cyber-physical systems, and

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digital and computing technologies. Construction 4.0 is a concept that applies the principles and technology of Industry 4.0 to the construction industry.

Much work has been done on Construction 4.0 since it was coined in 2016. However, little is known about the practical use of the technologies that enable Construction 4.0 in the UK's small and medium-scale construction industries (Bousfield *et al.,* 2023). Using a mixed-methods research approach, this research aims to identify the levels of adoption of Construction 4.0 amongst Small and Medium Construction (SME) firms in the UK by specifically looking at the technologies used and their usage levels.

The fundamental theories supporting this research are Industry 4.0, the Fourth Industrial Revolution, and Construction 4.0. Construction 4.0 is an offshoot of Industry 4.0 that benefits the construction industry. Industry 4.0 refers to a wide range of current concepts, which include smart factories, cyber-physical systems, self-organisation, new systems in procurement and distribution, new systems in the development of products and services, adaptation of human needs, and social corporate responsibility (Lasi *et al.,* 2014). Industry 4.0 emphasizes digital manufacturing. Digital manufacturing refers to the manufacturing process with the support of technologies such as virtual (VR), computer networks, rapid prototyping and databases (Cañas *et al.,* 2021).

Construction 4.0 is based on construction firms' awareness of the industry's digitisation and four key concepts: digital data, automation, connectivity, and digital access (Forcael *et al.,* 2020). Construction 4.0 could be seen as a transformative framework that includes industrial production, construction, cyber-physical systems, and digital technologies (Sawhney *et al.,* 2020).

The development of Construction 4.0 is geared by various enabling technologies that are changing how construction projects are planned, managed, and executed. Several authors have identified technologies such as Building Information Modelling (BIM), virtual and augmented reality (VR/AR), mixed reality (MR), the Internet of Things (IoT), and robotics as critical components of this evolution (Hossain and Nadeem, 2019). While these technologies facilitate project visualisation, real-time data integration, and automation, they predominantly change how construction processes are managed. Further, Craveiroa *et al.,* (2019) and Forcael *et al.,* (2020) emphasize the role of additive manufacturing (3D printing), drones, and sensor technologies in accuracy and efficiency. Sawhney *et al.,* (2020) explain how they streamline construction processes and enhance safety by providing a broader overview of prefabrication, offsite manufacturing, and cyber-physical systems (CPS) such as robots and drones. Sawhney *et al.,* (2020) also discussed industrial production (prefabrication, 3D printing, assembly, offsite manufacture) as aspects of construction 4.0. Similarly, Júnior *et al.,* (2021) highlight the application of wearables and safety sensors, which improve worker safety through real-time monitoring and advanced protective equipment like smart helmets and bionic exoskeletons. Newman *et al.,* (2021) further purport that integrating artificial intelligence (AI), cloud computing, and cybersecurity into construction processes could help optimise operations and safeguard information.

The construction industry has long been acknowledged for its inefficiencies, low productivity, low-profit margins, and cost overruns (Klinc and Turk, 2019). Industry 4.0 technologies, however, have the potential to address and redeem these challenges due to their inherent characteristics, such as automation, digitisation, and integration, which are cornerstones of Industry 4.0.

These technologies offer significant opportunities for improving productivity, design quality, and construction processes. However, the adoption of these new technologies within the construction industry remains slow due to various challenges (Papadonikolaki *et al.,* 2023). The persistent challenges of fragmentation, coordination, communication, and the complexities (Egan, 1998; Latham, 1994). While large enterprises may possess the resources to overcome the above challenges (Chen *et al.,* 2024), the extent to which technologies are being integrated into small and medium-sized construction companies (SMEs) in the UK remains underexplored. SMEs often face unique challenges, including limited resources and technical expertise, which can hinder their adoption of digital technologies (Poirier *et al.,* 2015).

Given SMEs' critical role in fostering growth and sustainability within the construction industry, examining how they confront and respond to adopting digital transformation is imperative (Lam *et al.,* 2017). This research, therefore, aims to evaluate the current level of adoption of Construction 4.0 technologies within UK SMEs and identify barriers to implementation, and this would provide a platform to facilitate more comprehensive integration. Awareness of the dynamics around DT adoption among SMEs is crucial for fostering innovation and maintaining competitive advantage in an industry where rapid change takes place (Sawhney *et al.,* 2020)

The existing literature predominantly focuses on adopting Industry 4.0 technologies in large-scale organisations, overlooking SMEs' challenges and opportunities (Talla and McIlwaine, 2024). While there are existing studies on digital adoption in construction overall, there is a lack of emphasis on the level of usage for specific technologies (Nagy *et al.,* 2021) and the distinct barriers and opportunities that SMEs encounter (Talla and McIlwain, 2024) in the adoption process. According to the summary report presented by the latter author, while some studies highlight the potential benefits of technologies such as Building Information Modeling (BIM), Internet of Things (IoT), and Artificial Intelligence (AI) in enhancing productivity and efficiency, there remains a notable gap in understanding their utilisation within SMEs additionally, there are a notable amount of studies (Papadonikolaki *et al.,* 2023; Bousfield *et al.,* 2023; Chen *et al.,* 2024) that offer general insights into the adoption capacity of Industry 4.0 technologies by the construction sector, but limited research available for a detailed exploration of the unique contexts and constraints experienced by SMEs in the UK construction industry. Presumably, SMEs' utilisation of industry 4.0 enabling technologies has not been adequately explored. Hence, this gap in the existing body of knowledge underscores the necessity for this research study. There is a pressing need for industry practitioners and academics to understand the SMEs' level of usage in DTs because the increased usage of digital technology among construction SMEs benefits individual firms and strengthens the industry by driving innovation, competitiveness, and sustainability. Moreover, understanding the level of usage of enabling technologies for Industry 4.0 among SMEs is essential for identifying the barriers and facilitators they encounter, which help inform strategies for successful implementation, leading to improved productivity, efficiency and cost-effectiveness in the sector. This is the gap in the literature that this research seeks to fill.

METHOD

This is a survey research based on a case study of the UK. It adopted a pluralistic methodological approach by adopting both qualitative and quantitative research design, and hence, it is mixed methods research. The participants are domiciled in the UK and mostly got via snowballing. Using qualitative and quantitative research

provides a more robust approach to data collection and understanding the construct being studied (Easterby-Smith *et al.,* 2008).

To achieve this study's objectives, a thorough literature review was conducted. This included consulting and interrogating several databases, such as ScienceDirect, Scopus, and Google Scholar.

The interviews enabled findings on the specific technologies used and their relevance to the organisation, as well as the levels of usage of these technologies. The questionnaire survey reflects more on the levels of usage and acceptability of the different technologies. This would provide some triangulation as both instruments were used simultaneously (Bryman and Bell, 2007).

Purposive, convenient, and snowballing sampling techniques were used for the interviews. Consequently, respondents were obtained through referrals and platforms such as Twitter and LinkedIn and from personal associates working in construction management. However, because of the large sampling size required, the questionnaire survey data was collected through probabilistic and non-probabilistic sampling techniques. Conversely, random and, in some cases, convenience sampling was explored.

The target was to conduct fifteen or more interviews. However, saturation was reached when ten interviews were conducted. Based on the varied opinions of other scholars, there are no rules for achieving the appropriate size for data collection (Zin, 2013).

The criteria for both the interview and the online questionnaire survey are as follows:

1. The respondents must be presently working in the construction industry.
2. The respondents must be domiciled and working in the United Kingdom.
3. The respondents must work with either the design, production, or asset management teams.

The questionnaire questions mainly were offshoots from the review of the literature. The first three sections focus on the role of the respondents, the number of people employed in their organisation and the specific construction 4.0 enabling technologies they use. The fourth section is a five-Likert question with twenty-two construction 4.0 enabling technologies. The respondents were to select as many as necessary and indicate the usage levels and if they were never used. A section was also provided for the respondents to indicate other technologies that they use but were not mentioned in the questionnaire. The fifth and the sixth questions are also Likert questions to enable the respondents to indicate the benefits and challenges they have encountered concerning using construction 4.0 enabling technologies. A target of 100 responses was set. However, the total number of responses was 41, representing 41% of the target.

Inferential and descriptive statistics with the help of SPSS were used to analyse the data collected using the questionnaire survey. The semi-structured interview was analysed using thematic analysis. The questionnaire variables are majorly nominal and ordinal. The research used mostly descriptive statistics and minimal inferential statistics. Consequently, Cronbach alpha, mean statistics and Spearman's rank correlation were used. Thematic analysis was used to analyse the qualitative data. This was done through identifying, analysing, and reporting the patterns/themes based on the guidelines by Flick (2014).

The UK was chosen because it is a developed economy and arguably should be at the forefront of construction technology.

FINDINGS

The findings are divided into two major segments: the quantitative findings (questionnaire survey analysis and discussion) and the qualitative findings (semi-structured interview analysis and discussion).

Quantitative Findings

Discussion on the levels of usage of the various digital and computer technologies, cyber-physical systems, and industrial production platforms based on the percentage usage

The results relating to the selected twenty-two digital and computer technologies, cyber-physical systems, and industrial production platforms show that all the selected construction 4.0 enabling technologies are used by small and medium-scale construction firms in the UK. However, the levels of usage differ significantly (See Table 1). Over 80% of the respondents said they have never used cobots and eye-tracking devices. Over 70% of the respondents said they have never used blockchains, actuators, digital twins, or mixed reality. Over 50% said they have never used artificial intelligence, simulations, the Internet of Things, or 3D printing and assembly.

The top five construction 4.0 enabling technologies always used by personnel in small and medium-scale construction companies in the UK are Cloud Computing, BIM, Common data environment, big data and data analytics, and Offsite manufacturing.

The data shows that the overall mean score ranges from 2.21 to 3.87. This shows that all 22 digital technologies fall within the categories of "sometimes used "and "often used" by small—and medium-scale construction companies in the UK (Table 1).

The results represent the percentage of those who always, often, sometimes, and never use these technologies. The mean score shows Robots, Cobots, eye-tracking devices, Blockchains, and Digital Twins as the highest-ranked digital technologies used.

The respondents were also asked to write about the construction 4.0 enabling technologies they use that are not included in the questionnaire. Their responses included CAD, Candy, Cost X, infoworks, ICM, REFH2, FEH2, horizon, SharePoint for sharing data, Nextcloud CDE) and Revit.

The benefits of the construction 4.0 enabling technologies to the construction industry based on the questionnaire survey responses

Based on information obtained from the literature review, the respondents were asked to rate the benefits of the construction 4.0 technologies to their companies. This was to ascertain the benefits of these construction 4.0 enabling technologies to UK small and medium-scale construction companies. They were given eight benefits and had to indicate strongly agree, agree, undecided, or disagree. The benefits mentioned in the questionnaire survey include reduction of waste, enhanced safety, enhanced sustainability, enhanced communication, enhanced productivity and innovation, improved design, improved production and reduced fragmentation among project teams.

The mean score ranged from 1.92 to 2.26, showing that most respondents either "disagreed" or were "undecided "about the factors mentioned. This aligns with the findings from the semi-structured interviews, which reflect that small and medium-

scale construction companies do not mostly use these technologies because of the associated challenges of the cost of software acquisition and worker training. Consequently, it is difficult to appreciate the benefits of Technologies that are not used.

However, when the mean scores were ranked, reduction of waste, enhanced safety, enhanced sustainability, enhanced communication, and enhanced productivity were the top five factors considered to be benefits of using construction 4.0 enabling technologies by the respondents in the order they are listed with reduction of waste coming first.

Table 1 Usage of digital and computer technologies, cyber-physical systems and industrial platforms

Digital Computer Technologies	Level of usage (The mean)	Rank	Standard Deviation
Robots	3.87	1	0.34
Cobots	3.87	2	0.41
Eye tracking device	3.74	3	0.64
Blockchain	3.68	4	0.65
Digital twin	3.65	5	0.67
Actuators	3.65	6	0.74
Mixed reality	3.63	7	0.67
Video & laser scanning	3.6	8	0.87
Artificial intelligence	3.5	9	0.72
Virtual reality	3.5	10	0.72
Reality capture	3.44	11	0.93
Simulation	3.32	12	0.93
3D printing & assembly	3.32	13	0.86
Internet of things	3.21	14	1.03
Drones	3.21	15	0.83
Sensors	3.18	16	0.98
Geographical information systems	3.03	17	0.95
Common data environment	3.0	18	0.87
BIM	2.79	19	1.2
Big data analytics	2.67	20	1.09
Offsite manufacturing	2.67	21	1.05
Cloud computing	2.21	22	1.14

Challenges associated with the adoption and usage of construction 4.0 enabling technologies

The respondents to the questionnaire survey were provided with some challenges associated with adopting construction 4.0 enabling technologies in their organisations based on a literature review. This was to ascertain how these challenges relate to using construction 4.0 enabling technologies in the UK. The responses were based on four Likert scale responses: strongly agree, agree, undecided, and disagree.

The challenges mentioned in the survey were the lack of standards and policies, the low investment in research by construction firms, the complex nature of the construction industry, the failure of construction workers to embrace change, low technological knowledge, and the high cost of acquiring and maintaining technologies. The mean score ranges between 2.1 and 2.77, and this shows that the respondents are majorly undecided about these factors being the challenges associated with their

adoption and usage of construction 4.0 enabling technologies. This then brings to light some challenges mentioned in the semi-structured interviews, which reflect the low-profit margins as a demotivation for wanting to use these technologies, as it may further erode the profits. However, when ranked based on the mean score, lack of standards and policies came tops as a fundamental challenge, and the ranking of the other factors is in order of the list of the challenges above.

Qualitative Findings

The interview was conducted with ten professionals, including six surveyors, two Architects and two project managers. All the interviewees work with small and medium-scale construction companies with staff numbers ranging from 10 to 100. Most of the interviewees were Surveyors, some Architects and Project Managers. The interviewees were asked to give some insights into the construction 4.0 enabling technologies used by their organisation, including the usage of technologies such as digital twin, BIM, Robotics, etc, that their companies use.

The interviewees were asked to discuss the impacts of these technologies on their organisation's performance.

Most of the interviewees attested to using Building Information Modelling (BIM). According to the interviewees, some of the impacts of these technologies include enhanced design and production. Much emphasis was placed on the benefits of collaboration amongst project teams, especially among the users of Revit/BIM.

This aspect of the semi-structured interviews provides some more answers to the third research question: What are these technologies' impacts on the performance of the construction industry?

The interviewees were asked to discuss the barriers or challenges to their using these technologies in their organisation. The recurring response to this question was the cost. From the first interviewee to the last, they all complained about the cost of the construction of 4.0 enabling technologies. They complained that the cost represents a significant percentage of their turnover. They also said that the usage is not heavily implemented apart from BIM. In relating cost as a fundamental challenge, one of the interviewees, a Project manager in the construction industry with over 20 years of experience, concluded that large companies like Mace mostly use these technologies. He said,

> "These technologies are used mainly by big companies like Mace because of the cost "- Interviewee 1 from London.

Lack of experience is also attributed to one of the barriers to using construction 4.0 enabling technology, as shown in the quote below from one of the interviewees from Devon. He said,

> "It's down to cost and experience" - Interviewee 2 from Devon

Some of those interviewed said they do not have projects that would warrant the usage of such technologies. They also said they would avoid the training and associated costs to enable them to use the technologies. There is also the challenge of not being willing to use the technologies.

The implication of the findings from the semi-structured interviews
Interviews confirmed the limited use of Construction 4.0 technologies by small and medium-sized construction companies in the UK, aligning with survey data. Both

methods identified similar benefits (improved design and production) and challenges (cost and lack of experience) hindering adoption.

To address this gap and achieve the research objective of "enhancing usage of Construction 4.0 technologies", the next section proposes recommendations to encourage UK SMEs to embrace these advancements.

Implication of the findings to academia, industry, and government
This research could contribute significantly to academia, industry, and government policymakers. The potential contribution to academia is that it provides a platform for curriculum development that would enhance students' knowledge of the practicability and usage of construction-enabling techniques. This is because some interviewees cited experience/lack of knowledge as fundamental challenges with adopting and using the construction 4.0 enabling technologies.

The potential contribution to the industry is that it could provide a platform for recruiting personnel with the right skills and competencies, as it involves using construction 4.0 enabling technologies. It also could call the attention of industry decisions on the training requirement for their employees that would enhance the usage of construction 4.0 enabling technologies, which comes with enhanced production, safety, sustainability, and other benefits associated with using construction 4.0 enabling technologies (see earlier section on the benefits).

This research could provide a platform for government policymakers to develop policies that would enhance the usage of construction 4.0, enabling technologies by small and medium-scale construction companies in the UK. This is because the findings from the research show that these technologies are important. However, the findings also show a significantly low adoption and usage of the technologies. Hence, some government support through incentives to both the providers and users of the technologies would enhance their usage.

CONCLUSION

The study on construction 4.0 enabling technologies in small and medium-scale construction companies in the UK has been undertaken. The results relating to the selected twenty-two digital and computer technologies, cyber-physical systems, and industrial production platforms reflected in the questionnaire survey show that all the selected construction 4.0 enabling technologies are used by small and medium-scale construction firms in the UK. However, the levels of usage differ significantly. According to the survey responses, the top five construction 4.0 enabling technologies always SMEs in the UK are Cloud Computing, BIM, a Common data environment, big data and data analytics, and Offsite manufacturing. However, the interview findings do not significantly reflect the usage of the technologies mentioned in the questionnaire survey. The interviewees mentioned they also use technologies such as Trimble GPS, Autodesk, 3D Designs, Drones, Pointfuse for scanning, AutoCAD, Robotic Dog, and BIM. The findings from the semi-structured interviews show BIM as the most used construction 4.0 enabling technology by small and medium-scale construction companies in the UK.

Based on the questionnaire survey, the top five impacts of the identified digital technologies on small and medium-scale construction companies include enhanced productivity and innovation, reduction of waste, improved production, communication, and safety. According to the interviewees, some of the impacts they claim it made include enhanced design and production.

Based on the questionnaire survey, the top five challenges associated with the adoption and usage of construction 4.0 enabling technologies include the high cost of acquiring and maintaining the technologies, the construction firm's low investment in research, the failure of construction workers to embrace change, low technological knowledge, and the complex nature of the construction industry. However, the findings from the semi-structured interview show cost and lack of experience as the fundamental challenges associated with small and medium-scale construction firms in the UK adopting and using construction 4.0 enabling technologies.

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