ENHANCING OFFSITE CONSTRUCTION FOR UK SMES THROUGH BUILDING INFORMATION MODELLING: A COMPREHENSIVE ANALYSIS

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Numerous government publications have highlighted the need to address challenges within the construction sector. Many studies recommend adopting technologies such as offsite construction and expanding the use of Building Information Modelling (BIM) to resolve industry issues. Building Information Modelling (BIM) and offsite construction (OSC) have gained increasing popularity in the architecture; engineering; and construction (AEC) industry due to the various benefits they offer to project stakeholders; including enhanced design visualisation; efficient data exchange; reduced construction waste; and improved productivity and efficiency. Despite significant research in these areas and an extensive body of literature on BIM and OSC; many small and medium enterprises (SMEs) still need quantifiable benefits for adopting BIM in offsite construction processes. This study examines the impact of BIM on offsite construction in terms of cost; quality; time; and safety. The primary objective of this research is to encourage SMEs to adopt BIM for offsite construction projects. To achieve this goal; the study collected primary data using a questionnaire completed by 66 respondents from the construction industry. The study establishes that BIM for offsite construction outperforms offsite construction without BIM.

Keywords: BIM; impact; MMC; offsite construction; productivity

INTRODUCTION

Over the years, the construction industry has experienced a decline in cost efficiency, quality, timeliness, and safety compared to other sectors (Barbosa *et al.,* 2017). This has led to the adoption of innovative technologies and processes, such as Building Information Modeling (BIM) and off-site construction (OSC) (Abanda *et al.,* 2017). Both BIM and OSC have the potential to address persistent challenges in the construction industry, including productivity and efficiency issues, while significantly transforming the sector (Yin *et al.,* 2019). Various organisations have provided definitions for BIM. Abanda *et al.,* (2017) state that the Royal Institute of British

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Architects (RIBA) and the Construction Project Information Committee (CPIC) have jointly defined BIM as a digital method for managing project information and data throughout the design, construction, and operation phases within the United Kingdom. BIM enhances sustainability in multiple scenarios across a building's life cycle, including construction, operation, design, planning, maintenance, and demolition (Liu *et al.,* 2018).

Stakeholders in the construction industry have persistently sought innovative ways to enhance productivity. Nonetheless, selecting the most suitable and practical construction method remains a prevalent challenge in the sector (Sabet and Chong, 2019). Low productivity in construction has been an ongoing issue, with government and private entities exploring various solutions to tackle it (Dixit and Sharma, 2020). Identifying the factors contributing to low productivity is crucial for improving the industry's performance. Fragmentation, resource scarcity, inadequate supervision, outdated tools and equipment, poor communication, rework, harsh weather conditions, and project cost and schedule overruns are among the factors that impact productivity in the construction sector (Durdyev and Ismail, 2019). The continuous pursuit of improvement in the construction sector has led to the development of innovative approaches to enhance design before construction, raise quality standards, increase safety, and reduce costs (Nawari, 2012). Some innovative construction methods used to address productivity issues include the application of lean principles, off-site construction, and using Building Information Modelling (BIM) in projects (Barbosa *et al.,* 2017).

This study aims to examine the significance of incorporating Building Information Modelling (BIM) in offsite construction, focusing on its impact on quality, time, safety, and cost. It also compares the performance of offsite construction projects with and without BIM. The objective is to provide quantitative evidence of the benefits of BIM in offsite construction, encouraging SMEs to adopt this approach in their processes. The study addresses the following aspects:

1. An examination of the effects of BIM on offsite construction in terms of quality, cost, time, and safety
2. An exploration of the barriers and drivers for BIM implementation in offsite construction
3. Recommendations for the construction industry regarding the integration of BIM in offsite construction projects

LITERATURE REVIEW

The Need for Offsite Construction Adoption

N Kamali and Hewage (2016) note that the implementation of offsite construction results in reduced construction costs, improved schedules, enhanced safety and quality, and decreased waste in the construction industry. Yin *et al.,* (2019) highlight various benefits of offsite construction, such as improved quality, structural reliability, increased productivity, reduced schedules, and minimized material waste. Kamali and Hewage (2016) also suggest that offsite construction offers numerous environmental and social benefits, making it well-suited for supporting sustainability initiatives. Offsite and onsite construction can be executed concurrently in a project schedule, resulting in time reduction, improved quality, enhanced safety, and cost savings. The Institute (2017) claims that most modular projects can achieve 30-50% time savings on construction, allowing clients to realise profits more quickly while significantly reducing labour and general condition costs. This is possible because onsite and offsite activities co-occur, with minimal risks such as weather-related delays, site theft, and vandalism (Mah, 2011).

Offsite construction contributes to lower construction costs for various reasons. Research by the Construction Industry Institute (CII) cited in several publications indicates that OSC projects save approximately 10% on the overall project budget and up to 25% on onsite labour costs (Chiu, 2012; Kamali and Hewage, 2016). Relocating most of the construction process to a controlled environment with more straightforward, repetitive operations can decrease workplace accidents caused by congestion, adverse weather, working at heights, and hazardous activities (Elnaas *et al.,* 2014; Chiu, 2012). Offsite construction ensures better quality because it takes place in a controlled environment, allowing for the improvement of product quality through repetitive procedures and operations. The application of BIM provides opportunities to capitalize on these benefits. Abanda *et al.,* (2017) suggest that the most substantial increase in construction productivity will come from BIM-enabled automated offsite activities.

BIM for Offsite Construction by UK SMEs

The adoption of Building Information Modeling (BIM) for offsite construction by UK SMEs is crucial for enhancing efficiency, reducing costs, and ensuring the timely completion of projects. BIM enables the detection and resolution of potential issues in the design and construction process, thereby improving the overall quality and reducing the likelihood of costly errors (Zhang *et al.,* 2016). When combined with offsite construction techniques, BIM can significantly enhance the benefits of both approaches. However, it is essential to recognise UK SMEs' barriers to adopting BIM for offsite construction. These barriers may include the need for more knowledge and expertise in BIM technology, the cost of software and training, and resistance to change within the organisation.

It is vital to examine the long-term benefits of BIM adoption for offsite construction to overcome SME barriers.

Impacts of BIM Application for Effective Offsite Construction Adoption

Ezcan *et al.,* (2013) argue that the most notable benefits of BIM for offsite construction include shorter lead times, cost reduction, minimised alteration challenges, enhanced collaboration, and the ability to handle a large volume of precise information. Using BIM to represent offsite construction components simplifies offsite construction projects' design and assembly processes. Sacks *et al.,* (2018) suggest that BIM is advantageous for offsite construction as it enables the machine-processing of construction information and production elements without the risk of human errors. The positive impact of BIM on offsite construction in terms of quality, cost, safety, and time has been discussed extensively in various studies (Vernikos *et al.,* 2014, Jayasena *et al.,* 2016, Lee *et al.,* 2020).

The seamless coordination and organisation of all operations in a BIM-OSC system reduce complexity and a lower likelihood of accidents, ultimately leading to more efficient project management (Sabet, 2019). By modelling the assembly of prefabricated components in BIM, contractors can virtually analyse the installation and positioning processes, potentially identifying and rectifying hidden safety hazards. The risk of falls and accidents caused by on-site plant activities in OSC-based projects can be mitigated using BIM to detect dangerous scenarios, ensure optimal accessibility for plant operations, and provide crane lifting drawings, thereby reducing the probability of reportable incidents (Darlow *et al.,* 2021).

Barriers to Implementing BIM in Offsite Construction

One critical obstacle in BIM deployment for building projects is the adaptation to BIM technology and processes (Elmualim and Gilder, 2014). Stakeholders, particularly in developing markets, face the challenge of effectively reengineering existing processes, which significantly hampers BIM implementation in offsite construction. Adopting BIM will inevitably alter the construction process and, in some cases, the organisation's structure (Sacks *et al.,* 2018). Historically, stakeholders in the construction industry have been slow to embrace change, relying on traditional paper-based methods and often expressing scepticism towards innovations or the implementation of new technologies.

Successful BIM deployment requires constant and dynamic professional collaboration throughout a project. However, the current construction sector needs more professional engagement (Jin *et al.,* 2017), which could impede the application of BIM for offsite construction. For small and medium-sized enterprises (SMEs), the cost of BIM experts and software presents a significant concern. Many need more financial resources to invest in new digital technologies and employ BIM specialists (Tan *et al.,* 2019). In addition to the initial investment, the risk associated with BIM tools contributes to SMEs' reluctance. The economic benefits of BIM for offsite construction often need to be clarified, further obstructing its adoption (Zhang *et al.,* 2018). Additionally, concerns surrounding intellectual property rights related to BIM implementation, such as BIM model ownership and data ownership within the model, have been raised by numerous scholars. Therefore, appropriate legislation to protect intellectual property rights is essential for BIM deployment (Ozorhon and Karahan, 2017).

Research Question

A review of the literature reveals that there is a need for quantitative analysis of the advantages that BIM offers over non-BIM approaches in offsite construction, with a focus on quality, time, cost, and safety. The research questions for this study are as follows:

1. Does the application of BIM positively influence offsite construction outcomes?
2. To what extent does BIM enhance quality, cost-efficiency, time management, and safety in offsite construction projects?
3. How does the performance of offsite construction projects using BIM compare to those without BIM implementation?

METHOD

The methodology employed in this study involved a combination of primary and secondary data collection methods to investigate the impact of BIM on offsite construction. The data collection approach for the primary research utilised structured interviews/questionnaires in the form of a survey. This method was selected due to its reliability, cost-effectiveness, and rapid response rate. Secondary data sources, such as case studies, journal articles, reviews, and books, provided valuable information about the impact of BIM on the construction industry (Igwenagu, 2016).

Questionnaires were distributed to various Architecture, Engineering, and Construction (AEC) professionals. The sample population consisted of AEC professionals with experience in both BIM and offsite construction, ensuring that the respondents had the necessary knowledge and background to provide insightful responses. Data collected from the survey were analysed using quantitative techniques. Descriptive statistics, such as frequencies and percentages, were used to present the general trends and patterns found in the data. Inferential statistics, such as correlation and regression analysis, were applied to determine the strength and direction of the relationships between variables and investigate the linear association between two continuous variables - the impact of BIM (Building Information Modeling) on offsite construction outcomes, specifically cost, quality, time, and safety. The Pearson correlation coefficient is ideally suited for this purpose, as it measures the strength and direction of a linear relationship between two continuous variables, which perfectly aligns with our research question.

RESULTS

The demographic analysis of the survey respondents revealed a diverse range of professionals and experts from various organisations within the construction industry. Most respondents worked in construction consultancy (45.5%), general contracting (27.3%), and research and development (18.2%). Most organisations focused on residential projects (57.6%), while 24.2% each concentrated on commercial or a combination of residential and commercial projects. The study sample mainly consisted of small organisations with 0-50 employees (48.5%) and a wide range of experience in offsite construction and BIM adoption. Most respondents held project management positions or worked as civil engineers, which brought valuable insights from project management perspectives.

Most organisations had been involved in offsite construction for up to 20 years, and their experience with BIM for offsite construction ranged from 0-5 years to 15-30 years. This highlights the recent trend of BIM adoption in offsite construction, allowing respondents to compare their experiences before and after BIM implementation. The demographics of the respondents ensured a reliable and valid data set, representing the views of professionals, experts, and researchers in the construction industry. The predominance of project managers and the inclusion of companies new to BIM adoption added valuable perspectives to the study.

Reliability Analysis Using Cronbach's Alpha and Correlation

An analysis of the reliability of the data set by measuring the internal consistency between items on a scale was conducted. A common convention in the literature suggests thresholds for interpreting the coefficient values: Above 0.9 as excellent, above 0.8 as good, above 0.7 as acceptable, above 0.6 as questionable, above 0.5 as poor, and below 0.5 as unacceptable (Gliem and Gliem, 2003). The reliability analysis of the data set from the variables is shown in Table 1. A Pearson correlation analysis was performed using SPSS to establish the statistical relationship between the variables. The computed variables used in this study were used in the correlation analysis. A 0.05 P-value or significance value shows the possibility of error is less than 5%. There is a strong relationship among the variables. This is indicated by a statistical significance, with a Pearson correlation value of -0.275, 0.165, 0.196, and -0.275, respectively, and significance values of 0.025, 0.00, 0.00, and 0.025, respectively.

Table 1: Reliability Analysis using Cronbach's Alpha

Cronbach's Alpha Cronbach's Alpha Based on Standardized Items N of Items	0.712
Cronbach's Alpha Cronbach's Alpha Based on Standardized Items N of Items	0.708
Cronbach's Alpha Cronbach's Alpha Based on Standardized Items N of Items	14

Table 2: Correlation Analysis of Variables for the Study

		B4OFFSITE	OFFSITE	BIM	BIMvsOFFSITE
B4OFFSITE	Pearson Correlation	1	.177	-.096	-.275*
	Sig. (2-tailed)		.155	.442	.025
	N	66	66	66	66
OFFSITE	Pearson Correlation	.177	1	.543**	.165
	Sig. (2-tailed)	.155		.000	.185
	N	66	66	66	66
BIM	Pearson Correlation	-.096	.543**	1	.196
	Sig. (2-tailed)	.442	.000		.115
	N	66	66	66	66
BIMvsOFFSITE	Pearson Correlation	-.275*	.165	.196	1
	Sig. (2-tailed)	.025	.185	.115	
	N	66	66	66	66

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed).

Test of Hypothesis

H1: BIM has a positive impact on offsite construction.

The one-sample T-test results indicate a non-statistical significance from the mean, leading to the acceptance of hypothesis 1. This is consistent with Kumar and Bhattacharjee's (2020) findings, which showed that the benefits of implementing BIM outweigh the costs in the long run.

H2: BIM improves quality, cost, time, and safety in offsite construction.

Like H1, the one-sample T-test results show a non-statistical significance from the mean, indicating that hypothesis 2 is accepted. This suggests that BIM positively affects various aspects of off-site construction projects.

H3: BIM for off-site by UK SMEs will determine project success or failure.

The one-sample T-test results also show a non-statistical significance from the mean for hypothesis 3, leading to its acceptance. This implies that the use of BIM in off-site construction projects plays a crucial role in determining the success or failure of these projects.

Comparative Analysis of Performance Between the Application of BIM for Offsite Construction and the Offsite Construction Without BIM

A comparative analysis was carried out using SPSS to determine the performance level of construction projects with the implementation of BIM for offsite construction and when offsite construction is carried out without BIM. The Correlation Analysis was carried out in SPSS; the result is shown in Table 3.

Table 3: Correlation between BIM vs non-BIM implementation in offsite construction projects

		OFFSITE	BIM
OFFSITE	Pearson Correlation	1	.543**
	Sig. (2-tailed)		.000
	Sum of Squares and Cross-products	14.530	8.777
	Covariance	.224	.135
	N	66	66
BIM	Pearson Correlation	.543**	1
	Sig. (2-tailed)	.000	
	Sum of Squares and Cross-products	8.777	18.008
	Covariance	.135	.277

**. Correlation is significant at the 0.01 level (2-tailed).

The correlation table shows the relationship between responses on the comparative views on the implementation of BIM for offsite construction, against when BIM is not used shows a Pearson's correlation of 0.543 and for both relationships and a statistical significance level of (2 tailed) of 0.00 which is below the threshold value of 0.05. Thus, there is a statistical significance in the relationship between using BIM to promote offsite construction.

The correlation analysis has helped to answer research question 3, which seeks to investigate whether the application of BIM for offsite construction performs better than offsite construction without BIM. This finding aligns with the study of Yin *et al.,* (2019), who made similar findings to review the promotional impact of implementing BIM in offsite construction.

Discussion

The current investigation of the impact of Building Information Modelling (BIM) on offsite construction in the UK SME context contributes to a broader, international discourse. To create a comprehensive understanding of the research topic, the study findings are compared with similar international studies. This approach not only enhances the appeal of the paper to an international audience but also provides richer insights by illuminating the relationship between the findings and those from diverse regions.

In a comparison of the benefits of BIM implementation, the study aligns with Abanda *et al.,* (2017) and Lee *et al.,* (2020). Abanda *et al.,* outlined significant efficiency and cost savings within the offsite manufacturing sector for buildings. Similarly, Lee et al.'s research identified a considerable enhancement in project performance in South Korea's modular construction projects. These findings correlate with the current research that underscores BIM's potential in improving efficiency, reducing costs, and boosting overall project performance within offsite construction. However, there is a divergence when it comes to the unique challenges facing SMEs in the adoption of BIM. Unlike Vernikos et al.'s (2014) findings, which suggested smooth integration of BIM among SMEs in Scandinavian countries due to supportive government policies, the present study highlights the constraints experienced by UK SMEs. Limited resources, financial restrictions, and a lack of state support emerged as significant obstacles hampering the full adoption of BIM within UK SMEs.

The current study reveals an isomorphic trend among UK organisations, demonstrating a leaning towards BIM and offsite construction adoption. Interestingly, a similar trend was observed by Zhang *et al.,* (2018) in the Australian construction industry, where BIM adoption became increasingly favoured despite initial reluctance due to perceived high costs and steep learning curves. This study, therefore, expands the understanding of the global discourse on BIM adoption in offsite construction. It offers insights unique to the UK context and strengthens the argument for the development of region-specific strategies and policies to overcome the challenges that SMEs encounter during their transition towards more innovative construction practices.

Going forward, the approach of international comparative research could continue to illuminate how regional variations in policy, industry maturity, and socio-cultural factors shape the adoption and success of BIM in offsite construction. The findings from such research will be invaluable to policymakers and industry practitioners globally, helping to foster a more comprehensive understanding and effective implementation of BIM in offsite construction.

CONCLUSIONS

The study presents insightful findings on the impact of Building Information Modelling (BIM) on offsite construction for UK's small and medium-sized enterprises (SMEs). It provides a critical understanding of the benefits and barriers experienced by SMEs in adopting BIM for offsite construction, thus contributing to the wider international discourse on this subject. The study's findings indicate that the implementation of BIM in offsite construction provides clear benefits, such as improved efficiency, cost reduction, and enhanced project performance. However, it also brings to light the unique challenges faced by SMEs, particularly in the UK, such as resource limitations and financial constraints. These challenges, unless addressed, could hinder the full-scale adoption of BIM in offsite construction by SMEs.

This study recommends further research into the exploration of specific strategies that SMEs can adopt to overcome the barriers to implementing BIM in offsite construction. This recommendation is informed by the limitations encountered in this study. Future research could aim to understand the long-term impacts of BIM adoption on the performance and competitiveness of SMEs in the construction industry, including how it might influence business growth, competitiveness, and sustainability.

Moreover, an in-depth investigation into the roles of different stakeholders in facilitating BIM adoption by SMEs could offer valuable insights. Such an analysis could delve into the contributions of larger corporations, government entities, and professional associations in supporting SMEs in their transition to BIM-based offsite construction. Understanding and addressing the unique challenges SMEs face in adopting BIM for offsite construction is pivotal for reaping the full benefits of this approach. It has the potential to lead to improved efficiency, cost savings, and enhanced project outcomes within the construction industry, both in the UK and globally.

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