LEAN AND BIM IMPLEMENTATION TOWARDS ACHIEVING NET-ZERO: BARRIERS WITHIN OFF-SITE CONSTRUCTION

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ABSTRACT

The UK Government aims to achieve net-zero buildings by 2050, thus prompting many construction companies to adopt sustainable practices. Small and medium-sized enterprises (SMEs) make up a significant portion of the sector and face challenges in embracing digitalisation through BIM, which could facilitate this transition. This paper presents initial findings from a Knowledge Transfer Partnership (KTP) project focused on enhancing digitalisation and achieving net-zero within an off-site construction SME. The research adopts Action Research to identify barriers to implementing BIM and Lean towards net-zero and propose improvement actions. The study emphasises incorporating digital tools through the project's lifecycle, using sustainable materials, accurately measuring carbon footprints, enhancing production processes and optimising production workflows. This research offers insights on innovative technologies driving net-zero initiatives within off-site construction SMEs.

Keywords: *BIM, Lean, Digitalisation, Sustainability, Net-zero, Off-site construction*

INTRODUCTION

With the construction industry currently contributing to 36% and 39% of global energy use and carbon emissions respectively (WGBC, 2019), the Committee on Climate Change, (CCC, 2019) notes that emissions must decrease by an average of 15 MtCO2e annually in order for the UK to achieve net-zero greenhouse gas emissions by 2050. Given these challenges, the construction industry must enhance efficiency and productivity, especially through innovative approaches like lean construction and BIM (Tezel et al., 2020). Additionally, the Department for Business & Trade (2023) reports that the construction

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sector hosts the largest share of SMEs in the UK private sector, about 883,000. Thus, encouraging BIM and lean construction adoption among these businesses is crucial for the transformation of the construction industry.

This paper focuses on the initial outputs of a three-year Knowledge Transfer Partnership (KTP) project aimed at improving digitalisation and processes through BIM, reducing carbon emissions, improving procurement and resources efficiency, and exploring low-carbon modular construction materials towards achieving net-zero targets. It includes an assessment of BIM and lean strategies within one SME off-site construction company, highlighting barriers to implementation and proposing solutions to these challenges.

LITERATURE REVIEW

Off-site manufacturing and prefabrication enhance construction speed, reduce labour needs, and lower environmental impact (Gunawardena and Mendi, 2022). Although off-site manufacturing already promotes lean principles, adopting BIM can offer further benefits, improving collaboration, decision-making and productivity (McHugh et al., 2019). Furthermore, Sacks et al. (2010) suggest that integrating lean practices with BIM can enhance off-site manufacturing efficiency, focusing on waste reduction, improved flow, and reduced construction time. Despite the UK government's 2016 target for Level 2 BIM maturity in public projects, the industry largely remains at Level 1 with SMEs – responsible for 75% of work – facing adoption challenges (Prabhakaran et al., 2021; IPA, 2016).

Furthermore, although current building emissions are predominantly operational carbon, as reduction efforts continue, embodied carbon is projected to increase significantly, potentially representing 40-70% of emissions from new buildings in the UK (LETI, 2020). Current policies recommend reducing both operational and embodied carbon to achieve net-zero targets, underscoring the need for whole lifecycle assessment (WLCA) to evaluate environmental impacts and improve building performance (Hollberg et al., 2020; UKGBC, 2021). Faludi et al. (2012) highlighted the importance of LCA modelling in guiding sustainable choices for prefabricated buildings. Additionally, Hollberg et al. (2020) emphasised that BIM tools can streamline LCAs, and early integration in architectural design is essential for minimising environmental impacts.

BIM awareness has grown from 13% in 2011 to 73% in 2020, mainly in medium-to-large firms (NBS, 2020). However, barriers such as resistance to change, high costs, software complexity, and interoperability issues hinder widespread adoption (Ayman et al., 2018; Carvalho et al., 2019). Furthermore, while BIM can streamline lifecycle assessments (LCA) and support net-zero efforts, research on integrating BIM, Lean, and LCA in off-site construction SMEs remains limited. This paper explores the challenges SMEs face in adopting these practices and proposes strategies for improvement.

RESEARCH METHOD

This research employs Action Research (AR) to tackle practical challenges in Lean, BIM, and net-zero within one SME off-site construction company, Company A, who specialise in 3D volumetric construction within the commercial building sector. Company A plans to enhance digitalisation and align with the UK's Net-Zero 2050 targets through a Knowledge Transfer Partnership (KTP) with the University of Huddersfield. The initial stage of this 3-year project involved understanding the company's strategic goals, key processes, products, and clients, alongside the work-flow of the 3D volumetric modules from design through off-site production to transportation and on-site installation. The initial study presented in this paper involved observations, process mapping, and stakeholder interviews to understand existing workflows and identify areas for improvement as well as barriers limiting the company from adopting Lean and BIM.

FINDINGS

BIM implementation and net-zero at Company A is summarised in Table 1.

Table 1: Current state of BIM implementation and net-zero at company A (Onyenokporo et al., 2024)

CURRENT APPLICATION OF BIM	CURRENT STATE OF NET-ZERO IN DESIGN AND PRACTICE
Company A's use of BIM is limited to big projects where it is mandated by clients or large construction companies.	No automation or digitalisation during the production process to improve productivity and quality of modules and reduce waste. They however create standardised cassettes for floor and roof to improve output speed.
They rely on 2D CAD drawings and only recently started creating 3D models using Autodesk Revit. They have their own procedures for their practice but there is a lack of design coordination.	Manual material take-offs for materials which lead to high waste production. However, some of the timber off-cuts are used as fuel for the factory biomass burner. Waste generated from off-site manufacturing process is not clearly quantified and often lumped together in skips.
Company A has not adopted other features of BIM such as 4D, 5D or 6D BIM.	Embodied carbon of materials is not considered during procurement, and lack of information regarding embodied carbon of building materials used for the module envelope design and end-of-life. Some of their materials have no EPDs to verify their environmental impact.
Only one design staff has the skillset to generate 3D models, and most of the factory and installation team still work off 2D paper drawings.	Whole Life cycle assessments are not yet conducted for projects. Main considerations for material selection are fire performance, thermal performance (u-values), and cost. Although the company uses timber-framed construction which stores carbon, and hot-rolled steel with high recyclable material content.
Clash detection is currently done using 2D drawings, leading to issues on-site that require reconfiguring designs during on-site installation.	Building performance analysis is typically conducted at final design stage. Simplified Building Energy Modelling (SBEM) is conducted for many projects, but Dynamic Simulation modelling (DSM) is done only when requested by clients or when complex HVAC systems are used

Furthermore, barriers to implementing digitalisation, lean practices, and net-zero were identified. These include the fast-paced modular construction process which limits the adoption of Lean and BIM, and the continued use of 2D CAD for smaller projects due to client requirements. Subcontractors often work in 2D, making 3D clash detection unviable, while limited in-house control over subcontracted work exacerbates interoperability issues.

Additionally, significant costs for training and software, a lack of technical know-how, concerns about return on investment, and the alignment of sustainability initiatives with regulations create further obstacles. The absence of standardised designs adds to these challenges, as sector-specific requirements can vary widely.

The authors proposed strategies towards achieving net-zero at Company A. These include enhancing BIM digital skills and processes, decreasing the company's carbon footprint by striving for carbon-neutral building manufacturing, optimising procurement, minimising material waste, and exploring new low-carbon materials. Additionally, automation can streamline design and planning processes to increase productivity. The adoption of smart technology can also improve building monitoring to enhance occupant satisfaction and gather post-occupancy data for better performance simulations.

CONCLUSIONS

This paper examines the UK off-site construction industry, highlighting challenges faced by one off-site manufacturer in achieving net-zero targets, and in order to identify areas for improvement and propose strategies for improvement through Lean and BIM. Key recommendations include leveraging digital tools, conducting whole lifecycle assessments, and engaging stakeholders to foster a sustainability culture. The findings offer valuable insights for off-site SMEs and emphasise the need for collaborative approaches to drive sustainable change. Future research will explore the implementation of Lean and BIM strategies at Company A to improve efficiencies and achieve net-zero goals.

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