

GREEN AND DIGITAL INNOVATIONS FOR MANAGING CONSTRUCTION SUPPLY CHAIN IN THE NET ZERO ECONOMY (NZE)

Ali Al-Zaini¹, Melissa Chan², Victor Arowoia³, Saeed Aramesh⁴, & Asrul Masrom⁵

ABSTRACT

The construction industry is a major contributor to global greenhouse gas emissions, requiring clear pathways toward net-zero outcomes. One promising approach is adopting green and digital innovations in construction supply chain management. Grounded in Lean Construction philosophy particularly value generation, waste elimination, flow efficiency and continuous improvement, this study examines factors that drive and facilitate the adoption of green and digital innovations. It also explores policy and regulatory barriers, innovative business models and industry-specific strategies supporting the transition to a Net Zero Economy (NZE). From a lean perspective, carbon-intensive supply chain activities can be understood as systemic waste resulting from variability, overproduction, rework and inefficient logistics. The circular economy aligns closely with lean thinking by promoting lifecycle value optimisation and resource efficiency to support decarbonisation. However, research on developing lean-enabled NZE supply chains in the building sector remains limited. Using a systematic literature review, this study synthesises strategies to advance the adoption of eco-friendly and digital technologies within lean-oriented supply chain management. The findings extend current knowledge by integrating green and digital innovations with lean principles to support a more sustainable, efficient and net-zero construction production system.

KEYWORDS

Digitalization, supply chain, lean construction, Net Zero Economy (NZE), systematic review

INTRODUCTION

In response to the urgent need for global decarbonisation, the building and construction industry responsible for more than one-third of global carbon emissions (IEA, 2020) faces significant challenges in achieving a Net Zero Economy (NZE) by 2050 as outlined in the Paris Agreement (BPIE, 2022). While countries and companies have committed to climate neutrality, current data indicate that the sector remains off track for decarbonisation (BPIE, 2022). Achieving NZE in construction therefore requires more than the adoption of isolated technologies as it demands systemic transformation across the construction supply chain. Green materials, digital platforms,

¹ Graduate/Mr, College of Sport, Health and Engineering, Victoria University, Melbourne, Australia, ali.alzaini1@live.vu.edu.au

² Senior Lecturer/Dr, College of Sport, Health and Engineering, Victoria University, Melbourne, Australia, melissa.chan@vu.edu.au, orcid.org/0000-0003-1589-6850

³ PhD Graduate/Dr, College of Sport, Health and Engineering, Victoria University, Melbourne, Australia, victor.arowoia@vu.edu.au, orcid.org/0000-0002-7436-9762

⁴ PhD Graduate, Mr, School of Property, Construction and Project Management, RMIT, Melbourne, Australia, saeed.aramesh@vu.edu.au

⁵ Associate Professor/Dr, Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia, Johor, Malaysia, asruln@uthm.edu.my, orcid.org/0000-0001-5221-2855

and circular economy strategies offer potential pathways for reducing emissions, but their effectiveness depends on how these innovations are integrated into value creation, waste reduction, and production flow. Lean construction, grounded in the Transformation–Flow–Value (TFV) theory (Koskela, 2000) provides both a theoretical and operational foundation for such integration. Lean principles emphasizing value maximization, waste minimization and workflow reliability enable green and digital innovations to enhance environmental performance while improving operational efficiency.

Despite growing adoption of green and digital solutions, the construction industry currently lacks a cohesive framework that aligns these innovations with lean principles. Supply chain inefficiencies including fragmentation, variability, overproduction, and material waste reduce productivity and increase carbon-intensive outputs (Darko et al., 2017; Farooque et al., 2019). Accordingly, this study addresses this gap by focusing on the intersection and integration of green, digital, and lean innovations. Specifically, it systematically reviews selected publications to examine how these innovations interact to improve sustainability and efficiency in construction supply chains. The results highlight key mechanisms, enablers, and challenges, providing actionable insights for implementing innovations effectively to support the transition toward a Net Zero Economy.

LITERATURE REVIEW

The development of green construction and its supply chain management have been widely recognized as critical for achieving a Net-Zero Economy (NZE) (Hampson & Kraatz, 2012; Liu, Dong, & Shen, 2020). Existing research suggests that conventional construction supply chains characterized by high uncertainty, frequent design changes and informal procedures face structural and operational challenges that impede sustainability objectives (Dallasega, 2018). While studies have explored strategies such as partnering, lean construction, and technology integration to address these challenges, there is a lack of comprehensive frameworks linking these approaches to environmental performance (Meng, 2019; Naoum & Egbu, 2015).

Critical analysis of prior work indicates that effective green supply chain management (GSCM) requires both technological and managerial interventions. Musarat et al. (2022) argue that incorporating environmental considerations such as eco-friendly procurement and sustainable design into traditional supply chains can significantly enhance green construction outcomes. Similarly, Badi & Murtagh (2019) highlight that innovation, strategic leadership, and organizational culture are key enablers of sustainable practices, yet practical guidance on operationalizing these factors remains limited. This suggests that while the literature identifies success factors, it often treats them in isolation without examining their interaction or integration across the supply chain.

The literature also points to methodological advancements for evaluating GSCM. Banihashemi et al. (2020) examine how innovations, including green and digital practices, influence sustainable construction project outcomes, providing a foundational framework for integrating green and digital strategies in construction supply chains. Green design refers to planning and designing buildings to minimize environmental impact while green construction supply chain management refers to the adoption of environmentally sustainable practices such as resource efficiency, waste reduction and eco-friendly material sourcing throughout procurement, logistics, and project delivery processes in the construction industry. Banihashemi et al. (2020) provided a framework for integrating green and digital innovations, while Ali et al. (2020) and Liu et al. (2018) demonstrate decision-support tools such as TOPSIS, Balanced Scorecard, and SCOR for assessing performance. These approaches underscore the need to consider both environmental and operational dimensions simultaneously, rather than assessing innovations separately. Yet, evaluations remain fragmented, and the role of digital technologies

in amplifying sustainability impacts is underexplored, particularly when combined with lean principles.

Emerging trends further highlight the importance of circular economy principles in construction supply chains. Yang (2011) demonstrates that green supply chains involve complex reverse logistics networks, emphasizing recycling, by-product recovery, and material reuse. Integrating these approaches with lean construction can theoretically extend waste-reduction principles to environmental emissions: overproduction, rework, and transport variability directly translate into carbon-intensive outputs. Evaluating green construction supply chain performance through digital innovations is essential because digital tools such as BIM, IoT and AI-enabled monitoring facilitate efficient resource management, performance tracking, and decision-making. Studying these concepts together allows for an integrated understanding of how digital technologies can amplify the sustainability impact of green construction practices. Consequently, the literature suggests that environmental performance should not be treated as a standalone concern but as an extension of production efficiency within lean frameworks.

Lean Construction has traditionally emphasized production efficiency, supply chain flow and waste reduction. While these operational aspects are critical, Lean also extends to design management and early-phase collaboration, particularly through Target Value Design (TVD). TVD sets cost and performance targets at the outset of a project, enabling iterative design decisions and active stakeholder engagement to align project outcomes with client and sustainability goals (Ballard, 2000; Koskela & Ballard, 2006; Dave & Koskela, 2009). Studies have shown that TVD supports value-focused decision-making, reduces downstream waste, and improves predictability, while facilitating the integration of green and digital innovations in construction projects (Malvik et al., 2021; Zimina et al., 2012). By connecting early-phase design management with production and supply chain principles, TVD operationalizes Lean theory across the project lifecycle, enhancing resource efficiency, sustainability performance and the transition toward carbon-aware, net-zero construction supply chains.

Overall, synthesizing these studies reveals a gap in current research: while green, digital, and lean innovations have been studied individually, there is limited understanding of their combined effect on supply chain efficiency and sustainability. This study addresses this gap by examining the intersection and integration of these innovations, offering insights into mechanisms, enablers and challenges for implementing sustainable practices in construction supply chains.

METHODOLOGY

This study adopts a Systematic Literature Review (SLR) approach to comprehensively examine the integration of green, digital, and lean innovations in construction supply chains and their role in achieving a Net-Zero Economy (NZE). The SLR approach was selected because it allows for structured, transparent, and replicable identification, evaluation, and synthesis of relevant studies, which is essential for addressing the research objectives. The methodology aligns with established SLR frameworks, including PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) and the research onion approach, ensuring rigor and reproducibility (Aromataris & Pearson, 2014; Farahzadi & Kioumars, 2023).

The research objectives defined in the Introduction are directly mapped to the SLR process, which examines how green and digital innovations enable eco-friendly construction, how stakeholder engagement and organizational culture affect adoption and the advantages and limitations of these innovations in balancing sustainability and efficiency. To address these objectives, the methodology involved defining research questions to guide a targeted literature search, developing a structured search strategy using keywords derived from the objectives such as ‘green construction supply chain management,’ ‘digital innovation in construction,’ ‘net-

zero economy,’ and ‘circular economy’ and conducting searches across Scopus and IEEE Xplore. Inclusion criteria focused on publications from 2012–2025, in English, and peer-reviewed journals or conference papers directly relevant to the research questions, while iterative screening of titles, abstracts and full texts refined to 44 studies.

Key findings, themes and relationships were systematically extracted and synthesized from both qualitative and quantitative studies to develop an integrated understanding of green, digital, and lean innovations in construction supply chains. Each study was evaluated for research design, methodology and data analysis to ensure reliability and validity. This systematic and transparent approach ensures a direct link between the research objectives and methodological procedures, enabling the identification of gaps, enablers and barriers therefore providing a foundation for a conceptual framework to support the construction industry’s transition toward a Net-Zero Economy.

Results are recorded for each search for each of the terms used, this repetitive process will refine the search process to obtain as much relevant literature as the proposed research topic (5) after relevant articles are identified the screening and selection process will take place. The titles and abstracts, introduction, results, discussion, and conclusions that relate most to the research topic and research questions will be selected for (6) data extraction. The data extraction of the filtered literature will be used to address some key findings based on the green construction topic, key findings, and implications to the research problem. The data are synthesized to identify relevant patterns, themes and relationships between the studies that will be addressing the research question to develop a conceptual framework. (7) Then, the findings will be analysed and combined from the qualitative and quantitative studies issuing appropriate available methods to give a thorough understanding of the research question. (8) The quality and accuracy of the relevant studies will be evaluated based on the study design, methodology used, data analysis result reporting. This process will help to ensure the literature’s findings are based on reliable, relatable, and valid evidence. (9) The findings will be presented in a concise manner emphasizing the main key themes, patterns and relationships identified in the literature.

This review will help in identifying and pinpointing gaps in the current research, key concepts, and relevant theories that will aid in building a conceptual framework for the study. Additionally, this systematic approach to literature review will be almost comprehensive, unbiased to a degree possible, and will provide a rigorous review of the exiting literature on the adoption of green and digital innovations in the construction industry and the strategies to facilitate the industry’s transition towards NZE. The process followed for the systematic review (Pluye & Hong, 2014). For the article to be eligible for the study, it must meet several criteria:

1. Included articles were required to focus on digital innovations that support sustainable construction practices, ensuring alignment with the study’s objectives on green construction performance or supply chain management aimed at the net-zero carbon economy. Brief mention of the theme might not be sufficient however, it needs to have investigated, analysed or discussed the issues revolving around the construction industry’s net-zero goal and the green digital innovations.
2. Strong research methods, with presentation of data or in-depth case studies, surveys, or thorough analyses of the topics mentioned.
3. The paper must address major areas within the study’s research questions.

An initial search across multiple databases retrieved 104 publications, including journal articles and conference papers. Following the application of inclusion and exclusion criteria focusing on relevance to green construction and digital innovation, 44 studies were selected for detailed analysis.

RESULT AND DISCUSSION

The findings are interpreted in relation to the research questions, emphasizing how green, digital and lean innovations interact to influence sustainable construction performance. Rather than simply summarizing existing literature, this discussion identifies patterns, relationships, and practical insights, highlighting the synergy between these innovation domains. Digital innovations such as BIM, IoT and AI-enabled monitoring enhance resource efficiency, facilitate real-time performance tracking, and support the adoption of green construction practices. Lean approaches streamline processes, minimize waste, and improve project delivery efficiency, further reinforcing sustainability objectives. By framing each theme in direct connection with the research questions, this section provides a coherent understanding of how the integration of these innovations contributes to improved environmental, operational, and economic outcomes in construction projects.

GREEN INNOVATIONS IN CONSTRUCTION

Green innovations in construction play a critical role in improving sustainability performance, reducing environmental impact, and enhancing resource efficiency. Studies indicate that technological and process-based innovations are central to achieving these outcomes. For example, research on innovative city construction in China (Li et al., 2022) demonstrates that the adoption of new technologies and resource-efficient practices within urban construction projects can stimulate green innovation. The effectiveness of these initiatives varies depending on city size, location and industrial structure, highlighting the need to tailor green strategies to specific construction contexts. Within the construction sector itself, green building technologies (GBTs) and sustainable materials are key drivers of environmental performance (Miller et al., 2021; Osman et al., 2023). Despite potential benefits, adoption is often constrained by factors including high initial costs, limited knowledge and resistance to change (Darko et al., 2017). These barriers emphasize that promoting green innovations requires not only technological solutions but also supportive policies, stakeholder awareness and capacity-building initiatives.

Additionally, integrating circular economy principles into construction supply chains has been shown to enhance sustainability outcomes (Farooque et al., 2019). Circular practices such as material recycling, process optimization and waste minimization complement green innovations by improving resource efficiency and reducing environmental impact. Collectively, these studies underscore that green innovations in construction are most effective when combined with strategic management, technological adoption and stakeholder engagement. Overall, the evidence demonstrates that green innovations, whether through materials, technologies, or processes are closely linked to improving sustainability performance in construction projects. This section addresses research questions by highlighting the mechanisms, enablers and challenges of implementing green innovations, providing a foundation for understanding how digital and lean innovations may enhance project outcomes.

RISKS, BARRIERS, AND OPPORTUNITIES

In the pursuit of Net Zero economy, the construction industry just like any other industry faces its own unique challenges and opportunities in the adoption of green and digital innovation for effective supply chain management. This sector's environmental impact along with its economy presents risks and barriers to achieving sustainability and environmentally friendly objectives. However, the aim of self-conscious countries is to raise awareness of climate change and the need for sustainable infrastructure. Meanwhile digital technologies and sustainable practices potentially can revolutionize construction supply chain management through the increase of efficiency and transparency while reducing the industry's carbon footprint.

While the critical risks factors identified in (Bajpai & Misra, 2020) case study for digitalization in the construction industry ranked by using the Fuzzy TOPSIS method; as they

the most significant risk factors were data privacy, security, user skills, poor resource planning, deviation of policies and inappropriate business processes. On the other hand, a study (Shi et al., 2013) surveyed major stakeholders in Shanghai's construction industry to find most significant barriers include additional cost, incremental time, a limited availability of green suppliers and information while there was a consensus amongst the stakeholders on the importance of considering environmental requirement in green construction projects. While the recent study by (Wang et al., 2021) carried out through questionnaire surveys and statistical analysis to identify associated barriers. They have found 16 critical barriers, the top five being lack of government incentives, extra cost associated with green construction technology (GCT), dependence on traditional construction technology, shortage of tech training, conflict of interest amongst stakeholders. It is found in some countries that stakeholders within the construction industry have a low to moderate knowledge of the concept of green/sustainable construction (AlSanad, 2015).

A recent study (Silva et al., 2021) finds that (i) educational programs that are related to the green building technologies for developers, contractors, and policymakers, (ii) sufficient information to the cost and benefits, (iii) mandated codes and regulations are amongst the top simulating measures to promote the use of green building technologies. An investigation has also researched and interviewed professionals from 11 developing countries to find the top barriers (Ahmed, Thaheem, & Maqsoom, 2020) however the study have also identified 23 opportunities; the top being improved reputations, potential for cost reduction, increased profitability, reduced environmental risks In the same vein, Liu et al. (2020) investigated the practical impact of the sustainable construction on the developed countries' macroeconomics. A strong correlation was found between the GDP growth and the number of large sustainable infrastructure facilities constructed in Russia and China.

Studies uncovers the mechanisms that influence the green technology innovation behaviour (GTIB) of construction firms (Li et al., 2022). Through a vector autoregressive model and time series data between 2000 and 2018 to analyse the factors influencing GTIB, it found that government investment had most significant impact on green technology innovation behaviour. These studies collectively emphasize the importance of strategic planning and process optimisation to enhance green technology innovation, sustainability, and efficiency in the construction industry. The opportunities suggest that in today's competitive business landscape, green innovation has emerged as a crucial strategy for businesses to expand their market presence and ensure long-term viability. Given these advantages, green innovation has become the key focus for organisational leaders in pursuit of sustainable business practices (Karimi Takalo et al., 2021).

Overall, green construction faces various risks, challenges and opportunities that have a major effect on industry. Although higher initial costs, lack of awareness and complex regulations could impede its adoption, the opportunities for environmental benefits, improvement to humans' health, long-term costs savings are compelling reasons to push forward for growth and achieving lower carbon footprint. There is a need to address the barriers and emphasize opportunities to transition towards a more sustainable future in the construction industry.

CONCEPT OF NET-ZERO AND ITS IMPACT ON CONSTRUCTION

The building and construction sector is currently at crossroads, where a decision must be made on how to navigate the obstacles of digital transformation and the transition to a net-zero economy. One of the most important areas where all these challenges arise is in the construction industry. Recent research has brought light on the potential for green and digital innovations to support efficiency, cut down the environmental impact aid in the transition to Net-Zero Economy (Rockström et al., 2017). The innovations vary in the approach, which include the

use of environmentally friendly materials, waste management strategies, renewable energy, digital technologies (such as AI and IoT), and new strategies for the utilisation of energy in the building process. However, incorporating this advancement into construction supply chain is a challenging Endeavor that calls for more research. The purpose of this section is to explore the studies pertaining to the Net-Zero issue and its impact on construction.

The road map to achieve Net-Zero Economy within the construction necessitates a collective awareness and commitment from countries, governments, corporations, businesses, and societies at large. This is response to the precarious situation humanity finds itself in due to the escalating environmental impact of our activities (Sertyesilisik, 2019). Previous studies in the area draws the road map in decades intervals, it suggests that between 2030-2040 a breakthrough must occur, especially to the building and construction section as it must be “carbon neutral or carbon negative” industry. The study suggests that for the construction industry to achieve this, the technology of emissions-free concrete and steel is to be implemented or replace this with traditional materials used that have zero or negative-emissions substances such as wood, stone and carbon fibre (Rockström et al., 2017).

LEAN CONSTRUCTION AND THE REFRAMING OF NET ZERO AS A PRODUCTION SYSTEM PROBLEM

Achieving a Net-Zero Economy in construction requires more than implementing green technologies; it demands a redesign of the production system consistent with Lean principles. Lean Construction reframes inefficiencies—such as overproduction, rework, and inventory buffers as forms of systemic waste, which directly contribute to carbon emissions when applied to construction supply chains. By integrating the Transformation–Flow–Value (TFV) framework, this perspective positions environmental performance as an inherent aspect of production management rather than a separate objective. Digital technologies, including BIM, IoT and AI-enabled monitoring, enhance Lean production control by improving workflow reliability, enabling pull-based procurement, and reducing variability, thereby operationalizing Lean principles in a carbon-constrained context. Furthermore, Lean’s emphasis on lifecycle value aligns with circular economy strategies, promoting material reuse, recycling and resource efficiency across the entire supply chain. Together, these approaches provide a coherent framework for embedding sustainability into production processes and advancing NZE goals.

In addition to production-focused strategies, Lean Construction extends into design management and early-phase collaboration, notably through Target Value Design (TVD). TVD sets cost and performance targets during the design phase, facilitating iterative decision-making, cross-stakeholder collaboration, and alignment of project objectives with sustainability outcomes. When combined with green and digital innovations, TVD strengthens both design and production processes, enabling the construction supply chain to minimize waste, enhance resource efficiency, and improve environmental performance. Conceptually, this integration demonstrates that Lean and circular economy principles are mutually reinforcing Lean reduces inefficiencies and optimizes value flow, while circular strategies extend this optimization to materials, energy, and lifecycle performance. By bridging design, production, and lifecycle considerations, Lean Construction provides a holistic, carbon-aware framework for transitioning construction supply chains toward net-zero outcomes.

CONCLUSION

This research explores the adoption of green and digital innovations in the construction industry, focusing on improving supply chain management to support the transition toward a net-zero carbon economy. Drawing on a systematic review of relevant literature, the study identifies key challenges, risks, barriers and opportunities shaping innovation adoption and provides insight into the industry’s current state and transformation potential. Grounded in Lean

Construction principles, the findings emphasise that technological adoption alone is insufficient; effective supply chain practices aligned with value generation, waste elimination, and flow efficiency are essential to achieving meaningful decarbonisation outcomes. The study proposes a structured framework that integrates green and digital innovations within Lean-oriented supply chain management to enhance coordination, reduce variability and minimise carbon-intensive waste. By conceptualising emissions as a form of production inefficiency, the research extends Lean thinking toward carbon-aware construction systems. Several limitations should be acknowledged, including the scope of the literature review, contextual and geographical variations, potential generalisation constraints and the rapidly evolving nature of digital technologies that may affect long-term relevance. Overall, the adoption of green and digital innovations, when embedded within Lean Construction philosophy, is critical to enabling a sustainable, efficient, and resilient construction industry aligned with net-zero objectives. The study contributes to the growing body of knowledge supporting environmentally responsible and performance-driven transformation.

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