Exploring the Integration of Digital Technologies and Lean Principles for Transformative Construction Project Management: A Review

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Abstract

This study explores the synergies between digital technologies and lean project delivery to address persistent challenges in the construction industry. The primary aim is to examine the integration of digital technologies, such as Building Information Modelling (BIM) and modular construction techniques, with lean principles to transform construction project management. Building on previous research highlighting the potential of these approaches, a narrative literature review examined existing knowledge on leveraging digital tools to enable lean project delivery. The review process involved secondary data from scientific databases, with 150 potentially relevant papers scrutinized and reduced to a final sample of 68. Findings demonstrate that integrating digital technology and lean principles drives substantial improvements in collaboration, visualization, data-driven decision-making, productivity, supply chain management, and overall project performance, as evidenced by global case studies. The study identified key challenges and implementation considerations, including the need for cultural shifts, training investments, and robust data management capabilities. BIM's role in enhancing design coordination and modular construction's contribution to waste reduction and efficiency are highlighted as critical components of this integrated approach. The research builds upon earlier studies emphasizing the importance of digital transformation in construction, while uniquely focusing on its synergies with lean principles. Future research directions include in-depth case studies, empirical investigations, and collaborative initiatives to further validate benefits, develop best practices, and explore emerging technologies' role in enhancing digital-lean synergies, thus unlocking the full potential of this integrated approach.

Keywords

Digital technology, Lean project delivery, Building Information Modeling, Construction project management, Modular construction, Construction industry.

1. Introduction

The construction industry has long faced persistent challenges related to productivity, cost overruns, and quality issues (Emmanuel et al., 2018; Momade, 2018). While projects have historically struggled to meet deadlines, stay within budgets, and deliver the expected level of quality (Momade, 2018), recent years have seen improvements in these areas. For instance, Gartoumi et al. (2023a) demonstrate how implementing lean construction techniques has improved quality and efficiency in megaproject construction, showcasing a real-world case study of successful application. These challenges underscore the need for a more efficient and practical approach to project delivery in the construction sector. Lean project delivery offers a promising solution to these longstanding issues (Babalola et al., 2019; Abina et al., 2023). Rooted in lean manufacturing principles, lean project delivery focuses on minimising waste and maximising value throughout the project lifecycle (Forbes & Ahmed, 2020; Mesa et al., 2019). By eliminating non-value-adding activities, reducing variation, and improving workflow, lean practices can enhance productivity, reduce costs, improve quality, and increase client satisfaction (Forbes & Ahmed, 2020; Alizadehsalehi et al., 2019).

Digital technology has emerged as a crucial enabler of lean project delivery in the construction industry (Babalola et al., 2019a). A wide range of digital tools and techniques, such as Building Information Modeling (BIM), project management software, mobile applications, data analytics, and automation, can support and facilitate the implementation of lean principles (Babalola et al., 2019b). These digital technologies can enhance collaboration, improve communication, streamline processes, and provide data-driven insights that drive informed decision-making (Ojelabi et al., 2019; Opoko et al., 2019).

Previous studies have explored the synergies between lean project delivery and individual digital technology applications, particularly during the COVID-19 pandemic. This period has underscored the importance of integrating digital technology with lean principles. For instance, Gartoumi et al. (2023b) mapped effective practices and frameworks used by the Architecture, Engineering, and Construction (AEC) industry, demonstrating how digital tools synergized with lean approaches to maintain project continuity and efficiency in challenging circumstances. Despite these insights, there remains a lack of comprehensive research on the integration of lean project delivery with the full suite of digital technologies currently employed in the construction sector. Understanding this integration is crucial for construction practitioners aiming to unlock the full potential of these strategies and achieve superior project outcomes (Sholanke et al., 2019; Sholanke, Opoko et al., 2019; Babalola et al., 2019b; Babalola et al., 2019; Emmanuel et al., 2018; Forbes & Ahmed, 2020; Babalola et al., 2019a; Chowdhury et al., 2019; Wang et al., 2020; Turner et al., 2021; Abioye et al., 2021; Tetik et al., 2019; Rafsanjani & Nabizadeh, 2023; Woodhead et al., 2018; Bolpagni & Bartoletti, 2021).

The paper's objective was to provide a comprehensive exploration of the synergies between digital technology and lean principles in the delivery of lean-guided construction project management. A comprehensive literature review on integrating digital technologies and lean principles for transformative construction project management was conducted to achieve this. Research related to digital technologies, lean construction, construction management, and construction project management was reviewed and analysed comprehensively. The gaps were also identified and discussed. Thus, this paper makes a modest contribution to discussing lean-guided construction projects toward achieving a more effective digitalised construction project management system.

The remaining sections of this paper is structured as follows: Section 2 outlines the materials and methods used in this review. Section 3 delves into the integration of digital technology and lean principles in construction project management, exploring key technologies, lean practices, and their synergies. Section 4 discusses the findings, including benefits, challenges, and future directions. Finally, Section 5 concludes the paper, summarizing key insights and implications for the construction industry. The findings of this study will also contribute to the growing body of knowledge on integrating digital technology and lean construction by providing a roadmap for the industry to enhance efficiency, reduce waste, and deliver projects more successfully.

2. Materials and Methods

This study employed a traditional (narrative) literature review approach to identify, consolidate, and synthesise the existing knowledge on the use of digital technology in achieving lean project delivery in the construction industry. As highlighted by Grant and Booth (2009), the narrative review method allows for the examination of what has been accomplished previously, enabling the consolidation of existing work, the identification of gaps, and the avoidance of duplication. Additionally, the study utilised content analysis techniques to examine current trends and patterns within the reviewed literature. The review process involved secondary data, which refers to information gathered and published by other researchers for a primary purpose (Johnston, 2014). This approach is beneficial as it allows for the gathering and analysing of data in a time- and resource-efficient manner, unlike conducting original data collection and analysis (Johnston, 2014). The literature search was conducted using various scientific databases. Google Scholar, Science Direct, Web of Science, and Elsevier were selected for the literature search due to their inclusive coverage of quality peer-reviewed journals in the research field of the construction industry, most especially in digital Technologies and lean Principles. The search keywords used were "lean project delivery," "digital technology," "construction industry," "quality improvement," and "automation." The search was limited to English-language publications between 2014 and 2024 to ensure the study is within the current state of knowledge in the field.

The initial search yielded 150 potentially relevant papers, which were then carefully scrutinised, and the final sample was reduced to 68 papers. The inclusion criteria for the selected literature were that the articles must address the use of digital technology and lean principles in achieving lean-guided project delivery. Articles that had not undergone peer review or were not pertinent to the study's focus were excluded, while the retrieved literature was restricted to journal articles written in English. The data extraction process involved thoroughly reading the selected papers and recording relevant information, such as the types of digital technologies covered, the approaches taken, and the outcomes of any empirical studies (Ogunbayo et al., 2023). The extracted data were then subjected to content analysis, where similar topics were grouped to identify common themes throughout the literature. This thematic approach was employed to organise and present the findings. The analysis of the data was carried out using a qualitative methodology to identify patterns and trends. The results are presented and discussed using a descriptive approach, providing a comprehensive overview of the synergies between digital technology and lean principles in lean-guided project delivery in the construction industry. Also, the study was limited to construction project management within the built environment to provide a focused context for examining the integration of digital technology and lean principles. This scope allows for a more targeted analysis of how these approaches are specifically applied and interconnected within construction project management processes, rather than broader applications across the entire built environment sector.

3. Digital Technology and Lean Principles in Construction Project Management

3.1 Lean Project Delivery

Lean project delivery is a powerful approach that has gained significant traction in the construction industry due to its ability to enhance efficiency, reduce waste, and promote value creation throughout the project lifecycle. Drawing from lean thinking principles, this methodology offers a comprehensive framework for optimising construction processes, improving quality, and fostering a culture of continuous improvement (Ogunbayo et al., 2023). One of the fundamental tenets of lean project delivery is eliminating non-value-adding activities, also known as waste. Babalola, Ibem, and Ezema (2019b) highlight the importance of identifying and eliminating activities that do not contribute to the desired outcome, such as unnecessary transportation, inventory, motion, waiting, overproduction, over-processing, and defects. By focusing on value-adding activities and minimising waste, lean construction practices enable more efficient resource utilisation, leading to cost savings and improved productivity (Akinradewo et al., 2018). Another critical aspect of lean project delivery is the reduction of variability, which is achieved through standardisation and implementing robust processes. Jin et al. (2019) emphasise the importance of minimising variability in materials, labour, and information flow to ensure consistent quality and reduce rework. This approach promotes a smooth workflow and enhances predictability, enabling better planning and coordination among project stakeholders.

Lean construction also strongly emphasises continuous improvement, often called "kaizen" in the lean philosophy. This principle encourages a culture of learning and adaptation, where processes are continuously evaluated and refined based on feedback and performance metrics (Yamamoto et al., 2019). By involving all stakeholders in the improvement process, lean project delivery fosters a collaborative environment that promotes innovation and problem-solving. Furthermore, lean project delivery emphasises the importance of understanding and meeting client needs. Chowdhury et al. (2019) highlights the focus on delivering projects that align with client requirements on time and within budget. This client-centric approach enhances customer satisfaction and ensures value is consistently delivered throughout the project lifecycle. Lean practices also contribute to improved safety on construction sites. Forbes and Ahmed (2020) note that lean principles such as standardisation, visual management, and practical communication help reduce hazards, improve coordination, and foster a culture of safety awareness. By prioritising safety, lean construction practices create a safer working environment, which can lead to reduced accidents and associated costs.

It is worth noting that the successful implementation of lean project delivery requires a cultural shift within the construction industry. Sholanke et al. (2019) emphasise the need for effective leadership, training, and a willingness to embrace change to reap the benefits of lean practices fully. Additionally, Opoko et al. (2019) highlight the importance of collaboration and integration among all project stakeholders, including designers, contractors, suppliers, and clients, to maximise the impact of lean principles. Lean project delivery offers a comprehensive approach to optimising construction processes, reducing waste, and promoting value creation. By drawing from the principles of lean thinking, this methodology addresses the unique challenges of the construction industry. It provides a framework for enhancing productivity, improving quality, reducing costs, increasing client satisfaction, and fostering a culture of safety and continuous improvement.

3.2 Digital Technology in Construction Project Management

The construction industry has witnessed a significant transformation by adopting various digital technologies that can potentially enhance project management practices (Turner et al., 2021). Building Information Modeling (BIM) is at the forefront of this transformation, a digital representation of a construction project's physical and functional characteristics. BIM facilitates the integration of design, construction, and operational data, allowing for improved decision-making, clash detection, and project performance tracking (Opoko et al., 2019; Ahmed, 2018). BIM models provide a comprehensive digital database that can be accessed and updated throughout the project lifecycle, fostering collaboration among project stakeholders (Hasan & Rasheed, 2019). By creating a virtual 3D model of the project, BIM enables the identification and resolution of design conflicts before construction, minimising rework and enhancing design coordination (Vilutienė et al., 2019).

BIM for design is always linked to interoperability between engineering professions. This interoperability is crucial for ensuring that different disciplines, such as architecture and structural engineering, can effectively collaborate. For example, Gartoumi, Zaki, et al. (2023) conducted a real case study on a high-standing villa where the BIM process was implemented based on the spirit of collaboration and interoperability using both Revit and Robot software. The results described the ease of modeling, verification, transfer, exchange, and error detection within the BIM process. This led to faster and easier modifications and improved decision-making.

In addition to BIM, construction project management has benefited from adopting comprehensive software solutions. These project management tools offer features for planning, scheduling, communication, and document management, streamlining project workflows and improving overall visibility (Tetik et al., 2019; M. Wang et al., 2020). By providing a centralised platform for managing project data, tracking performance, and generating reports, these software solutions help project teams plan and schedule activities, communicate effectively, and access relevant documentation, leading to improved coordination and efficiency (Emmanuel et al., 2018; Chowdhury et al., 2019).

Complementing these digital tools, mobile applications have become invaluable in enabling real-time communication, progress tracking, and data collection on construction sites (Amusan et al., 2018). These mobile apps ensure that field teams have immediate access to the necessary project information, improving communication between site and office, reducing delays, and enabling timely decision-making (Amusan et al., 2018; Klinc & Turk, 2019). Integrating digital technologies has also enhanced the construction industry's data analytics and visualisation capabilities. Techniques such as predictive analytics and machine learning can be applied to project data, allowing project managers to gain valuable insights, optimise resource allocation, forecast project outcomes, and identify areas for improvement (Gondia et al., 2020; Abioye et al., 2021). Visualisation tools like dashboards and data visualisation software help stakeholders interpret complex project information, facilitating informed decision-making (Akinosho et al., 2020).

The deployment of Internet of Things (IoT) devices and sensors on construction sites has further contributed to the industry's digital transformation (Gamil et al., 2020). These IoT-enabled systems can collect real-time data on equipment usage, energy consumption, environmental conditions, and worker activities, enabling performance monitoring and optimisation (A. Ghosh et al., 2020; Oke & Arowoiya, 2021). This data-driven approach allows project teams to make informed decisions to enhance productivity and efficiency. Immersive technologies, such as Augmented Reality (AR) and Virtual Reality (VR), have also found their way into construction project management. These technologies enable stakeholders to visualise and interact with project designs and simulations, enhancing collaboration, design coordination, and stakeholder engagement (Piroozfar et al., 2018; Noghabaei et al., 2020). AR and VR facilitate more effective communication and collaboration among project teams, allowing them to understand the project scope better and identify potential issues before construction (Oke & Arowoiya, 2021b; Nassereddine et al., 2022).

Robotic and automated technologies, including drones, autonomous equipment, and robotic process automation (RPA), are increasingly used in construction projects (Delgado et al., 2019; Gharbia et al., 2020). These technologies can enhance construction efficiency by automating time-consuming activities and reducing the reliance on manual labour (Achammer et al., 2018; Cai et al., 2019; Q. Chen et al., 2018). Cloud-based platforms provide a centralised and secure environment for storing, sharing, and accessing project data and documentation. Cloud computing facilitates real-time collaboration, data synchronisation, and remote access, enabling seamless communication and project coordination among distributed teams (Bello et al., 202; Xu et al., 2018). Cloud-based project management platforms allow project stakeholders to access and update information from any location, improving overall project efficiency and coordination (Garyaev & Rybakova, 2018; Oke et al., 2022; Oke et al., 2021).

These digital technologies significantly impact construction project management, providing tools and techniques to streamline processes, enhance collaboration, improve decision-making, and drive efficiency throughout the project lifecycle.

3.3. Integrating Digital Technology and Lean Project Delivery

The integration of digital technology and lean project delivery in the construction industry can be observed across several key areas, each contributing to the enhanced efficiency and effectiveness of construction projects (Tetik et al., 2019). At the forefront of this integration is the role of digital tools and platforms in fostering collaboration and communication among project stakeholders (Emmanuel et al., 2018; Oraee et al., 2019). Real-time collaboration software and digital communication platforms enable instant information sharing, file exchange, and simultaneous document editing, facilitating effective teamwork and improving decision-making (Oke et al., 2021; Bello et al., 202; Xu et al., 2018). Building upon this collaborative foundation, the construction industry has also witnessed the transformative impact of virtual design and visualisation through the adoption of Building Information Modeling (BIM) and 3D modelling (Ding et al., 2014; Ahmed, 2018; Bamgbose et al., 2024). These digital technologies provide a detailed, three-dimensional representation of the project's geometry, spatial relationships, and various components, allowing stakeholders to identify and resolve design conflicts early in the process (Tetik et al., 2019; M. Wang et al., 2020). This enhanced design coordination and clash detection significantly reduced rework, improving efficiency and productivity (Chowdhury et al., 2019; Kocakaya et al., 2019).

Blockchain technology has emerged as a promising tool for enhancing lean construction practices, particularly in supply chain management. By providing a secure, transparent, and immutable ledger system, blockchain can improve traceability, reduce disputes, and streamline processes in construction supply chains (Adewale et al., 2024; Ahmed, 2018; Bamgbose et al., 2024). For example, blockchain can be used to create smart contracts that automatically execute when predefined conditions are met, reducing delays and enhancing trust among stakeholders. Furthermore, blockchain can improve material tracking and verification, ensuring that the right materials are delivered to the right place at the right time, thus supporting just-in-time delivery principles of lean construction (Adewale et al., 2024).

Collecting and analysing project data through digital technologies further contribute to integrating lean principles in construction. Data-driven decision-making, enabled by the insights gained from robust data analysis, supports informed decisions, identifies areas for improvement, and optimises processes to reduce waste and enhance overall efficiency (Abioye et al., 2021; Akinosho et al., 2020). This data-centric approach is crucial in driving continuous improvement and consistently applying lean best practices (Opoku et al., 2021; Mesa et al., 2019). Integrating digital technology and lean project delivery extends to prefabrication and modular construction. Digital models and automated manufacturing processes facilitate precision, improved quality control, and faster on-site assembly, aligning with the principles of lean construction (Mesa et al., 2019; Sholanke, Opoko et al., 2019). By streamlining off-site construction, these digital tools and techniques contribute to reduced material waste, enhanced quality, and shorter construction schedules (Cifone et al., 2021). Furthermore, adopting automation and robotic technologies in construction can improve productivity, reduce manual labour, and enhance safety by automating repetitive and labour-intensive tasks (Achammer et al., 2018; Chen et al., 2018). These automated systems and robotic technologies perform tasks with greater precision and efficiency, increasing productivity and reducing reliance on manual labour (Gharbia et al., 2020).

Recognising the importance of supply chain management in lean project delivery, digital tools, such as real-time visibility, tracking, and data integration, can optimise material flow, improve inventory management, and enhance supplier collaboration (Le & Nguyen, 2021; Mesa et al., 2019). These digital solutions support lean supply chain management by providing stakeholders with up-to-date information on inventory levels, delivery schedules, and material locations (Meng, 2019). The integration of digital project management software and tracking tools enables real-time progress monitoring, key performance indicator (KPI) measurement, and early identification of deviations, facilitating informed decision-making and project control (Sepasgozar et al., 2019; Ratajczak et al., 2018). This centralised platform for managing project data and tracking performance ensures that project managers have the information to make informed decisions and maintain control over the project (Alizadehsalehi et al., 2019).

The effective integration of these digital technologies with lean project delivery holds immense potential for the construction industry, delivering significant benefits in improved collaboration, enhanced visualisation, data-driven optimisation, increased productivity, and streamlined supply chain management, ultimately leading to more successful project outcomes.

3.4. Benefits of Digital Technology in Lean Project Delivery

The synergetic application of digital technology and lean project delivery in construction offers numerous benefits that can significantly improve project performance and efficiency. At the core of these benefits is the enhanced collaboration and communication enabled by digital tools and platforms (Ikuabe et al.,2023). Real-time collaboration tools and digital communication platforms facilitate seamless information flow, allowing project stakeholders to work in a more integrated and efficient work environment (Mesa et al., 2019; Xing et al., 2021). By ensuring that relevant project information is easily accessible, these digital solutions enhance teamwork and enable effective decision-making, reducing communication delays (Tetik et al., 2019; Sepasgozar et al., 2020). Building upon the improved collaboration, integrating digital technology and lean project delivery also significantly enhances virtual design and visualisation. Through the adoption of Building Information Modeling (BIM) and 3D modelling, project designs can be visualised in great detail, enabling stakeholders to identify and resolve conflicts early in the design stage (Cifone et al., 2021; Alizadehsalehi et al., 2019). This detailed digital representation of the project allows for improved design coordination and minimises rework, contributing to the overall efficiency of the construction process. Furthermore, collecting and analysing project data through digital technologies provides valuable insights that support informed decision-making and process optimisation. Data-driven decision-making, enabled by these digital solutions, helps identify areas for improvement and optimise processes to reduce waste, aligning with the principles of lean project delivery (Mesa et al., 2019; Oraee et al., 2019). By using project data to gain insights into performance, productivity, and resource allocation, project teams can implement lean practices and eliminate inefficiencies, leading to enhanced overall efficiency.

Integrating digital technology and lean principles also extends to prefabrication and modular construction. Digital models and automated manufacturing processes facilitate the seamless integration of prefabricated elements, improving quality control, faster on-site assembly, and reduced material waste (Sholanke Opoko et al., 2019). By streamlining off-site construction, these digital tools and techniques contribute to prefabrication and modular construction benefits, aligning with the lean principles of minimising waste and improving productivity (Lekšić et al., 2020). In addition to these process-oriented benefits, integrating digital technology and lean project delivery enhances productivity by incorporating automation and robotic technologies. Integrating automated systems and robotic technologies can improve productivity, reduce manual labour, and enhance safety by automating repetitive and labour-intensive tasks (Achammer et al., 2018; Cai et al., 2019; Q. Chen et al., 2018). Robotic systems perform tasks with greater precision and efficiency, leading to increased productivity and reduced reliance on manual labour, further contributing to the lean objectives of the construction industry. The optimisation of supply chain management is another area where the synergetic application of digital technology and lean principles yields significant benefits. Digital tools that provide real-time visibility, tracking, and data integration can optimise material flow, improve inventory management, and enhance supplier collaboration, supporting lean principles in the supply chain (Sepasgozar et al., 2019; Ratajczak et al., 2018). These digital solutions facilitate better coordination and planning by providing stakeholders with up-to-date information on inventory levels, delivery schedules, and material locations, ensuring efficient material flow (Abioye et al., 2021; Akinosho et al., 2020).

Finally, integrating digital project management software and tracking tools enables effective project monitoring and control, contributing to the overall efficiency of lean project delivery. These digital tools facilitate real-time progress monitoring, key performance indicator (KPI) measurement, and early identification of deviations, allowing project managers to make informed decisions and maintain control over the project (Alizadehsalehi et al., 2019). By providing a centralised platform for managing project data and tracking performance, these digital solutions ensure that project managers have the necessary information to make informed decisions and effectively control the project. The effective integration of these digital technologies with lean project delivery strategies can lead to significant improvements in project performance, including enhanced productivity, reduced costs, improved quality, and increased client satisfaction, ultimately contributing to the success of construction projects.

3.5. Case Studies and Examples

The successful implementation of digital technology in lean project delivery is evident in various case studies and examples from around the world, showcasing the tangible benefits of this integrated approach. One such prominent example is the construction of The Shard, a 95-story skyscraper in London, which utilised Building Information Modeling (BIM) extensively to optimise the design, construction, and operation of the building (Alahyari et al., 2019; Koseoglu et al., 2019). The collaborative BIM approach facilitated clash detection, streamlined communication among project teams, and improved coordination, leading to significant time and cost savings.

Similar success stories can be found in other major construction projects, such as the expansion of the Oslo Airport in Norway. This project leveraged digital technology, including BIM, to enhance lean project delivery (Koseoglu et al., 2019). The digital model enabled efficient coordination among various disciplines and subcontractors, facilitating clash detection, optimised resource allocation, and off-site prefabrication. As a result, the project experienced improved construction productivity and reduced rework, aligning with lean construction principles. Akademiska Hus, a real estate company in Sweden, provides another illustrative case study of the successful implementation of digital technology and lean project delivery. The company implemented BIM and project tracking tools in various construction projects, enabling effective collaboration, reducing errors, and improving overall project performance (Koseoglu et al., 2019; Patching et al., 2023). This digital approach and adoption of lean principles contributed to the successful delivery of these construction projects.

Across the Atlantic, the construction of the Seattle Children's Hospital in the United States also demonstrates the integration of digital technology, particularly BIM, to optimise the design and construction processes (Alahyari et al.,

2019). BIM facilitated clash detection, prefabrication, and improved coordination among various trades, reducing construction rework and enhancing overall project efficiency.
In the realm of road and urban systems, the integration of digital technology and lean principles has also shown promising results. Gartoumi et al. (2022) proposed a framework that integrates Building Information Modeling (BIM) and Lean Construction (LC) to improve construction processes in urban environments. Their study demonstrated how this integrated approach can enhance project visualization, improve coordination among stakeholders, and reduce waste in urban construction projects. The framework showed particular promise in managing the complexities of urban infrastructure projects, where multiple systems and stakeholders often intersect.
These diverse case studies from around the world, ranging from high-rise buildings in Europe to hospital projects in the United States, collectively illustrate the tangible benefits of the synergetic implementation of digital technology and lean project delivery. The effective integration of tools like BIM, project tracking software, and collaborative platforms has improved coordination, reduced errors, optimised resource utilisation, and enhanced overall project performance, showcasing the transformative potential of this approach in the construction industry.

4. Discussion

The findings of this review highlight the significant potential and synergistic benefits of integrating digital technology and lean project delivery in the construction industry. The analysis of the existing research illustrates how this integrated approach can drive substantial improvements in project performance, efficiency, and overall success. At the core of these benefits is the enhanced collaboration and communication enabled by digital tools and platforms. Real-time collaboration software and digital communication platforms have been shown to facilitate seamless information flow, allowing project stakeholders to work in a more integrated and efficient work environment (Mesa et al., 2019; Xing et al., 2021). By ensuring that relevant project information is easily accessible, these digital solutions enhance teamwork and enable effective decision-making, reducing communication delays (Tetik et al., 2019; Sepasgozar et al., 2020).
Building upon this collaborative foundation, integrating digital technology and lean project delivery has also significantly enhanced virtual design and visualisation. The adoption of Building Information Modeling (BIM) and 3D modelling allows project designs to be visualised in great detail, enabling stakeholders to identify and resolve conflicts early in the design stage (Cifone et al., 2021; Alizadehsalehi et al., 2019). This detailed digital representation of the project facilitates improved design coordination and minimises rework, contributing to the overall efficiency of the construction process (Ding et al., 2014; Ahmed, 2018). Furthermore, collecting and analysing project data through digital technologies provide valuable insights that support informed decision-making and process optimisation. Data-driven decision-making, enabled by these digital solutions, helps identify areas for improvement and optimise processes to reduce waste, aligning with the principles of lean project delivery (Mesa et al., 2019; Oraee et al., 2019). Project teams can implement lean practices and eliminate inefficiencies by using project data to gain insights into performance, productivity, and resource allocation, leading to enhanced overall efficiency (Abioye et al., 2021; Akinosho et al., 2020).
Integrating digital technology and lean principles also extends to prefabrication and modular construction. Digital models and automated manufacturing processes facilitate the seamless integration of prefabricated elements, improving quality control, faster on-site assembly, and reduced material waste (Sholanke Opoko et al., 2019). By streamlining off-site construction, these digital tools and techniques contribute to prefabrication and modular construction benefits, aligning with the lean principles of minimising waste and improving productivity (Lekšić et al., 2020). In addition to these process-oriented benefits, integrating digital technology and lean project delivery enhances productivity by incorporating automation and robotic technologies. Integrating automated systems and robotic technologies can improve productivity, reduce manual labour, and enhance safety by automating repetitive and labour-intensive tasks (Achammer et al., 2018; Cai et al., 2019; Q. Chen et al., 2018). Robotic systems perform tasks with greater precision and efficiency, leading to increased productivity and reduced reliance on manual labour, further contributing to the lean objectives of the construction industry.
The optimisation of supply chain management is another area where the synergetic application of digital technology and lean principles yields significant benefits. Digital tools that provide real-time visibility, tracking, and data integration can optimise material flow, improve inventory management, and enhance supplier collaboration, supporting lean principles in the supply chain (Sepasgozar et al., 2019; Ratajczak et al., 2018). These digital solutions facilitate better coordination and planning by providing stakeholders with up-to-date information on inventory levels, delivery schedules, and material locations, ensuring efficient material flow (Abioye et al., 2021; Akinosho et al., 2020). Integrating digital project management software and tracking tools enables effective project monitoring and control, contributing to the overall efficiency of lean project delivery. These digital tools facilitate

real-time progress monitoring, key performance indicator (KPI) measurement, and early identification of deviations, allowing project managers to make informed decisions and maintain control over the project (Alizadehsalehi et al., 2019). By providing a centralised platform for managing project data and tracking performance, these digital solutions ensure that project managers have the necessary information to make informed decisions and effectively control the project.

The case studies and examples presented in this review further reinforce the tangible benefits that can be achieved through the synergetic implementation of digital technology and lean project delivery. The construction of The Shard in London, the expansion of the Oslo Airport in Norway, the projects undertaken by Akademiska Hus in Sweden, and the construction of the Seattle Children's Hospital in the United States all demonstrate how the effective integration of digital tools such as BIM, project tracking software, and collaborative platforms, has enabled improved coordination, reduced errors, optimised resource utilisation, and enhanced overall project performance (Alahyari et al., 2019; Koseoglu et al., 2019).

4.1 Challenges and Considerations

While integrating digital technology and lean project delivery holds immense potential, construction practitioners and researchers must also consider this approach's various challenges and implementation considerations. One of the primary challenges is the need for a cultural shift within the construction industry. Successfully adopting this integrated approach requires a mindset change among project stakeholders, moving away from traditional, siloed and fragmented ways of working towards a more collaborative, data-driven, and process-oriented mindset (Oraee et al., 2019; Patching et al., 2023). Overcoming resistance to change and fostering a culture of continuous improvement and lean thinking is crucial for effectively implementing this integrated approach.

Additionally, integrating digital technology and lean project delivery necessitates significant training, upskilling, and capacity-building investments within construction organisations (Alizadehsalehi et al., 2019; Sepasgozar et al., 2019). Project teams must be equipped with the necessary skills and knowledge to leverage digital tools, interpret data, and apply lean principles effectively, which can be challenging and resource-intensive. The interoperability and compatibility of various digital technologies used in construction projects also pose a potential challenge (Kocakaya et al., 2019; Patching et al., 2023). Ensuring seamless data exchange, integration, and harmonisation across different software platforms and systems is crucial for realising the full benefits of this integrated approach. Addressing these technological integration challenges requires collaboration among technology providers, industry associations, and construction firms. Furthermore, implementing this integrated approach may face barriers related to organisational structure, project governance, and existing procurement practices within the construction industry (Sholanke et al., 2019; Cifone et al., 2021). Aligning digital technology adoption and lean principles with prevailing organisational and contractual frameworks can be a complex and context-dependent process that requires careful planning and adaptation. The availability and quality of data and the development of robust data analytics and visualisation capabilities are critical enablers of the synergies between digital technology and lean project delivery (Gondia et al., 2020; Akinosho et al., 2020). Organisations must invest in data management strategies, analytical tools, and the necessary expertise to leverage data-driven insights effectively for continuous improvement and decision-making. A significant challenge in implementing digital technology and lean principles in construction is the skills gap in the workforce. Ogunrinde et al. (2024) highlight the necessity of transforming AEC curricula to address this issue. Traditional AEC education often lacks comprehensive coverage of digital technologies and lean methodologies, creating a disconnect between academic training and industry needs. There is a pressing need to integrate courses on Building Information Modeling (BIM), data analytics, lean construction principles, and emerging technologies like blockchain and artificial intelligence into AEC programs. This curriculum transformation would help produce graduates who are better equipped to navigate the digitally-driven, lean-oriented construction landscape of the future.

The resistance to change in the construction industry stems from deeply ingrained traditional practices and a historically fragmented project delivery approach. This resistance has significant implications, including slower adoption of innovative technologies and lean methodologies, potentially leading to continued inefficiencies and reduced competitiveness in the global market. To overcome this, industry leaders must champion a cultural shift, demonstrating the tangible benefits of integrated digital and lean approaches through pilot projects and case studies.

The interoperability challenges between various digital tools reflect the rapid and often uncoordinated development of construction technologies. This fragmentation in the digital ecosystem can lead to data silos, inefficient workflows, and missed opportunities for optimization. Moving forward, there's a need for increased collaboration between technology providers and industry stakeholders to develop standardized data exchange protocols and open-source platforms that facilitate seamless integration.

The mismatch between existing organizational structures and the collaborative requirements of digital and lean integration points to a deeper issue of outdated project governance models. Traditional hierarchical structures and siloed departments often impede the cross-functional collaboration necessary for successful implementation of these approaches. The industry needs to explore new organizational models that foster agility, cross-disciplinary teamwork, and continuous learning.

Looking ahead, the successful integration of digital technology and lean principles in construction will likely require a multi-faceted approach. This includes:

1) Developing comprehensive change management strategies tailored to the construction industry's unique characteristics.
2) Establishing industry-wide standards for digital tool interoperability and data exchange.
3) Redesigning project delivery models to align with lean principles and digital workflows.
4) Investing in ongoing professional development and upskilling programs for existing workforce.
5) Collaborating with educational institutions to reform AEC curricula.

By addressing these challenges systematically, the construction industry can unlock the full potential of digital technology and lean principles, leading to improved productivity, reduced waste, and enhanced project outcomes.

5. Conclusions

The comprehensive literature review presented in this paper highlights the significant potential and synergistic benefits of integrating digital technology and lean project delivery in the construction industry. The findings demonstrate how this integrated approach can drive substantial improvements in collaboration, visualisation, data-driven decision-making, productivity, supply chain management, and overall project performance and efficiency. The case studies and examples further reinforce the tangible benefits of effectively implementing this integrated approach, showcasing enhanced coordination, reduced errors, optimised resource utilisation, and improved overall project outcomes. While integrating digital technology and lean project delivery holds immense promise, construction practitioners and researchers must also carefully consider the various challenges and implementation considerations. These include the need for a cultural shift towards a more collaborative and data-driven mindset, significant investments in training and capacity building, ensuring interoperability of digital technologies, aligning with existing organisational structures and procurement practices, and developing robust data management and analytics capabilities.

It is important to acknowledge the limitations of this study. The review was primarily based on secondary data from scientific databases, which may not capture all aspects of practical implementation in the field. Additionally, the focus on English-language publications may have excluded relevant insights from non-English speaking regions. The review also covered a broad range of digital technologies and lean principles, which may have limited the depth of analysis for specific tools or practices.

Future research should focus on conducting in-depth case studies and empirical investigations to validate further the benefits of integrating digital technology and lean project delivery and identify best practices and strategies for overcoming the noted challenges. Collaborative research initiatives involving academia, industry associations, and construction firms would be precious in developing a more comprehensive understanding of this integration and its impact on project performance. Furthermore, research should explore this integrated approach's specific barriers and enablers in different geographical and cultural contexts, as the construction industry's maturity and digital readiness can vary significantly across regions. Investigating the role of emerging technologies, such as artificial intelligence, the Internet of Things, and advanced analytics, in enhancing the synergies between digital tools and lean principles would also be a fruitful area for future exploration.

By exploring these avenues for future research, the construction industry can gain a deeper understanding of the practical implementation of the integrated digital technology and lean project delivery approach, ultimately leading to more successful and efficient project delivery.

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