TOWARDS VSM-BIM INTEGRATION IN ROAD DESIGN: IDENTIFYING TRANSFERABLE CRITICAL SUCCESS FACTORS THROUGH A SYSTEMATIC LITERATURE REVIEW AND THEMATIC ANALYSIS

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Andy Faizal Sahapadin
Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia

Zulhasni Abdul Rahim
Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia

Corresponding Email: andyfaizal@graduate.utm.my

ABSTRACT

Purpose: This study aims to explore the current state of knowledge and identify transferable critical success factors (CSFs) from Lean-BIM literature that may inform future VSM-BIM integration in road design processes.

Methodology: A Systematic Literature Review (SLR) was conducted following the PRISMA 2020 guidelines, complemented by a reflexive thematic analysis of five conceptually relevant peer-reviewed studies published between 2014 and 2024.

Findings: The review revealed a significant research gap, with no studies directly addressing VSM-BIM integration in road design. Consequently, the thematic analysis focused on extracting transferable insights from related Lean-BIM integration studies within the broader construction domain. The analysis identified fifteen CSFs organised into five interrelated themes: Leadership and Organisational Support, Collaboration and Early Stakeholder Engagement, Process Efficiency and Waste Reduction, Technology Enablement and Visualisation, and Training and Knowledge Sharing. These themes collectively represent organisational, technological, collaborative, and capability-related factors that may support future VSM-BIM integration efforts within road design environments.

Implications: This study contributes to the emerging body of knowledge by providing an exploratory conceptual framework that can inform future empirical investigations and support practitioners, policymakers, and infrastructure agencies seeking to advance Lean and digital transformation in road project delivery.

Keywords: *Value Stream Mapping (VSM); Building Information Modelling (BIM); Lean Construction; Road Design; Critical Success Factors; Systematic Literature Review; Thematic Analysis*

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INTRODUCTION

The construction industry continues to face significant challenges in ensuring the efficient and timely delivery of infrastructure projects, particularly during the design stage. Road design processes are often characterised by fragmented workflows, siloed disciplines, and redundant activities that lead to inefficiencies, rework, and delays. These issues are not unique to any country but represent a global concern that hinders productivity, increases costs, and affects project quality and sustainability (Anderson et al., 2019; Demir & Paksoy, 2023).

Lean Construction (LC) principles and digital technologies, such as Building Information Modelling (BIM), have emerged as transformative approaches to overcome these challenges. LC emphasises the elimination of non-value-adding activities and the pursuit of continuous improvement across the project lifecycle (Shabeen & Krishnan, 2022; Suparno et al., 2021), whereas BIM provides a centralised platform for real-time collaboration, data integration, and model-based planning (Eldeep et al., 2022; Liu et al., 2021). Although both tools have shown individual value, few studies have explored their combined potential, particularly in infrastructure design contexts such as road projects (Morato & Ferreira, 2024; Raviv et al., 2022).

In developing countries such as Malaysia, these challenges are particularly pronounced. The increasing complexity of infrastructure projects, rapid urbanisation, and growing public demand have placed pressure on the construction sector to improve design efficiency and project delivery outcomes (Ridzuan & Maiddin, 2024; Wei et al., 2020). Recent performance reports under Malaysia's Twelfth Plan (RMK-12) indicate that a substantial number of projects experience delays during the planning and design phases, with design-related factors identified as key contributors (Jaafar et al., 2024; Unit Perancang Ekonomi, 2021).

Integrating Value Stream Mapping (VSM) and BIM presents a promising opportunity to optimise design processes by enhancing stakeholder collaboration, reducing waste, and supporting data-driven decision-making (Anuar et al., 2023; Moballeghi et al., 2023). VSM enables the visualisation and analysis of current design workflows to identify process bottlenecks, whereas BIM provides the digital infrastructure for simulation, coordination, and communication (Panah & Kioumarsi, 2021; Tanko et al., 2024). When used together, these tools can offer synergistic benefits that improve the technical and operational aspects of road design.

Despite the recognised potential of integrating VSM and BIM, little is known about how these approaches can be effectively combined within road design environments. Preliminary evidence suggests that research examining VSM-BIM integration in road infrastructure remains scarce, with most existing studies focusing on building projects, manufacturing environments, or broader Lean-BIM implementation contexts. Consequently, there is limited understanding of the organisational, technical, and process-related conditions that may facilitate future VSM-BIM integration in road design. To address this gap, this study adopts an exploratory approach to identify transferable CSFs from conceptually related Lean-BIM literature that may inform future implementation and empirical investigation within road infrastructure projects. This study was guided by the following two research questions:

RQ1: What is the current state of published research on VSM-BIM integration relevant to road design between 2014 and 2024?

RQ2: What transferable critical success factors can be derived from existing Lean-BIM literature to inform future VSM-BIM integration in road design?

By addressing these research questions, this study contributes to the emerging discourse on Lean-BIM integration within infrastructure design by developing an exploratory conceptual framework of transferable critical success factors. The framework is intended to provide a foundation for future empirical validation and support practitioners, researchers, and policymakers seeking to advance VSM-BIM integration in road design processes. In doing so, the study responds to the current lack of dedicated research in this area and establishes a basis for subsequent investigation into the practical implementation of Lean and digital methodologies in road infrastructure projects.

Conceptual Positioning of the Study

This study adopts an exploratory conceptual perspective to examine the potential integration of VSM and BIM within road design processes. Given the absence of direct studies investigating VSM-BIM integration in road design, the research focuses on identifying transferable CSFs from conceptually related Lean-BIM studies within the broader construction domain. Rather than developing or evaluating a formal theory, this study seeks to synthesis existing knowledge and identify organisational, collaborative, technological, and capability-related factors that may facilitate future VSM-BIM integration in road infrastructure projects. Through a combination of a systematic literature review (SLR) and reflexive thematic analysis, the study develops an exploratory conceptual framework that can serve as a foundation for future empirical validation and practical implementation.

LITERATURE REVIEW

Integrating Lean Construction principles and digital tools, such as BIM, is increasingly recognised as a transformative approach to improve productivity, reduce waste, and enhance stakeholder collaboration in construction projects. This section reviews the relevant literature on LC, VSM, BIM, and their integration, specifically focusing on road design processes. It also highlights the CSFs that influence the successful implementation of these tools.

Lean Construction and Value Stream Mapping

Rooted in the Toyota Production System, LC has been widely adopted across multiple industries, including construction, to improve operational efficiency and reduce waste (Anderson et al., 2019; Demir & Paksoy, 2023). LC focuses on delivering value to clients by eliminating non-value-adding activities and fostering a culture of continuous improvement. Its application in the construction industry has shown potential for streamlining complex project workflows and enhancing productivity.

Among the core LC tools, VSM is one of the most effective techniques for process analysis and waste identification. VSM provides a structured method for mapping existing workflows and pinpointing sources of inefficiencies, such as duplication, waiting time, and rework (Shabeen & Krishnan, 2022; Suparno et al., 2021). It enables project teams to visualise current-state processes and collaboratively design future-state workflows that are leaner and more efficient.

Recent studies have shown that VSM is applicable in manufacturing and is highly adaptable to the construction context, particularly in analysing design and planning processes (Anuar et al., 2023; Lee et al., 2021). In road projects, VSM facilitates the identification of bottlenecks in the early project phases, allowing stakeholders to restructure the process for improved coordination and reduced design cycle time.

Building Information Modelling

BIM is a digital platform that enables the development of intelligent 3D models to support the planning, design, construction, and operation of infrastructure. BIM allows real-time collaboration among various disciplines, improving transparency, reducing errors, and enabling initiative-taking decision-making (Liu et al., 2021; Panah & Kioumarsi, 2021). The use of BIM in infrastructure projects, including highways, allows for enhanced visualisation of road geometries, integration of traffic simulation, and coordination of structural elements. BIM also incorporates sustainability features, energy analysis, and asset lifecycle management (Eldeep et al., 2022; Toprak & Demirkesen, 2023). These features support a more holistic and efficient approach to infrastructure development.

The Malaysian government has mandated BIM adoption in public-sector projects exceeding RM10 million as part of its broader strategy to digitise the construction industry (Jabatan Penyiaran Malaysia, 2024). Despite growing acceptance, challenges persist, including insufficient training, organisational resistance, and a lack of standardisation within the industry (Manzoor et al., 2021; Tanko et al., 2024). Nevertheless, BIM remains a key enabler of improved collaboration and quality during the design phase of construction projects.

Integration of VSM and BIM

The integration of VSM and BIM offers a strategic advantage by combining lean process improvement with digital modelling capabilities. VSM enables stakeholders to identify inefficiencies and optimise workflows, whereas BIM facilitates real-time design visualisation, clash detection, and data sharing across disciplines (Moballeghi et al., 2023; Osorio-Gomez et al., 2020). By combining these tools, construction teams can simultaneously address process and technical challenges. For example, while VSM highlights delays in approval cycles or rework due to design changes, BIM enables the early simulation of design options, reducing the likelihood of downstream conflicts (Rathnasinghe et al., 2022; Saleh et al., 2024). This integration enhances communication, shortens design timelines, and improves coordination among consultants, engineers, and regulatory agencies.

Several studies have highlighted the positive outcomes of this integration, including improved stakeholder engagement, fewer design errors, and accelerated project approval (Bayhan et al., 2023; Chahrour et al., 2021). These benefits are especially valuable in infrastructure projects, where coordination between technical disciplines and timely decision-making are critical for project success.

Critical Success Factors for VSM-BIM Integration

Identifying and understanding CSFs is essential for successfully implementing VSM-BIM integration in construction. The literature suggests that leadership commitment, stakeholder collaboration, digital competency, and standardisation of workflows are among the key enablers of integration (Gaur & Tawalare, 2022; McDermott et al., 2023).

Other CSFs include training and capacity building, real-time data accessibility, and the alignment of regulatory processes with digital workflows (Pérez et al., 2024; Saleh et al., 2024). These factors contribute to reducing resistance to change, improving process transparency, and fostering innovation in design management. Despite the emerging interest, current research remains fragmented, with most studies focusing on the isolated applications of either VSM or BIM. Limited empirical studies have systematically identified CSFs for their combined use, particularly in infrastructure and road design contexts. Consequently, there is a pressing need to establish a structured framework that captures these enablers and provides guidance for practitioners and policymakers.

MATERIALS AND METHODS

This study employed an SLR methodology guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) framework (Page et al., 2021) to examine the current state of knowledge regarding the integration of VSM and BIM within construction and infrastructure design contexts. The primary objective was to identify transferable CSFs from conceptually related Lean-BIM studies that may inform future VSM-BIM integration in road design processes. Accordingly, the review adopted an exploratory approach to synthesis relevant insights from the broader construction literature.

The review followed a multi-phase approach consisting of (i) identification of relevant literature, (ii) screening of titles, abstracts, and keywords, (iii) eligibility assessment through full-text review, and (iv) final inclusion of studies based on predefined criteria. The screening process was designed to identify studies directly addressing VSM-BIM integration in road design and infrastructure contexts. In addition, the review incorporated an assessment of conceptually related studies to capture transferable insights on Lean-BIM integration, implementation success factors, and process improvement mechanisms that may inform future VSM-BIM integration in road design. This approach ensured methodological transparency, reproducibility, and rigour in synthesising evidence from both direct and conceptually related sources. Figure 1 presents the overall study flow adopted in this research.

Figure 1 Research Methodology Flowchart

The selection of databases—Scopus, Web of Science (WoS), and Emerald Insight—was based on their extensive coverage of peer-reviewed literature in engineering, construction management, LC, BIM, and digital transformation within the Architecture, Engineering, and Construction (AEC) industry. The search was limited to publications published between 2014 and 2024 to capture contemporary developments in Lean-BIM integration and related process improvement approaches. This timeframe ensures that the information is current, reflecting the latest advancements, trends, and methodologies relevant to ongoing developments in the construction industry (Ammar & Nassereddine, 2022). Restricting the review to this period ensured that the findings reflected current implementation challenges, emerging integration strategies, and evolving industry practices relevant to future VSM-BIM adoption.

The Boolean search string applied across the databases was ("Lean" OR "Value Stream Mapping" OR "VSM" OR "lean construction") AND ("Building Information Modelling" OR "BIM") AND ("Critical Success Factors" OR "CSF*" OR "Key Success Factors") AND ("construction" OR "AEC industry" OR "infrastructure projects" OR "road"). The search string was developed to capture studies addressing Lean methodologies, BIM implementation, integration enablers, and critical success factors within construction and infrastructure-related contexts. The broad search scope was intended to maximise the identification of potentially relevant studies and to enable the exploration of transferable insights where direct evidence on VSM-BIM integration in road design was limited.

Only peer-reviewed journal articles, conference proceedings, technical reports, book chapters, and doctoral theses published in English were included in this review. Studies were excluded if they focused on unrelated industries (e.g., healthcare, logistics, or software engineering), lacked discussion of Lean-BIM integration or process improvement mechanisms, or did not provide insights into implementation enablers, organisational factors, or critical CSFs. Tables 1 and 2 summarise the review protocol and inclusion/exclusion criteria used to refine the selection of relevant studies. These criteria were designed to identify literature relevant to Lean-BIM integration and related implementation practices within construction and infrastructure contexts, while also allowing the inclusion of conceptually transferable evidence where direct studies on VSM-BIM integration in road design were unavailable.

Following the search and screening procedures, the selected literature was analysed using reflexive thematic analysis in accordance with Braun and Clarke (2006, 2021). Thematic analysis was chosen because it provides a systematic and flexible approach for identifying, analysing, and interpreting patterns of meaning across a body of literature. In this study, the method was used to synthesis implementation enablers, organisational factors, and integration-related success factors reported in the selected studies. The combination of SLR and reflexive thematic analysis enabled both a structured review of the existing literature and an in-depth exploration of transferable critical success factors relevant to future VSM-BIM integration in road design.

Table 1: Review protocol parameters and search sources

Component	Search Parameters
Databases Used	Scopus, Web of Science (WoS), and Emerald Insight
Year of Publication	2014–2024 (Last 10 years)
Keywords Used	("Lean" OR "Value Stream Mapping" OR "VSM" OR "lean construction") AND ("Building Information Modelling" OR "BIM") AND ("Critical Success Factors" OR "CSF*" OR "Key Success Factors") AND ("construction" OR "AEC industry" OR "infrastructure projects" OR "road")
Document Type	Peer-reviewed journal articles, conference proceedings, book chapters, and technical reports
Language	English Only

Table 2: Inclusion and Exclusion Criteria for the Boolean String

Component	Inclusion Criteria	Exclusion Criteria
Research Focus	Studies that discuss VSM, Lean, or LC, BIM, Lean-BIM integration, or process improvement approaches within road design, infrastructure, or broader AEC industry contexts.	Studies that discuss VSM or BIM separately without integration or relevance to process improvement.
Success Factors Focus	Studies explicitly identify critical success factors (CSFs), implementation enablers,	Studies that do not explicitly address success factors for VSM-BIM adoption.

Component	Inclusion Criteria	Exclusion Criteria
	organisational capabilities, collaboration mechanisms, or adoption factors related to Lean, BIM, or Lean-BIM integration.	
Industry Relevance	Research focused on construction, the AEC (Architecture, Engineering, and Construction) industry, or infrastructure projects (e.g., roads, highways, bridges, tunnels, public transport systems)	Studies focused on non-construction industries (e.g., healthcare, manufacturing, logistics, software engineering, and supply chain) unless they provide transferable insights on Lean-BIM adoption in construction.
Period	Studies published from 2014 to 2024	Studies published before 2014
Document Type	All publication types, including peer-reviewed journal articles, conference proceedings, book chapters, technical reports, government policy documents, and doctoral theses/dissertations.	Non-scientific sources (e.g., blogs, industry news, non-peer-reviewed white papers, trade magazines, individual opinions, or unpublished manuscripts)
Language	English-language publications only	Non-English publications

RESULTS

Overview of VSM-BIM in Road Design

The initial database search yielded sixteen records from Scopus, Web of Science (WoS), and Emerald Insight. Figure 2 illustrates the distribution of records across the selected databases. These databases were chosen because of their extensive coverage of peer-reviewed literature related to construction management, LC, BIM, and digital transformation within the AEC industry. Following the identification stage, two duplicate records were removed, resulting in fourteen unique studies for further screening and assessment. The inclusion of multiple databases helped mitigate potential biases from a single source, aligning with the best practices in the systematic reviews (Tranfield et al., 2003). Table 3 listed the fourteen studies and their relevance to VSM-BIM in a road design context.

During the screening stage, the titles, abstracts, and keywords of the retrieved records were reviewed to assess their relevance to the study objectives. Studies that did not address LC, VSM, BIM, or process improvement within construction and infrastructure contexts were excluded. Following the screening process, fourteen studies were retained for full-text assessment.

The full-text review was subsequently conducted using the predefined inclusion and exclusion criteria presented in Table 2. Attention was given to the extent to which each study discussed integration-related enablers, implementation challenges, organisational factors, or critical success factors associated with Lean, BIM, or Lean-BIM practices. Although no studies were found that explicitly addressed VSM-BIM integration in road design, several studies provided conceptually relevant insights into integration mechanisms and implementation success factors. These studies were subsequently considered for thematic analysis. Because no studies directly addressed VSM-BIM integration in road design, a secondary conceptual relevance assessment was undertaken to identify studies discussing Lean-BIM integration, implementation enablers, organisational capabilities, and critical success factors with potential transferability to future road design applications. Figure 3 presents the PRISMA 2020 flow diagram summarising the article selection process.

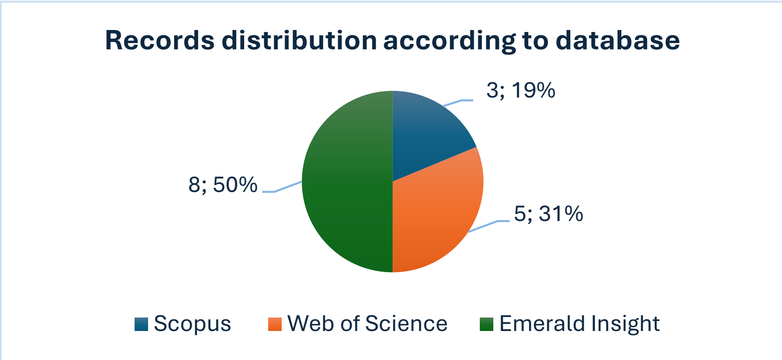

Figure 2 Sources of Material According to the Database

Although several screened studies discussed LC, VSM, BIM, or broader process improvement initiatives within the construction industry, none explicitly examined the integration of VSM and BIM within road design processes. This finding highlights a significant gap in existing literature and suggests that the combined application of Lean and BIM methodologies in road infrastructure design remains unexplored. The absence of direct evidence underscores the need for exploratory research capable of drawing insights from conceptually related studies and identifying implementation factors that may support future VSM-BIM integration in road design.

Most studies reviewed applied VSM or BIM in isolated contexts, such as off-site modular construction, vertical building projects, or manufacturing sectors. For instance, McDermott et al. (2023) explored Lean Six Sigma and BIM in modular design, whereas Evans et al. (2021, 2022) and Mellado and Lou (2020) examined the CSFs for BIM implementation in megaprojects and sustainability-focused frameworks. However, these studies lacked direct application to road design or process integration models involving both tools. Similarly, other studies mentioned VSM and BIM only tangentially, without offering insights into how these tools might be integrated or adapted to infrastructure workflow. The absence of empirical or conceptual studies focusing on VSM-BIM in road design underscores a clear research gap, confirming the novelty and relevance of this study.

Therefore, the findings of the systematic review highlight a significant research gap and provide justification for the exploratory thematic analysis undertaken in this study. This highlights the lack of research on VSM-BIM integration in road design, justifying the subsequent thematic analysis undertaken to identify transferable critical success factors and develop a preliminary conceptual framework.

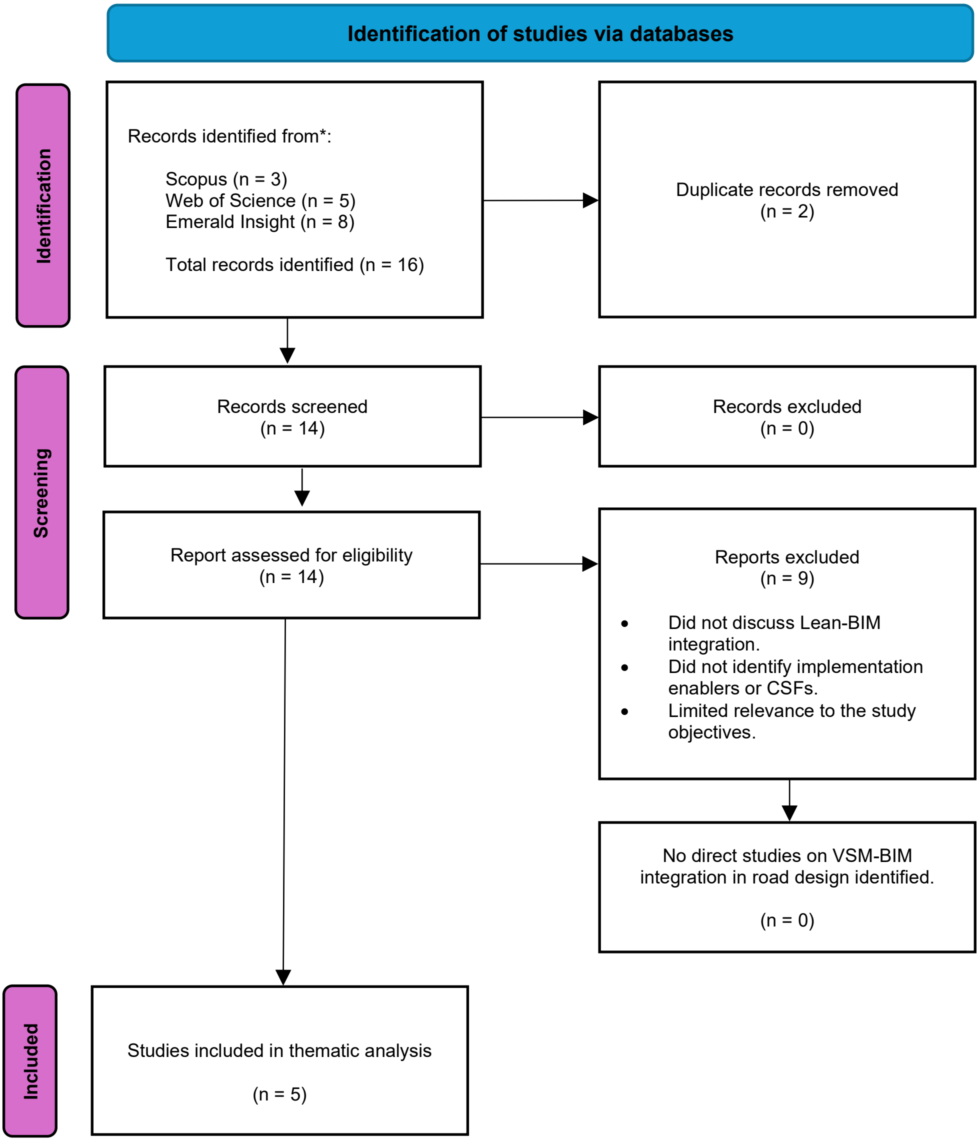

Figure 3 PRISMA Diagram

Table 3: Reviewed Studies and Their Relevance to Future VSM-BIM Integration in Road Design

No.	Author	Main Research Focus	Key Contribution Relevant to VSM-BIM integration	Selected for TA
1	Rashidian et al. (2023)	BIM-IPD-Lean maturity model's review.	Identifies common maturity dimensions, including collaboration, governance, waste minimisation, customer focus, and organisational readiness.	No
2	Bajjou and Chafi (2025)	LC implementation model.	Identifies validated lean implementation factors, including process transparency, waste elimination, continuous improvement, and information flow.	No
3	McDermott et al. (2023)	Lean Six Sigma–BIM framework for off-site construction manufacturing.	Demonstrates integration of Lean principles, VSM, and BIM to improve process efficiency, reduce waste, enhance digital coordination, and support process improvement.	Yes
4	Sharma et al. (2016a)	DEMATEL analysis of Lean implementation criteria.	Examines causal relationships among Lean implementation factors and highlights organisational readiness requirements.	No
5	Le and Nguyen (2021)	Lean tools for construction supply chain management.	Highlights VSM, VDC/BIM, IPD, Concurrent Engineering, and Last Planner System as process improvement tools.	No
6	Arrotéia et al. (2022)	BIM Critical Success Factors across project lifecycle phases.	Identifies BIM adoption factors related to leadership, collaboration, training, information management, and organisational readiness.	No
7	Mellado and Lou (2020)	BIM-Lean-Sustainability integration framework.	Identifies integration enablers, including collaboration, organisational readiness, leadership, standardisation, communication, training, and lifecycle thinking.	Yes
8	Evans et al. (2021)	CSFs for Lean-BIM integration in construction megaprojects.	Identifies and prioritises CSFs including leadership support, collaboration, communication, BIM capability, stakeholder engagement, and digital maturity.	Yes
9	Sarhan et al. (2020)	LC implementation framework using ISM.	Identifies implementation enablers including BIM adoption, VSM, training, teamwork, top management commitment, and continuous improvement.	Yes
10	Evans et al. (2022)	Lean-IPD-BIM competency framework.	Identifies governance, leadership, collaboration, BIM competencies, and organisational capabilities required for integrated project delivery.	Yes
11	Avelar et al. (2020)	Lean Construction implementation in SMEs.	Demonstrates VSM-based process improvement, continuous flow, waste reduction, and performance enhancement.	No
12	Sharma et al. (2016b)	DEMATEL analysis of Lean implementation criteria.	Examines causal relationships among Lean implementation factors and highlights organisational readiness requirements.	No
13	Schery et al. (2023)	BIM critical factors and benefits for public sector implementation.	Identifies BIM-related critical success factors, including leadership, collaboration, training, and organisational support.	No

No.	Author	Main Research Focus	Key Contribution Relevant to VSM-BIM integration	Selected for TA
14	Kääria and Shamsuzzoha (2024)	VSM application in Order-to-Cash process improvement.	Demonstrates VSM for identifying bottlenecks, information-flow failures, process waste, and performance improvement.	No

VSM-BIM Integration Critical Success Factors

Selection of Studies for Thematic Analysis

Given the absence of studies explicitly investigating VSM-BIM integration in road design, a thematic analysis was undertaken using conceptually relevant studies identified during the review process. The objective was not to identify empirically validated success factors specific to road design but rather to synthesis transferable implementation insights from related Lean-BIM literature that could inform future VSM-BIM integration efforts within road infrastructure projects. Five studies were selected for thematic analysis because they provided explicit discussion of integration enablers, implementation challenges, organisational capabilities, collaborative practices, or critical success factors associated with Lean, BIM, or Lean-BIM integration. These studies were considered information-rich and conceptually relevant to the objectives of this research, despite not focusing specifically on road design.

Although the five selected studies did not explicitly investigate VSM-BIM integration within road design workflows, they provided valuable conceptual and methodological insights into Lean-BIM integration, implementation enablers, and organisational success factors relevant to process improvement within construction environments. For example, McDermott et al. (2023) proposed a Lean Six Sigma–BIM framework for off-site manufacturing. While not linked to road design, the study identified integration-enabling CSFs such as stakeholder collaboration, data standardisation, and process visualisation, all of which are transferable to the VSM-BIM context.

Table 4: Articles for Thematic Analysis of CSFs.

No.	Author	Relevance
1	McDermott et al. (2023)	Integration of Lean Six Sigma and BIM in a modular environment, offering transferable CSFs related to process optimisation, stakeholder collaboration, and digital coordination.
2	Evans et al. (2021)	Comprehensive Delphi study on Lean-BIM constructive collaboration, which presents prioritised CSFs applicable to large-scale infrastructure design contexts.
3	Sarhan et al. (2020)	Structured CSFs from Lean implementation where both VSM and BIM are acknowledged, providing insight into enabler relationships even though not directly integrated.

No.	Author	Relevance
4	Mellado and Lou (2020)	A strong theoretical framework integrating BIM, Lean, and sustainability, highlighting critical enablers such as lifecycle thinking, organisational readiness, and stakeholder alignment.
5	Evans et al. (2022)	Competency-based framework supporting Lean-BIM-IPD integration, offering valuable organisational and technical CSFs suitable for adaptation in road design contexts.

Similarly, Evans et al. (2021) employed a Delphi survey to prioritise CSFs for Lean-BIM synergy in construction megaprojects, identifying factors such as top management support, collaborative culture, and digital tool maturity. These themes resonate with the foundational principles of VSM and BIM integration, where cross-functional alignment and digital workflows are essential components. Sarhan et al. (2020) introduced VSM and BIM within a Lean implementation framework for the Saudi construction industry, offering structured insights into the interdependencies between technical enablers and process-based factors. Although the tools were not fully integrated in practice, the study highlighted the complementary roles of Lean and BIM in improving process performance and organisational effectiveness. Mellado and Lou (2020) advanced a holistic integration framework that combined BIM, Lean, and sustainability principles. Their framework identified critical success factors such as lifecycle thinking, stakeholder commitment, and organisational readiness, all of which are relevant to future VSM-BIM integration efforts. Extending this perspective, Evans et al. (2022) presented a competency-based approach integrating Lean Construction and Integrated Project Delivery (IPD) with BIM, emphasising the importance of leadership, technical capability, and integrated governance in large-scale infrastructure delivery.

Although only five studies were included in the thematic analysis, these papers were selected because they were information-rich and directly addressed Lean-BIM integration, implementation enablers, organisational capabilities, and critical success factors. In reflexive thematic analysis, analytical depth and conceptual relevance are more important than the number of included studies (Braun & Clarke, 2006, 2021). The selected papers consistently reported recurring organisational, collaborative, technological, and capability-related factors, providing sufficient conceptual coverage to support the development of transferable themes. Therefore, the objective of this analysis was not statistical generalisation but the generation of theoretically informed insights that may guide future empirical investigation of VSM-BIM integration in road design.

Collectively, these studies demonstrate recurring organisational, technological, and collaborative factors that influence successful Lean-BIM implementation across different construction contexts. These five papers, while not directly addressing VSM-BIM integration in road design, were considered thematically relevant because of their focus on implementation enablers and integration strategies within Lean-BIM environments. Their insights provide a conceptual foundation for developing a preliminary framework of transferable critical success factors that may inform future research and practical implementation of VSM-BIM integration in road design.

Thematic Analysis Approach

Thematic analysis was conducted in accordance with Braun & Clarke's (2006, 2021) reflexive thematic analysis framework. The process was conducted in five phases: data familiarisation, coding, theme generation, theme review, and theme definition. The first phase involved a rigourous reading and familiarisation process with five selected peer-reviewed journal articles strategically chosen for their relevance to Lean-BIM integration, BIM adoption, and process improvement within construction and infrastructure contexts. These articles include McDermott et al. (2023), Evans et al. (2021), Sarhan et al. (2020), Mellado and Lou (2020), and Evans et al. (2022), as listed in Table 4. During this phase, the analysis involved an in-depth review and annotation of each study to identify recurring concepts, patterns of meaning, and emerging insights related to VSM, BIM, and their integration into road design.

The second phase involved a systematic coding process, in which meaningful features of the data relevant to the research objective were highlighted. Fifteen initial codes were generated through an iterative coding process in which relevant text segments were reviewed, compared, and refined across the five selected studies. Table 5 presents the initial codes with quotes from the papers. Codes were generated from the explicit and implicit content of the articles. For example, codes such as "Top Management Support," "Stakeholder Engagement," "Digital Transparency," and "Training and Education" were derived from excerpts that indicated enabling factors in VSM-BIM integration. These initial codes were documented along with direct quotations from the literature and grouped according to the source articles to facilitate traceability. Coding was performed semantically and latently to ensure that surface meanings and underlying assumptions were captured (Braun & Clarke, 2006).

Table 5: Initial Codes with Supporting Quotes and Source References

No.	Papers	Quote	Initial Code
1	McDermott et al. (2023)	“OSM, utilizing Lean and BIM, delivered a safe process and a completed project... eliminating material wastage, non-value-added work, and rework time.”	Error Reduction through BIM
2	McDermott et al. (2023)	“Skid designs... aim to create a modular package easily slotted into an area... the development of a BIM 3D model... approved for modular pipe racks.”	Standardisation via Modular Design
3	Evans et al. (2022)	“Collaboration in design, construction works, and engineering management” was identified as a top KD.	Collaboration in Project Lifecycle

No.	Papers	Quote	Initial Code
4	Evans et al. (2021)	"Senior organisational management support" as a key success factor in Lean-BIM and IPD.	Top Management Support
5	Sarhan et al. (2020)	"Training and education are necessary to implement lean strategies effectively."	Training and Education
6	Mellado and Lou (2020)	"Digital tools (BIM) function as enablers of collaboration and transparency."	Digital Transparency
7	Evans et al. (2022)	"Earlier and precise 3D Visualisation of designs supported effective integration."	3D Visualisation Tools
8	Evans et al. (2022)	"Senior organisational management support" and "cross-disciplinary communication" are top factors.	Leadership and Communication
9	McDermott et al. (2023)	"The project aimed to reduce process and environmental waste and deliver the project on schedule."	Schedule and Energy Efficiency
10	Mellado and Lou (2020)	"Use of 3D BIM facilitates clearer understanding of project scope and sequence among all stakeholders."	3D Visualisation Tools
11	Mellado and Lou (2020)	"BIM platforms were instrumental in supporting real-time updates and transparency across project teams."	BIM as Collaboration Enabler
12	Evans et al. (2022)	"Integration of IPD and Lean practices supported better collaboration through early stakeholder involvement."	Early Collaboration
13	Sarhan et al. (2020)	"Knowledge transfer across teams was supported through structured lean training programmes."	Knowledge Management
14	Evans et al. (2022)	"BIM Visualisation enabled initiative-taking clash detection during early planning stages."	BIM as Collaboration Enabler
15	Evans et al. (2022)	"Skills development initiatives help maintain Lean-BIM competencies across multinational teams."	Skills Development

The next phase of the reflexive thematic analysis was to construct candidate themes by identifying patterns of shared meanings across the coded data. An inductive and interpretive approach was employed, enabling themes to emerge directly from the data without relying on a pre-existing framework (Braun & Clarke, 2006, 2021). The refinement process involved comparing relationships among codes, identifying areas of conceptual overlap, and consolidating related concepts into broader thematic categories. This process reduced the initial set of fifteen codes into five higher-order themes that captured recurring patterns across the selected studies. For example, data segments referring to senior management support, leadership communication, and organisational alignments reported by Evans et al. (2021, 2022)—were consolidated under the theme "Leadership and Organisational Support." Similarly, references to cross-functional collaboration and early engagement during the design phase—drawn from Evans et al. (2022) and McDermott et al. (2023)-were grouped under "Collaboration and Early Stakeholder Engagement." Codes relating to standardisation, efficiency, and rework reduction, identified in McDermott et al. (2023), informed the theme "Process Efficiency and Waste Reduction." As emphasised by Mellado and Lou (2020), elements of digital enablement and visual communication contributed to the formation of the theme "Technology Enablement and Visualisation." Finally, codes about skills development, formal training, and knowledge dissemination, cited in Sarhan et al. (2020), were synthesisd into the theme "Training and Knowledge Sharing." These five themes were determined to be analytically distinct, internally coherent, and directly aligned with the research objectives. The candidate themes were subsequently reviewed and refined to ensure internal coherence, conceptual distinctiveness, and alignment with the study objectives before final theme definitions were established. Table 6 summarises the preliminary themes identified through inductive clustering.

Table 6: Themes, Initial Codes, and Theme Definitions.

No.	Themes	Grouped Initial Codes	Theme Definition
1	Leadership and Organisational	• Top Management Support • Organisational Commitment • Leadership and Communication Support	Covers the strategic, cultural, and structural conditions that support the integration of VSM and BIM, including executive commitment and vision alignment.
2	Collaboration and Early Stakeholder Engagement	• Early Collaboration • Stakeholder Engagement • Collaboration in Project Lifecycle	Represents the coordination and involvement of diverse project stakeholders from initial stages to ensure design and planning alignment.
3	Process Efficiency and Waste	• Error Reduction through BIM • Schedule and Energy Efficiency • Standardisation via Modular Design	Reflects process improvement outcomes associated with Lean-BIM implementation, including waste reduction, workflow efficiency, and standardisation.
4	Technology Enablement and Visualisation	• 3D Visualisation Tools • Digital Transparency • BIM as Collaboration Enabler	Captures how digital tools like BIM enable visualisation, communication, and

No.	Themes	Grouped Initial Codes	Theme Definition
			coordination for integration success.
5	Training and Knowledge Sharing	• Training and Education • Knowledge Management • Skills Development	Encompasses continuous learning, skills enhancement, and mechanisms to institutionalise Lean-BIM knowledge across teams.

Thematic Summary of Transferable CSFs

Reflexive thematic analysis provided a structured approach for exploring research question 2 by identifying CSFs from conceptually related Lean-BIM studies that may inform future VSM-BIM integration in road design processes. The analysis produced five interrelated themes comprising fifteen CSFs that represent organisational, technological, collaborative, and process-related factors associated with successful Lean-BIM implementation. These themes were derived from inductively coded data across five peer-reviewed studies and provide a conceptual foundation for understanding the enabling conditions that may support future VSM-BIM integration within road infrastructure design contexts.

The first theme, leadership and organisational support, emerged as foundational, with CSFs such as top management support, organisational commitment, and strategic leadership communication emerging. These factors are critical for aligning integration efforts with institutional objectives and providing the resources and authority necessary to drive transformation. Leadership creates an enabling context within which Lean and BIM methodologies can be effectively implemented (Evans et al., 2022; Evans et al., 2021).

Collaboration and early stakeholder engagement were identified as essential for aligning value stream improvements and digital modelling efforts. Subthemes, such as early collaboration and cross-disciplinary stakeholder engagement, highlight the importance of integrating diverse perspectives from the outset. This enhances decision-making and minimises the risk of rework due to misalignment (Evans et al., 2022; McDermott et al., 2023). Process efficiency and waste reduction, another core theme, reflect the tangible operational benefits of Lean-BIM integration. Subthemes such as error reduction, schedule and energy efficiency, and modular design standardisation reveal how integration directly contributes to improved performance outcomes, such as reduced cycle times and resource optimisation, which are also relevant objectives within road infrastructure design processes (McDermott et al., 2023).

Furthermore, the technology enablement and visualisation theme underscores BIM's instrumental role in facilitating integration. Through CSFs such as 3D Visualisation, digital transparency, and BIM as a collaboration enabler, this theme demonstrates how technology supports process clarity, real-time updates, and stakeholder coordination across the design lifecycle (Mellado & Lou, 2020). Finally, training and knowledge sharing provide human capacity to sustain integration. Training programmes, internal knowledge exchange mechanisms, and a focus on skills development enable continuous improvement and reduce dependency on external expertise (Sarhan et al., 2020). This theme is particularly relevant in contexts where VSM and BIM are emerging practices.

The themes form an interconnected framework, as illustrated in Figure 4, in which leadership, collaboration, technology enablement, process improvement, and capability development interact to support integration-oriented practices. The insights gained not only fill a theoretical gap in the Lean-BIM literature but also offer practical guidance for infrastructure professionals seeking to adopt integrated process improvement strategies in complex design environments. Table 7 summarises the CSFs for VSM-BIM integration in road design process improvement.

Table 7: Transferable CSFs Informing Future VSM-BIM Integration in Road Design

Theme 1: Leadership and Organisational Support 1. **Top Management Support:** Strategic endorsement and resource allocation from senior leadership. 2. **Organisational Commitment:** Alignment of VSM-BIM objectives with institutional goals and long-term strategy. 3. **Leadership and Communication:** Clear vision, active communication, and engagement across hierarchical levels
Theme 2: Collaboration and Early Stakeholder Engagement 4. **Early Collaboration:** Engagement of stakeholders at the conceptual and design stages. 5. **Stakeholder Engagement:** Inclusive participation of cross-functional project actors. 6. **Collaboration in Project Lifecycle:** Sustained cooperation across the planning, design, and delivery phases.
Theme 3: Process Efficiency and Waste Reduction 7. **Error Reduction through BIM:** Elimination of design clashes and rework using model-based coordination. 8. **Schedule and Energy Efficiency:** Improved time management and reduced resource consumption. 9. **Standardisation via Modular Design:** Application of modular solutions to streamline repetitive components.
Theme 4: Technology Enablement and Visualisation 10. **3D Visualisation Tools:** Enhanced design clarity and communication through digital modelling. 11. **Digital Transparency:** Real-time access to project data, models, and decision logs. 12. **BIM as Collaboration Enabler:** Use of shared BIM platforms to facilitate interdisciplinary coordination
Theme 5: Training and Knowledge Sharing 13. **Training and Education:** Structured programmes to build VSM and BIM competencies. 14. **Knowledge Management:** Systems and practices for capturing and disseminating integration knowledge. 15. **Skills Development:** Continuous upskilling to support long-term adoption and innovation.

Inter-Theme Relationship

These five themes address research question two by offering a multidimensional understanding of transferable CSFs that may inform future VSM-BIM integration in road design. Leadership is at the core of this framework, serving as the driving force behind strategic alignment and cultural readiness for Lean-BIM adoption. Strong top management commitment provides direction and resources and legitimizes process transformation and technology investment (Evans et al., 2022; Evans et al., 2021).

Leadership was frequently associated with training and knowledge-sharing initiatives by initiating continuous learning programmes, developing organisational competencies, and ensuring that multidisciplinary teams are adequately equipped to engage with Lean and BIM tools (Sarhan et al., 2020). Furthermore, leadership was found to facilitate collaboration and early stakeholder engagement, encouraging cross-disciplinary communication and fostering a culture of shared ownership over the design process (Evans et al., 2022).

Collaboration is a vital enabler of process efficiency, as early stakeholder involvement ensures that value stream activities are correctly identified and optimised before significant design commitments are made. Integrating VSM allows for mapping workflows and identifying inefficiencies, whereas BIM supports this through real-time model sharing and digital coordination (McDermott et al., 2023). These collaborative practices are further enhanced by technology enablement, with BIM serving as a visualisation tool and integration platform that supports traceability, version control, and multidisciplinary alignment.

Both technology and collaboration depend on adequate training. Without appropriate capacity building and institutional knowledge-sharing mechanisms, teams may struggle to operationalise VSM-BIM integration, resulting in fragmented workflows and inconsistent implementation (Sarhan et al., 2020). Thus, training acts as a foundational support system that reinforces the effective use of collaborative structures and digital tools.

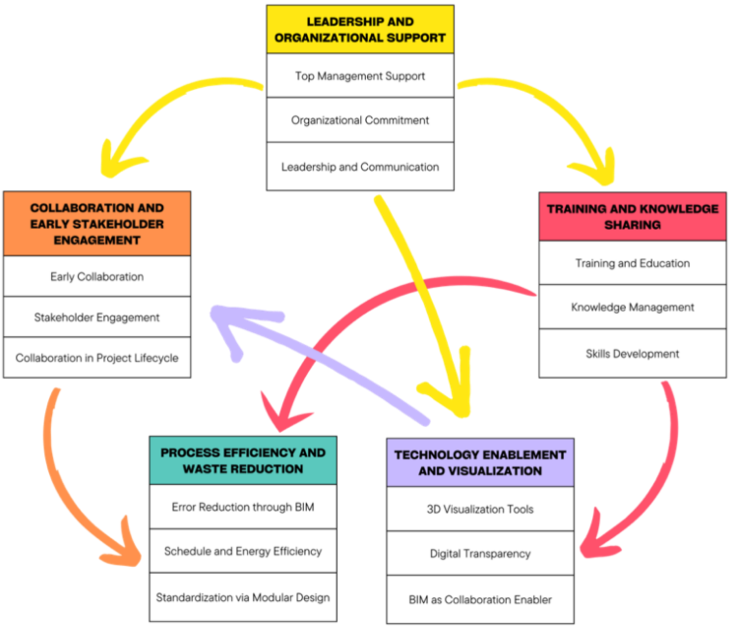

Figure 4 Conceptual Relationships Among Transferable Critical Success Factor Themes

The relationships among these themes can also be interpreted from a socio-technical perspective, whereby organisational factors such as leadership, collaboration, and knowledge sharing interact with technical capabilities such as BIM Visualisation, digital transparency, and information integration to support process transformation. Within this context, VSM contributes process-oriented improvement mechanisms through workflow analysis and waste identification, while BIM provides technological capabilities that facilitate visualisation, coordination, and information sharing. Together, these organisational and technological dimensions create enabling conditions that may support future VSM-BIM integration in road design environments. Figure 4 shows the relationships between themes.

DISCUSSION

This study explored the potential for future VSM-BIM integration in road design through an SLR and reflexive thematic analysis of conceptually relevant Lean-BIM studies. Together, these methods identified fifteen CSFs, structured into five interrelated themes: leadership and organisational support, collaboration and early stakeholder engagement, process efficiency and waste reduction, technology enablement and visualisation, and training and knowledge sharing. This section first reflects on the findings of the SLR and then synthesiss the themes generated through thematic analysis to discuss their contributions, practical implications, and limitations.

Reflections on SLR Findings

The findings from the SLR conducted in the initial stages of this study served as both a justification and triangulation mechanism for the subsequent thematic analysis. The review revealed that while the integration of LC and BIM has been widely discussed in the construction management literature, explicit applications of VSM-BIM integration remain limited. The reviewed studies primarily focused on BIM-enabled process improvement, Lean implementation strategies, or digital collaboration practices rather than the explicit integration of VSM and BIM within road design contexts.

A particularly significant finding was the absence of studies explicitly examining VSM-BIM integration within road design processes. This highlights a notable research gap and justifies the exploratory approach adopted in this study, whereby transferable insights were synthesisd from conceptually related Lean-BIM literature. Despite this gap, the reviewed studies provided valuable insights into organisational, technological, and process-related factors that may support future VSM-BIM integration efforts within road design contexts.

The SLR underscored a recurring emphasis on enabling factors such as leadership support, stakeholder collaboration, and training, which later re-emerged in the thematic analysis as core themes. This alignment enhances confidence in the consistency of the identified CSFs and demonstrates methodological triangulation between literature synthesis and qualitative interpretation. For instance, the importance of organisational leadership and digital coordination highlighted in McDermott et al. (2023), and (Evans et al., 2022; Evans et al., 2021) was echoed in the themes of “leadership and organisational support” and “technology enablement and visualisation."

Interestingly, the SLR also identified underexplored but emerging areas such as “digital transparency” and “standardisation via modular design," which became more prominent through latent coding in the thematic analysis. This suggests that while the SLR provides a snapshot of existing knowledge, thematic analysis offers the depth needed to surface new or evolving themes. Therefore, the integration of the SLR and thematic analysis provides a complementary understanding of the transferable factors that may support future VSM-BIM integration in road design contexts.

These findings demonstrate the value of combining systematic literature synthesis with qualitative thematic interpretation in construction management research, particularly when investigating emerging technological and process-oriented practices. They also highlight the need for continued exploration of Lean-BIM integration models within infrastructure sectors, where project characteristics, stakeholder structures, and workflow requirements differ from those encountered in vertical construction projects.

Synthesis of Thematic Findings

The CSFs identified in this study are not isolated enablers but interconnected elements that may support future VSM-BIM integration within road design contexts. The findings suggest that strategic leadership and institutional support are central to strengthening technical capability, collaborative practice, design efficiency, and project performance. This reflects the systemic nature of Lean-BIM adoption, where change must be initiated through strategic direction but sustained through continuous coordination, capacity development, and knowledge sharing.

The integration of BIM and VSM offers a dual-layered advantage. BIM provides a digital platform for data transparency, visualisation, and multidisciplinary coordination, while VSM introduces lean logic to identify waste, reduce non-value-adding activities, and align design processes with value creation. Collectively, these themes represent a shift from fragmented, document-based workflows towards integrated, value-driven, and technology-supported design practices. Such an approach is particularly relevant to road infrastructure projects, where early coordination, process clarity, and timely decision-making are essential to improving design efficiency.

Contribution to Research

This study contributes to the body of knowledge in two keyways. First, it highlights a significant gap in the existing literature by demonstrating the absence of studies explicitly addressing VSM-BIM integration in road design. Second, through the application of reflexive thematic analysis, the study synthesiss transferable critical success factors from conceptually related Lean-BIM studies into a coherent framework that may inform future research and implementation efforts within road infrastructure design context.

Previous studies have recognised the benefits of Lean and BIM separately (Azhar et al., 2012; Sacks et al., 2010). However, few studies have examined how these methodologies can be combined and applied specifically to design-related inefficiencies in infrastructure projects. Therefore, this study fills a critical research gap by emphasising design-stage integration, aligning with calls by researchers for a greater focus on the pre-construction stages.

Comparison with Previous Studies

Several of the CSFs identified in this study confirm findings from earlier studies, such as the importance of top management support (Evans et al., 2021), training (Sarhan et al., 2020), and stakeholder collaboration (McDermott et al., 2023). However, the current study extends previous frameworks by introducing a more granular view of collaboration, emphasising early engagement and lifecycle integration rather than generic coordination. Similarly, identifying digital transparency and BIM as collaboration enablers builds upon Mellado and Lou (2020) work by framing BIM as a visualisation tool and an operational platform for implementing lean processes.

Practical Implications

The transferable CSFs identified in this study offer practitioners—particularly project managers, road engineers, and public agencies—a structured guide to preparing for and executing Lean-BIM integration in road design. For example, prioritising leadership alignment and launching structured training programmes can create institutional capacity to drive integration. Moreover, embedding stakeholder engagement early in the design phase can significantly reduce the rework and design iteration cycles. From a technology perspective, the findings support investing in 3D Visualisation tools and integrated BIM platforms for real-time coordination and version control. Adopting these CSFs can also assist public sector bodies in improving the cost efficiency and speed of infrastructure delivery while ensuring that road designs are environmentally sustainable and socially responsive.

From a managerial perspective, successful implementation of VSM-BIM integration requires active leadership commitment and governance support. Senior management plays a critical role in allocating resources, establishing digital transformation strategies, promoting cross-functional collaboration, and fostering a culture of continuous improvement. Therefore, infrastructure agencies and road authorities seeking to implement VSM-BIM integration should prioritise leadership engagement alongside technological investments to support long-term organisational change.

Limitations and Recommendations for Future Research

While the thematic analysis was grounded in high-quality peer-reviewed sources, the dataset was limited to five studies, which may not fully represent the diversity of Lean-BIM practices across different geographical regions, organisational settings, or infrastructure sectors. Although the selected studies were considered information-rich and conceptually relevant to the research objectives, the small sample limits the breadth of perspectives captured within the analysis. Furthermore, the identified CSFs were derived from studies conducted in broader construction contexts rather than direct applications of VSM-BIM integration within road design environments. Consequently, the proposed framework should be regarded as exploratory, and its applicability to road infrastructure projects remains to be empirically validated. The findings therefore represent transferable insights derived from conceptually related Lean-BIM studies rather than validated road design-specific success factors. Additionally, the interpretation of CSFs relied on reflexive thematic analysis and textual coding. Although a systematic and transparent analytical procedure was adopted, the interpretation and synthesis of themes inevitably involved researcher judgment. As with any qualitative analysis, alternative researchers may identify different relationships, emphases, or thematic structures from the same dataset.

Given the absence of studies explicitly investigating VSM-BIM integration in road design, future research should focus on validating and refining the identified transferable CSFs within real-world road infrastructure contexts. This may be achieved through expert consensus techniques such as the Delphi Method or Fuzzy Delphi Method, enabling the prioritisation and contextualisation of the proposed factors. In addition, case study investigations should be undertaken to examine how these factors influence the implementation of VSM-BIM integration during actual road design projects and to assess their impact on design efficiency, collaboration, and project performance.

Future research may also explore the development of a VSM-BIM integration maturity model to assess organisational readiness and implementation capability within the road infrastructure sector. Longitudinal studies examining the evolution of Lean-BIM adoption over time would further enhance understanding of the dynamic relationships among leadership, collaboration, technology enablement, process improvement, and capability development. Such research would provide stronger empirical evidence to support the practical application of VSM-BIM integration in road design and contribute to the advancement of Lean and digital transformation within infrastructure delivery.

CONCLUSION

This study identified fifteen transferable CSFs from conceptually related Lean-BIM literature that may inform future VSM-BIM integration in road design. The review identified a significant research gap, namely the absence of studies explicitly examining VSM-BIM integration within road design processes. To address this gap, the study synthesisd transferable insights from relevant Lean-BIM literature and identified fifteen CSFs, which were consolidated into five overarching themes: Leadership and Organisational Support; Collaboration and Early Stakeholder Engagement; Process Efficiency and Waste Reduction; Technology Enablement and Visualisation; and Training and Knowledge Sharing.

These themes provide a conceptual framework of transferable factors that may support future VSM-BIM integration efforts within road infrastructure design contexts. The findings contribute to the growing body of Lean-BIM knowledge by highlighting organisational, technological, collaborative, and process-related conditions associated with successful integration initiatives in broader construction environments. From a practical perspective, the identified CSFs may serve as a preliminary reference for road design practitioners, project managers, and public agencies seeking to explore integration-oriented approaches to process improvement and digital transformation.

Although the study was limited by the small number of eligible studies and the absence of direct road design applications, it provides an important foundation for future research. Further work is needed to validate and prioritise the identified CSFs through expert consensus techniques, case studies, and real-world implementation within road infrastructure projects. Such efforts would help establish the applicability of the proposed framework and enhance understanding of how VSM and BIM can be integrated to support more efficient and collaborative road design processes.

In conclusion, this review does not provide direct empirical evidence of VSM-BIM integration in road design, highlighting a significant gap in the current literature. Nevertheless, the transferable CSFs identified through thematic analysis provide a preliminary conceptual foundation for future framework development, expert validation, and case-based investigation. The findings offer an initial roadmap for researchers and practitioners seeking to advance Lean and digital transformation within road infrastructure design.

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