

Toward a strategic framework for AI-BIM adoption in Ethiopian road infrastructure management

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Abstract

Purpose – Artificial intelligence (AI) and building information modelling (BIM) have transformed the architecture, engineering and construction (AEC) industry in developed countries, but their adoption in Ethiopia's road infrastructure management remains limited. Empirical evidence on adoption benefits, challenges and a context-specific strategic framework for developing countries is limited. This study addresses this gap by exploring the necessity of AI-BIM integration and identifying how it can be effectively implemented in Ethiopia. Specifically, it investigates: (1) professional perception on the benefits and challenges of AI-BIM adoption, (2) critical dimensions for adopting AI-BIM integration and (3) the development of a context-specific strategic framework to guide AI-BIM adoption.

Design/methodology/approach – This study employs a mixed-method exploratory design, combining a narrative literature review and structured questionnaire survey to investigate AI-BIM adoption in Ethiopian road infrastructure management. The literature review synthesises fragmented theoretical and empirical insights to identify six interrelated strategic dimensions, while the survey captures practitioner perceptions of adoption benefits and challenges. Data were collected from 33 professionals from the Ethiopian Road Administration (ERA) and the Addis Ababa City Road Authority (AACRA) using purposive and convenience sampling. Quantitative data were analysed using descriptive statistics to determine key patterns and priorities, and qualitative insights were thematically synthesised. The integration of findings follows a triangulation approach, enabling the development of a context-specific, empirically grounded, and practically applicable AI-BIM adoption framework.

Findings – Road infrastructure management practices in Ethiopia are conventional and fragmented. The findings highlighted the potential benefits and challenges of adopting AI-BIM integration. Six critical strategic dimensions were synthesised into a context-specific strategic framework tailored to Ethiopia's road sectors.

Research limitations/implications – This study provides timely, context-specific insights; however, it is limited by the sample size and focus on selected road sectors and technologies. The findings are primarily context-specific and may not be directly generalisable. Future research could expand the empirical scope, incorporate additional emerging technologies, and validate the framework in other sectors and geographical contexts.

Practical implications – The proposed framework offers structured and actionable guidance for policymakers and practitioners, emphasising phased implementation, capacity building and interdepartmental collaboration to enable successful AI-BIM adoption.

Social implications – The study promotes the adoption of AI-BIM integrations to support digital transformation, enhances transparency, improves service delivery, and contributes to sustainable road infrastructure development outcomes.

Originality/value – This study contributes evidence-based, context-specific insights and a strategic framework for AI-BIM adoption in Ethiopia, bridging the gap between global technological advancement and local



implementation realities. It contributes practical guidance for policymakers and practitioners in developing countries rather than theoretical innovation.

Keywords Artificial intelligence (AI), Building information modelling (BIM), Road infrastructure management, Technology adoption framework, Developing country context, Digital transformation

Paper type Research article

1. Introduction

The road networks are a fundamental public infrastructure asset that serves as a critical enabler of economic growth, social integration, and sustainable development (Kuncoro *et al.*, 2024; Rammelt, 2018). It facilitates mobility, enhances urban market access and strengthens regional connectivity (Badada *et al.*, 2023). In developing countries, particularly Ethiopia, road infrastructure plays a central role in poverty reduction and national economic development strategies (Abduletif *et al.*, 2024; Kesto and Gebre, 2022). Despite the strategic importance, its development and management in Ethiopia continue to lag behind the increasing transportation and economic demands, resulting in deteriorating asset conditions and widening performance gaps (Natsui *et al.*, 2022). Existing studies consistently identify chronic funding shortage, inefficient resource allocation, and maintenance backlogs as major constraints affecting infrastructure performance (Kesto and Gebre, 2022; Mouratidis, 2020; Negashi, 2022). However, while these studies primarily focus on financial and operational limitations, other studies further emphasise institutional and technical deficiencies, including ageing infrastructure, limited skilled manpower, outdated management systems, and unclear decision-making processes (Habte, 2014; Sedivy *et al.*, 2024; Semunigus, 2020). Collectively, these interconnected challenges increase operational cost, reduce lifecycle performance, and negatively affect the national economy's productivity (Melaku Belay *et al.*, 2021; Abduletif *et al.*, 2024).

Similarly, African road agencies have a fragmented organisational structure, which leads to inefficiency in infrastructure management (Bireda, 2018). Conventional infrastructure management practices frequently contribute to project delays, stakeholder conflicts, poor information exchange, and poor lifecycle coordination (Gadisa and Zhou, 2019; Kesto and Gebre, 2022). In response, previous studies advocate for an integrated and data-driven infrastructure management system capable of significantly improving planning, design, construction, maintenance, safety, mobility, and sustainability performance (Habte, 2014; Bliss and Breen, 2012; Natsui *et al.*, 2022; Chai *et al.*, 2024). Nevertheless, a critical comparison of these studies indicates that most recommendations remain conceptual or policy-oriented, with limited practical implementation frameworks tailored to developing country road agencies, practical in Ethiopia context. This reveals a significant research and practice gap and highlights the urgent need for a more integrated, digitalised, and data-driven approach to road infrastructure management.

In response to these challenges, digital technologies such as Artificial Intelligence (AI), Building Information Modelling (BIM), the Internet of Things (IoT), and Digital Twins have emerged globally as transformative solutions for infrastructure management. AI enables predictive maintenance, automation and advanced data analytics (Bassir *et al.*, 2023; Katsarov and Penkov, 2023), while BIM provides a centralised digital platform for storing, structuring, integrating, visualising and managing infrastructure data (Abbondati *et al.*, 2020; Hagedorn *et al.*, 2023). Increasingly, recent studies highlight that the greatest value lies not in the isolated adoption of these technologies but in their integration. AI-BIM integration enables real-time data processing, predictive insights, and enhanced decision-making support, where BIM provides the spatial and contextual foundation, and AI enhances analytical capabilities (Aziz *et al.*, 2017; Kim *et al.*, 2024). This integration supports more informed, data-driven decision-making and contributes to the development of resilient infrastructure systems (Ajrotutu *et al.*, 2024; Rane, 2023). However, existing research has predominantly focused on vertical

construction rather than road infrastructure management (Ajirotutu *et al.*, 2024; Ye *et al.*, 2024). Furthermore, many studies are either review-based or bibliometric in nature, with empirical evidence predominantly originating from developed countries (Khan *et al.*, 2024; Ozturk and Tunca, 2020; Ye *et al.*, 2024).

Recent studies have highlighted the growing role of BIM, AI and digital transformation in improving infrastructure planning, project delivery, and asset management. However, most existing research has focused on vertical construction application, project-level implementation, technical capabilities, or organisational adoption within developed economies. Limited attention has been given to the institutional, organisational, and contextual complexities influencing AI-BIM adoption and its strategic adoption for public-sector road infrastructure management in developing countries (Sampaio *et al.*, 2022; Alavi *et al.*, 2024; Zhou *et al.*, 2024). This has resulted in a critical knowledge gap regarding how AI-BIM can be effectively implemented within resource-constrained road agencies. In the Ethiopian context, no empirical studies or locally grounded frameworks currently exist to guide the strategic adoption of AI-BIM integration.

This study addresses this gap by developing an empirically grounded strategic framework tailored to the Ethiopian road sector context by focussing on two key public organisations: the Ethiopian Road Administration (ERA), responsible for federal road networks, and the Addis Ababa City Road Authority (AACRA), which manages the urban road network in the capital city. This study is guided by two critical questions: (1) Why is the adoption of AI-BIM integration necessary for road infrastructure management in Ethiopia? and (2) How can such integration be effectively implemented within this context? To address these questions, the study pursues three basic objectives: (1) to investigate professional perceptions on perceived benefits and challenges associated with AI-BIM adoption, (2) to critically review and identify key dimensions influencing adoptions, and (3) to develop a strategic AI-BIM adoption framework tailored to the Ethiopian road sector. To achieve these objectives, a mixed-methods approach was employed, combining a narrative systematic review with an empirical survey of industry professionals. The literature review critically synthesises AI-BIM adoption benefits, challenges to inform the design of the survey instrument and to review existing theories, frameworks, and models to identify strategic adoption dimensions and framework development, while the empirical component captures context-specific insights on benefits and challenges.

This study contributes to the emerging body of knowledge on AI-BIM adoption by developing a context-specific strategic framework for road infrastructure management in Ethiopia. Unlike previous studies that have predominantly focused on vertical buildings or generic digital transformation initiatives, this study addresses the unique institutional, organisational, and technological realities of public-sector road agencies in a developing-country context. Rather than proposing a new theory, the study highlights that AI-BIM adoption is shaped not only by technological readiness but also by the interaction of governance arrangements, organisational capacity, workforce development, data governance, and operational integration. By bringing these interrelated dimensions together within a six-pillar strategic framework, the study provides a context-sensitive perspective that enriches current understanding of the factors influencing digital transformation in infrastructure management. Methodologically, the study combines evidence from a narrative systematic literature review with insights gathered from industry professionals, thereby bridging global knowledge and local practice. This integrated approach provides a robust foundation for identifying contextually relevant adoption factors and developing a framework that is both theoretically informed and practically applicable. From a practical perspective, the framework offers strategic guidance for policymakers, infrastructure agencies, and practitioners seeking to advance digital transformation within resource-constrained environments. Although the study is geographically focused on Ethiopia, with particular emphasis on the ERA and the AACRA, the findings generate insights that may be transferable to other developing countries facing similar institutional, technological, and capacity-related challenges. Consequently, the

study provides an actionable roadmap for supporting the effective integration of AI and BIM in road infrastructure management and contributes to the broader discourse on digital transformation in developing-country infrastructure sectors.

2. Literature review

2.1 AI-BIM integration in road infrastructure management

Artificial Intelligence (AI) and Building Information Modelling (BIM) are increasingly recognised as transformative technologies for infrastructure lifecycle management. AI techniques such as machine learning (ML), deep learning, computer vision, and natural language processing have demonstrated strong potential in road asset classification, pavement condition assessment, traffic optimisation and predictive maintenance (Abduljabbar *et al.*, 2019; Zhang *et al.*, 2021; Sami *et al.*, 2023; Tamagusko and Ferreira, 2023). At the same time, BIM provides a centralised digital environment that supports planning, cost estimation, coordination and operational decision making across the asset life cycle (Abbondati *et al.*, 2020; Hagedorn *et al.*, 2023). While these studies clearly establish the technical capabilities of AI and BIM individually, a closer investigation reveals that they predominantly evaluate performance improvements within controlled or project-specific environments without assessing long-term organisational integration or scalability across the infrastructure systems.

Recent studies highlight that the integration of AI and BIM can significantly improve data-driven decision-making, enabling real-time monitoring, predictive maintenance, and supporting sustainable infrastructure management (Acerra *et al.*, 2022; Kaewunruen *et al.*, 2020; Rexhaj, 2024). Kaewunruen *et al.* (2020) primarily emphasise lifecycle optimisation and asset performance improvement through digital integration, while Acerra *et al.* (2022) focus on data interoperability enhancement and intelligent data exchange across the infrastructure system. Similarly, Hetemi *et al.* (2020) demonstrate the growing application of AI-enabled digital twins for scenario analysis and proactive infrastructure management. Although these studies collectively demonstrate the technological potential of AI-BIM integration, they predominantly concentrate on technical functionality and system performance, with comparatively limited attention given to organisational readiness, governance structures, policy alignment, and institutional transformation requirements. This limitation reduces the applicability of existing findings within complex public-sector environments, where infrastructure management decisions are strongly influenced by institutional capacity, budget limitations, stakeholder coordination, and regulatory conditions.

Despite the recognised benefits, previous studies consistently report multiple barriers that hinder effective AI-BIM integration. This includes high initial investment and operational costs (Wangchuk *et al.*, 2024; Li *et al.*, 2022), uncertainty regarding return on investment (Yuan *et al.*, 2019), lack of data, poor quality and privacy concerns (Ait-Lamallam *et al.*, 2021; Narindri *et al.*, 2022), interoperability challenges (Floros *et al.*, 2020; Hetemi *et al.*, 2020), stakeholder resistance to organisational change (Razkenari *et al.*, 2016; Loeh *et al.*, 2021), lack of skilled manpower (Hetemi *et al.*, 2020; Vilotienė *et al.*, 2020; Zawada *et al.*, 2024), a lack of a BIM standardised tailored to the infrastructure (Ngoc *et al.*, 2023), complexities of data collection and analysis (Ershadi *et al.*, 2022) and limited technology (Andri *et al.*, 2022). However, a closer examination of these studies indicates that these barriers are highly interconnected rather than isolated. Technological limitations are frequently reinforced by institutional weaknesses, fragmented organisational processes, limited digital governance frameworks, and inadequate human-resource capacity.

This challenge becomes more pronounced within developing-country contexts, where studies report that fragmented data environments, limited institutional capacity, inadequate policy support, and resource constraints substantially restrict practical AI-BIM implementation in road infrastructure sectors (Osunsanmi *et al.*, 2018; Saka and Chan, 2019a; Marzouk *et al.*, 2021). While existing studies identify important technological and operational barriers, most remain fragmented in scope and provide limited strategic guidance

on how technological, organisational, institutional, and governance dimensions can be integrated within a unified implementation framework. Consequently, the literature still lacks a comprehensive and context-sensitive approach capable of addressing the complex interaction between technology adoption, institutional readiness, organisational transformation, and infrastructure management practices in developing-country road sectors.

2.2 Global adoption practices and the developing country gap

AI-BIM integration has improved road infrastructure project coordination, lifecycle planning, and decision-making in developed countries. In Germany, using a common data environment for road projects has improved data management and value-driven risk mitigation (Matthei *et al.*, 2023). Italy's BIM-based rural road reverse engineering shows early stakeholder engagement benefits (Abbondati *et al.*, 2020), while China's combination of CAD and BIM improves precision and complex data handling in road design (Salvatore *et al.*, 2020). Large-scale projects, such as the Hong Kong-Zhuhai-Macao Bridge, reflect the versatility of BIM's lifecycle (Zhou *et al.*, 2024). Moreover, tools such as IFC Infra4OM support BIM in operations and maintenance (Ait-Lamallam *et al.*, 2021), and AI-enhanced BIM models facilitate real-time, intelligent decision-making (Adeel *et al.*, 2023; Ozturk and Tunca, 2020). In these contexts, AI-BIM adoption is often embedded within broader construction 4.0 strategies that integrate GIS, IoT and advanced analytics (Olanrewaju *et al.*, 2021; Kumar *et al.*, 2024). The critical implication of these cases shows that their success is not solely due to technological complexity but is strongly supported by mature institutional regulatory frameworks, standardised data protocols and sustained investment environments.

In contrast, developing regions, particularly in Africa, lag significantly behind in AI-BIM adoption. Studies consistently report low digital readiness, fragmented information systems, limited institutional support, and constrained financial and human resources (Pillay and Mafini, 2017; Osunsanmi *et al.*, 2018; Venter *et al.*, 2021; Wyk *et al.*, 2021). While some progress has been observed in parts of North and West Africa, adoption remains uneven and largely experimental, technological readiness is low, lack of skilled manpower, limited organisational commitment and capacity building (Saka and Chan, 2019a; Babatunde *et al.*, 2020). Unlike developed contexts, where adoption is technology-driven, the African context reveals that adoption challenges are predominantly institutional and structural, shifting the focus from "is the technology work?" to "is the system supporting the technology?" (Pillay and Mafini, 2017; Venter *et al.*, 2021). Critically, existing African-focused studies tend to be either exploratory or narrowly focused on BIM awareness, often overlooking AI integration, decision-making structure and sector-specific adoption strategies (Marzouk *et al.*, 2021; Olanrewaju *et al.*, 2021; Precious, 2024). Socio-cultural, institutional, and governance-related barriers are frequently acknowledged but rarely operationalised into actionable adoption strategies (Kavanancheeri, 2024; Ozturk and Tunca, 2020). This lack of analytical depth and operational focus results in an important gap: the absence of empirically grounded, context-specific frameworks that explain how AI-BIM adoption can be systematically enabled in resource-constrained public-sector road agencies.

2.3 Theoretical perspectives and the need for integrated strategic

To study the technology adoption, the previous studies have applied multiple theoretical perspectives. Institutional Theory emphasises regulatory pressure, norms, governance structures, and organisational behaviour (Yuan *et al.*, 2019). The Resource-Based View (RBV) highlights financial capacity, technical expertise, and organisational capabilities (Pinto, 2023). The Technology-Organisation-Environment (TOE) framework focuses on technological readiness, organisational capabilities, and external environments (Ozturk and Tunca, 2020), while the Technology Acceptance Model (TAM) explains perceived usefulness, ease of use, and influences user acceptance (Howard *et al.*, 2017; Sanchís-Pedregosa *et al.*, 2020). Moreover, the Data-Information-Knowledge-Wisdom (DIKW) hierarchy explains

how data can be transformed into actionable insights (Hong *et al.*, 2018). Strategic Capability perspectives emphasise administrative capacity, organisational vision, and policy alignment (Olugboyega and Windapo, 2022) and establishing supportive policies and frameworks emphasise the technological investment and personnel capabilities (Rane *et al.*, 2024; Zawada *et al.*, 2024). Critically, each theory or model explains only a partial dimension of the adoption process. For example, TOE effectively captures environmental and organisational readiness but underrepresents human behavioural factors, while TAM explains user acceptance but overlooks institutional and policy constraints. Similarly, RBV focuses on internal capabilities without adequately addressing external regulatory pressure.

Technological readiness and intelligent tools are critical for infrastructure lifecycle management (Zhou *et al.*, 2024), while organisational culture, leadership engagement, stakeholder collaboration, and adequate financial allocation reinforce adoption success (Castañeda *et al.*, 2024). Data governance and organisational learning are adaptive processes in digital infrastructure management (Alavi *et al.*, 2024), so data integrity and accessibility are essential for reliable decision-making (Karmakar *et al.*, 2022), and Agile principles support transformation in complex environments (Kazar *et al.*, 2022). Despite these advancements, the literature still lacks an integrated perspective that systematically combines Policy, Budget, technological, People, data, and process dimensions into a unified analytical structure. Furthermore, evidence from developing-country studies suggests that no single perspective sufficiently explains AI-BIM adoption in public-sector infrastructure (Saka and Chan, 2019a; Marzouk *et al.*, 2021). This reinforces the need for an integrated strategic approach that simultaneously considers policy, resources, technology, people, data, and processes as interdependent components of adoption rather than isolated factors. This is, therefore, the selection of the six strategic pillars is grounded in a systematic synthesis of the above-established theories, frameworks and models, where each pillar represents a critical and non-overlapping dimension of AI-BIM adoption. Specifically, policy reflects institutional and regulatory influences (Institutional Theory), budget captures organisational resource capacity (RBV), technology addresses system readiness and external environment (TOE framework), people represent user acceptance and behavioural factors (TAM), data aligns with information maturity and decision-making value (DIKW hierarchy), and processes reflect implementation and operational adaptability (Agile and continuous improvement principles). Together, these pillars provide a comprehensive yet practical structure that captures the multi-dimensional nature of adoption without redundancy, ensuring relevance to real-world infrastructure management contexts.

To enhance analytical transparency and demonstrate the theoretical grounding of this synthesis, Table 1 below presents a comparative mapping of the six strategic pillars, their theoretical foundations, and their relevance to AI-BIM adoption. This structured synthesis provides the conceptual basis for the subsequent empirical investigation and framework development.

2.4 Research gap

A synthesis of recent studies indicates a persistent and critical disconnect between the rapid technical advancement of AI-BIM integration and the development of strategic, governance-oriented, and context-sensitive frameworks required to guide its adoption in public-sector road infrastructure, particularly in developing-country contexts. While recent studies have significantly advanced AI-BIM applications in areas such as smart infrastructure, lifecycle optimisation, and digital twins, the institutional and strategic dimensions of adoption remain comparatively underdeveloped. For instance, Li *et al.* (2024) highlight through a comprehensive bibliometric analysis that existing research is heavily concentrated on technical performance and sustainability outcomes, while largely overlooking governance structures, organisational readiness, and financial and human-capacity constraints that shape real-world implementation, especially in a public-sector context. At the technical frontier, recent studies such as Scolamiero *et al.* (2025) and Scolamiero and Boccardo (2026)

Table 1. Theoretical foundation and justification of the six strategic pillars for AI-BIM adoption

Strategic pillar	Theoretical foundation	Key focus in literature	Relevance to AI-BIM adoption	Justification for inclusion
Policy	Institutional Theory	Regulatory frameworks, governance structures, and institutional pressure	Shapes organisational behaviour, compliance, and strategic direction in public-sector adoption	Included to capture the regulatory and governance environment influencing adoption decisions, particularly critical in public-sector road agencies
Budget (Resources)	Resource-Based View (RBV)	Financial capacity, organisational resources, and capability development	Determines availability of funding, technical infrastructure, and long-term sustainability	Selected to reflect the role of financial and organisational capacity constraints in enabling or limiting AI-BIM adoption
Technology	Technology-Organisation-Environment (TOE) Framework	Technological readiness, system compatibility, and infrastructure availability	Influences system integration, interoperability, and technical feasibility	Included to address core technological requirements and readiness necessary for AI-BIM adoption
People	Technology Acceptance Model (TAM)	User perception, ease of use, behavioural intention, acceptance	Affects user adoption, resistance to change, and skills utilisation	Essential for capturing human factors, including user acceptance, skills, and organisational culture
Data	DIKW Hierarchy	Data quality, information processing, knowledge creation, decision-making	Supports data-driven decision-making, analytics, and intelligent system functionality	Included to emphasise the foundational role of data quality, governance, and transformation into actionable insights
Processes	Agile and Continuous Improvement Principles	Process optimisation, adaptability, iterative improvement, workflow integration	Enables efficient lifecycle management and adaptive implementation	Selected to represent operational workflows, process integration, and adaptability in dynamic infrastructure environments

demonstrate the potential of BIM-integrated digital twins supported by LiDAR and mobile mapping systems for predictive maintenance and intelligent road asset management. These contributions define what is technologically feasible in AI-enabled infrastructure systems; however, they are predominantly situated in technologically mature environments and therefore provide limited guidance on how such advanced systems can be strategically enabled within a resource-constrained institutional context. This creates a clear gap between technical possibility and implementation reality. At the continental level, the African BIM Report 2024; [BIM Africa \(2024\)](#) further substantiates this gap by showing that AI, BIM, and digital twin adoption across Sub-Saharan Africa remain largely aspirational. The report identifies persistent constraints, including weak digital infrastructure, limited technical skills, and inadequate regulatory and institutional frameworks, and explicitly calls for context-specific implementation strategies rather than direct transfer of models from developed economies. This reinforces the need for frameworks that are both empirically grounded and institutionally sensitive to local conditions.

Collectively, existing studies on AI-BIM adoption (Osunsanmi *et al.*, 2018; Saka and Chan, 2019a; Marzouk *et al.*, 2021) remain fragmented, predominantly technology-driven, and largely focused on developed-country contexts. Although they identify important dimensions of adoption, they provide limited empirical explanation of how these dimensions interact within complex, resource-constrained public-sector environments such as road infrastructure agencies in developing countries. More critically, African-focused studies tend to remain exploratory and descriptive, with limited translation of findings into structured, actionable, and integrated strategic frameworks to guide implementation.

To address this gap, this study pursues three objectives: (1) to investigate professional perceptions of the benefits and barriers to adopting AI-BIM integration in Ethiopian road infrastructure, (2) to identify the critical dimensions that influence adoption decisions, and (3) to develop a strategic AI-BIM adoption framework tailored to the Ethiopian road sector. By integrating multiple theoretical perspectives with empirical evidence, the study advances a context-sensitive and operational framework that explains not only the determinants of adoption but also the dynamic interactions that enable or constrain AI-BIM implementation in developing-country road infrastructure systems.

3. Research methodology

This study employed a mixed-methods exploratory research design that combined qualitative and quantitative approaches to investigate the benefits and challenges of AI-BIM adoption in Ethiopian road infrastructure management and to develop a strategic conceptual framework. This approach was intentionally selected to support conceptual exploration with empirical assessment of AI-BIM adoption within a developing country context (Johnson and Onwuegbuzie, 2004; Creswell and Hirose, 2019). The narrative literature review enabled conceptual synthesis of fragmented theoretical and practical knowledge, while the questionnaire survey provided empirical insights into practitioners' perceptions and experience related to AI-BIM adoption (Hesse-Biber, 2010; Pluye and Hong, 2014). Together, these methods provided complementary evidence for identifying adoption dimensions and informing framework development.

The questionnaire instrument was developed based on the benefits and challenges identified from the narrative literature review, following a theory-informed approach appropriate for emerging and context-dependent constructs (Tong *et al.*, 2012; Boyle *et al.*, 2019). A structured closed-ended questionnaire was employed using a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5). This format ensured response consistency and facilitated descriptive statistical analysis (Creswell and Hirose, 2019). In addition, the questionnaire collected demographic and professional information, including participants' educational background, years of experience, organisational affiliation, professional role, and prior exposure to AI and BIM concepts. Capturing these characteristics supported contextual interpretation of responses and strengthened the reliability of the exploratory analysis.

Data were collected from professionals working in ERA and AACRA using purposive and convenience sampling. Purposive sampling was used to target professionals with relevant expertise or experience in road infrastructure management, digital technologies, AI, or BIM-related activities (da Silva *et al.*, 2022; Klar and Leeper, 2019). Convenience sampling supported efficient participant recruitment based on accessibility and willingness to participate (Acharya *et al.*, 2013). Participants were selected based on their familiarity with digital tools, AI/BIM-related concepts, or involvement in infrastructure project management and strategic planning functions, ensuring informed and contextually relevant responses for the study objectives (da Silva *et al.*, 2022; Klar and Leeper, 2019). The questionnaire was distributed to 50 professionals, resulting in 33 valid responses, of which 57.58% were from ERA and 42.42% from AACRA. The respondents represented diverse professional roles, including project managers, senior engineers, team leaders, and asset management

professionals. Most participants possessed 5–10 years of professional experience, while 60.61% held master’s degrees or higher qualifications.

The narrative literature review was also used to structure the critical dimension for AI-BIM adoption. This approach is appropriate for theory integration and conceptual development rather than hypothesis testing (Mohsin-Shaikh *et al.*, 2019; Sandelowski *et al.*, 2011). Through critical synthesis, six interrelated strategic pillars were identified: policy (Institutional Theory), budget (Resources-Based View), technology (TOE framework), people (TAM), Data (DIKW hierarchy), and processes (Agile and continuous improvement principles). These pillars were deliberately selected based on their complementary explanatory power in capturing the institutional, organisational, technological, human, informational, and operational dimensions of technology adoption. Their inclusion reflects the integration of multiple established theoretical perspectives rather than arbitrary selection, ensuring comprehensive coverage of the adoption ecosystem in public-sector infrastructure. The six pillars, theoretically derived and justified in section 2.3, were subsequently operationalised in this study to guide the development of the AI-BIM adoption framework.

Quantitative survey data were analysed using descriptive statistics in Microsoft Excel® (2019) and Power BI Desktop® (Version 2.139.2054.0), enabling the systematic identification of perceived benefits and challenges (Morris and Burkett, 2011; Nzabonimpa, 2018). Descriptive analysis was considered appropriate given the exploratory nature of the study and sample size, with emphasis placed on identifying patterns, trends, and relative importance rather than statistical generalisation. In parallel, findings from the narrative literature review were analysed thematically to extract key adoption themes, which were integrated with survey results to guide development of the strategic framework (Tong *et al.*, 2012; Boyle *et al.*, 2019). This integration followed a triangulation approach, where theoretical insights and empirical evidence were iteratively compared and synthesised, thereby enhancing analytical robustness and ensuring alignment between conceptual reasoning and practical (Hesse-Biber, 2010). The research process, illustrated in Figure 1, demonstrates the flow from literature synthesis to

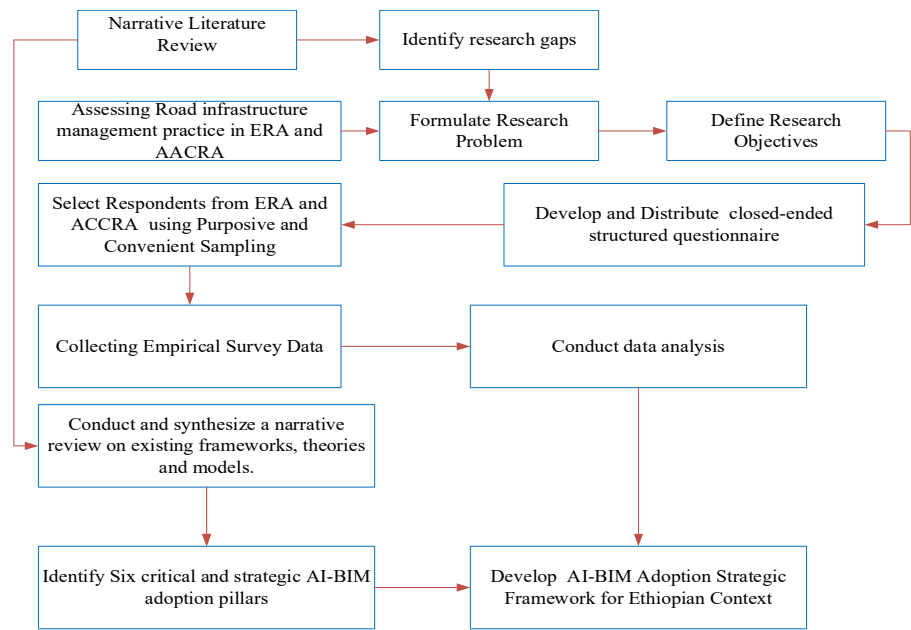


Figure 1. Research flowchart. Source: Authors’ own work

survey design, data analysis, and strategic framework development, providing methodological coherence and directly supporting the study objectives (Johnson and Onwuegbuzie, 2004). Ethical approval for this study was obtained before data collection, and all participants provided informed consent. Participation was voluntary, confidentiality was assured, and no personally identifiable information was collected or stored. All procedures followed established standards for research involving human participants (Creswell and Clark, 2017).

This study is limited by the small, context-specific sample of professionals and reliance on perception-based data at an early stage of AI-BIM adoption. Consequently, the findings cannot be statistically generalised but provide valuable insights for contextually relevant strategic decision-making. While the proposed framework is empirically informed, it has not yet been quantitatively validated, indicating an important direction for future research using larger samples and advanced analytical techniques.

4. Results and discussion

Road infrastructure Management (RIM) in developing countries is increasingly recognised as a critical domain requiring digital transformation to improve efficiency, sustainability, and resilience. Despite global advancement in technologies such as AI and BIM, many developing countries continue to rely on conventional, fragmented, and resource-intensive management systems. These limitations are often rooted in broader institutional, economic, and governance conditions, including constrained financial capacity, limited technical expertise, poor regulatory frameworks, and inadequate data ecosystems. In this context, the adoption of AI-BIM integration represents not only a technological shift but also a systematic transformation that necessitates alignment across policy, organisational structures, and technical capabilities.

Ethiopia's RIM practice reflects many of these structural challenges raised in developing countries, particularly within public-sector-led infrastructure systems. Understanding how these contextual conditions shape both the perceived benefits and challenges of AI-BIM adoption is essential for developing effective, context-sensitive strategies. Accordingly, this section presents and critically analyses the empirical findings of the study into five subsections. The first and second, the perceived benefits and challenges, are analysed and discussed through a comparative and context-sensitive lens. Third, the proposed strategic framework is discussed, demonstrating how empirical evidence and theoretical foundations converge to address Ethiopia-specific constraints. Fourth, the implications and contributions of this study are discussed, and finally, the limitations and future research directions are highlighted.

4.1 Perceived benefits of AI-BIM adoption

The empirical findings of this study reveal a strong recognition of the potential benefits of AI-BIM adoption in the Ethiopian RIM practice among respondents. As illustrated in Figure 2, 90.91% of respondents identified enhanced decision-making as a key benefit, followed by improvements in resilience and sustainability (87.88%), project delivery and stakeholders' collaboration (81.81%) and lifecycle cost optimisation (81.81%). Despite the limited practical adoption, these study results indicate a high level of awareness regarding the transformative potential of adopting AI-BIM technologies. Similarly, Ozturk and Tunca (2020) identifying AI-BIM adoption enhances the decision-making process, while Salleh *et al.* (2019) and Bilge and Yaman (2021) emphasise improvements in stakeholder coordination. Hetemi *et al.* (2020) and Ma *et al.* (2020) further highlight predictive analytics and scheduling optimisation capabilities of AI-BIM, and Pishdad and Onungwa (2024) underscore lifecycle cost management efficiency. The alignment between this study and the Ethiopian findings suggests that perceived benefits of AI-BIM are relatively universal across different contexts.



AI-BIM adoption Benefits

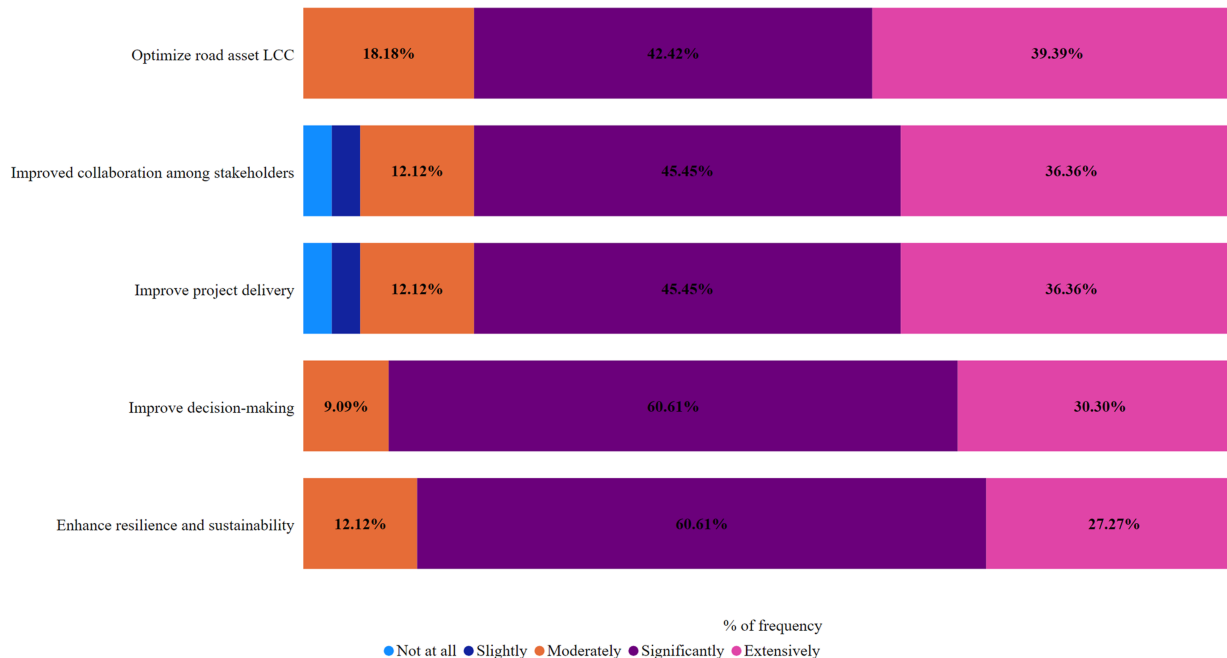


Figure 2. Benefits of adopting AI-BIM integration. Source: Extracted from Power BI®-V-2.139.20

4.2 Perceived challenges of AI-BIM adoption

Despite the identified benefits, the empirical findings of this study identify potential challenges of AI-BIM adoption in Ethiopia's RIM. As illustrated in Figure 3, the lack of skilled manpower (93.94%) was highlighted as the most significant challenge, followed by high initial investment costs (87.88%), resistance to change (78.79%), absence of clear policies (72.73%) and concerns related to data quality and security (63.64%). These findings indicate that the challenges to adoption are multidimensional, encompassing human, financial, operational and institutional factors.

The prominence of skilled labour shortages aligns with Olugboyega and Windapo (2021) and Saka and Chan (2019a, b), who identify human capital constraints as critical challenges in developing countries. However, the intensity observed in the Ethiopian context suggests a deeper structural issue linked to limited access to specialisation training programmes and insufficient integration of digital competence with engineering education and the professional development system. Unlike developed contexts, where capacity building often accompanies technological diffusion, Ethiopia faces a lag in capacity-building mechanisms, thereby amplifying the human resources gap. Financial constraints, reflected in the high ranking of initial investment costs, are consistent with Hamma-Adama *et al.* (2020), Ismail *et al.* (2022) and Best (2024). Nevertheless, this study provides a more detailed interpretation by distinguishing between structural and operational constraints. While financial limitations are embedded within Ethiopia's broader economic conditions and public-sector budgetary dependence, their impact is compounded by competing national development priorities. This contrasts with more developed countries, where private sector participation and diversified funding mechanisms often mitigate financial barriers. Resistance to change further highlights the organisational and cultural dimensions of technology adoption. Rane *et al.* (2024) and Tan *et al.* (2019) highlight that these challenges reflect low levels of technology acceptance and institutional unwillingness. In Ethiopia, this resistance is intensified by hierarchical organisational structures and limited exposure to digital innovation, which collectively slow the transition from traditional practice to a data-driven system. The absence of clear policies and regulatory frameworks represents another critical constraint, corroborating the studies of Srivastava *et al.* (2022) and Semunigus (2020). In the Ethiopian context, this gap is particularly significant due to the centralised governance system, where policy direction plays a decisive role in shaping technological adoption. Without enabling regulations, standardisation protocols, and national digitalisation strategies, the implementation of AI-BIM remains fragmented and uncertain. Data-related challenges, including poor data quality and accessibility, further reinforce the findings of Naji *et al.* (2024), who emphasise the importance of data governance in infrastructure management. In Ethiopia, these challenges are closely linked to the absence of data, poor data quality, an integrated system, and standardised data collection practices, which limit the potential for advanced analytics and informed decision-making. Importantly, these challenges are not independent but mutually reinforcing.

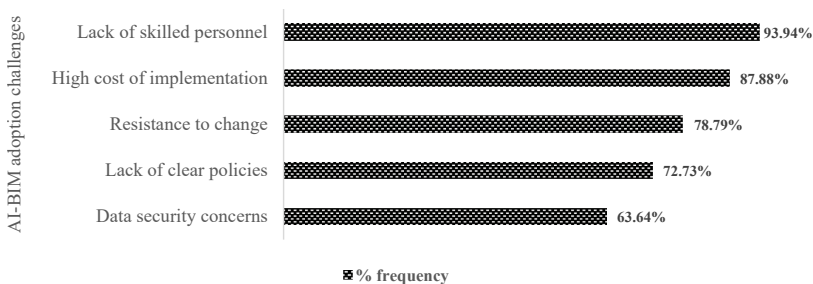


Figure 3. Challenges of adopting AI-BIM integration. Source: Extracted from Excel® 2019

For instance, limited financial resources restrict investments in training and technology, while the lack of skilled personnel reduces the effective utilisation of available tools. Similarly, poor policy frameworks hinder coordinated implementation, exacerbating issues related to data management and interdepartmental collaboration. This interconnected nature of barriers underscores the need for a holistic and coordinated approach to AI-BIM adoption, rather than isolated interventions.

4.3 Strategic framework for adopting AI-BIM integration in Ethiopia

Road infrastructure in Ethiopia continues to be inefficient in management, including a fragmented data environment, persistent reliance on a conventional management approach, and poor inter-organisational collaboration (Kesto and Tsega, 2022; Melaku Belay *et al.*, 2021). While these challenges have been widely acknowledged in previous studies in the developing countries, the empirical findings of this study provide context-specific evidence demonstrating how these limitations manifest across institutions, technological, and operational dimensions. Importantly, the results reveal that these challenges are not isolated but mutually reinforcing, thereby necessitating a holistic and strategically coordinated response.

To address this gap, this study develops a context-specific strategic Framework for AI-BIM adoption, synthesised from both empirical findings and a narrative systematic review. The framework is structured into six interrelated pillars, such as policy, budget, technology, people, data, and processes, which collectively capture the multidimensional nature of digital transformation in road infrastructure management. To ensure analytical rigour and transparency, Table-2 below presents the link of empirical findings to each framework pillar, thereby demonstrating how the proposed frameworks are directly grounded in perceived challenges and benefits.

As illustrated in Table 2, the six strategic pillars for the proposed AI-BIM adoption framework are systematically mapped from key empirical findings and a narrative review. It shows how specific challenges, such as regulatory gaps, financial limitations, technological incompatibility, limited skill manpower, poor data quality, and inefficient processes, connect to targeted strategic responses. This mapping provides a clear analytical link between the evidence gathered and the framework's design, reinforcing its empirical grounding.

Building on this foundation, Figure 4 presents the AI-BIM Adoption Strategic Framework using a Fishbone (Ishikawa) structure. This structure is well-suited to the task; it places the central goal of effective AI-BIM adoption at the head of the diagram and traces the contributing causes back through six interdependent strategic pillars.

As illustrated in Figure 4, the proposed framework is structured around six interrelated pillars: Policy and Legislation, Budget, Technology, People, Data, and Process. Rather than functioning as isolated dimensions, the findings indicate that these pillars collectively shape the institutional, organisational, and operational readiness required for AI-BIM adoption in Ethiopian road infrastructure management. The framework, therefore, reflects a systemic perspective, where weaknesses in one pillar can constrain the effectiveness of others. For example, technological investment without regulatory support, skilled personnel, or reliable data governance is unlikely to achieve sustainable implementation outcomes. This interdependency demonstrates that AI-BIM adoption extends beyond technological deployment and requires coordinated institutional and organisational transformation.

The Policy and Legislation pillar emerged as a foundational institutional enabler. Empirical findings presented in Table 2 reveal that the absence of formal BIM standards, weak regulatory enforcement, and fragmented policy structures significantly limit digital transformation efforts. While previous studies primarily frame policy as a supporting mechanism for technology adoption, the current findings suggest that institutional alignment plays a more central role in shaping implementation capacity within public-sector infrastructure organisations. This supports Institutional Theory (DiMaggio and Powell, 1983), which

Table 2. Linking empirical findings to AI-BIM framework pillars

	Empirical finding (Ethiopia)	Supporting literature	Strategic framework pillar	Contextual interpretation
RIM practice	Limited interdepartmental coordination	Naji et al. (2024)	Processes	Reflects institutional fragmentation; emphasises the importance of integrated workflows, collaborative platforms, and cross-agency coordination mechanisms
	Stakeholder collaboration challenges	Asif et al. (2024)	People/ Processes	Indicates weak stakeholder engagement; suggests strengthening communication frameworks and collaborative decision-making structures
	Outdated technologies and manual systems	Kesto and Tsega (2022) , Melaku Belay et al. (2021)	Technology	Highlights low digital maturity; calls for investment in digital infrastructure, interoperable systems, and adoption of emerging technologies such as AI, BIM and AI-BIM integration
AI-BIM adoption challenges	Lack of skilled personnel	Olugboyega and Windapo (2021) , Saka and Chan (2019a, b)	People	Highlights Ethiopia's human resource limitations; underscores the critical need for capacity-building initiatives, professional training programs, and institutional skill development to support AI-BIM adoption
	High initial investment cost	Hamma-Adama et al. (2020) , Ismail et al. (2022)	Budget	Reflects financial constraints and limited public-sector funding; emphasises the importance of investment planning, cost-benefit analysis and exploring public-private partnerships
	Resistance to change	Rane et al. (2024) , Tan et al. (2019)	People/ Processes	Indicates organisational culture challenges and low technology acceptance; suggests the need for change management strategies, awareness programs, and incremental implementation approaches
	Lack of clear policies and regulations	Srivastava et al. (2022) , Semunigus (2020)	Policy	Demonstrates regulatory and institutional gaps; highlights the necessity of establishing supportive legal frameworks, standards, and national digitalisation strategies
	Poor data quality and accessibility	Naji et al. (2024)	Data	Reveals weak data governance systems; underscores the need for structured data management, data standardisation, and integration mechanisms

(continued)

Table 2. Continued

	Empirical finding (Ethiopia)	Supporting literature	Strategic framework pillar	Contextual interpretation
AI-BIM adoption benefits	BIM enhances decision-making	Ozturk and Tunca (2020)	Technology/ Data	Demonstrates readiness for digital transformation and supports the use of AI-BIM for predictive analytics and evidence-based decision-making
	AI-BIM improves resilience and sustainability	Salleh et al. (2019) , Bilge and Yaman (2021)	Technology/ Processes	Reflects awareness of inefficiencies in current RIM; aligns with sustainability goals and long-term asset management
	AI-BIM enhances stakeholder collaboration and project delivery	Hetemi et al. (2020) , Ma et al. (2020)	People/ Processes	Indicates potential for improved communication and coordination across departments; reinforces the need for collaboration-focused strategies
	AI-BIM Lifecycle cost optimisation and efficiency	Pishdad and Onungwa (2024)	Processes/ Budget	Emphasises long-term economic benefits and supports the integration of lifecycle thinking into infrastructure planning and management

explains how regulatory and normative pressures influence organisational behaviour ([Hamilton, 2018](#); [Rahmandad, 2012](#)). However, the findings extend this perspective by demonstrating that policy fragmentation not only delays technology adoption but also reinforces uncertainty in budgeting, data governance, and process standardisation. Consequently, the study indicates that technological readiness alone is insufficient in contexts where institutional coordination remains weak.

The Budget pillar highlights that financial barriers are not solely associated with limited funding availability but are strongly linked to strategic investment prioritisation and perceived implementation risk. As shown in [Table 2](#), respondents identified high implementation costs, uncertain return on investment, and limited financial planning mechanisms as major adoption constraints. Although the Resource-Based View ([Barney, 1991](#)) emphasises resource allocation as a determinant of organisational performance ([Gupta et al., 2018](#); [Kero and Bogale, 2023](#)), the findings suggest that resource availability alone does not guarantee adoption readiness. Instead, organisations require clear value demonstration, phased implementation approaches, and long-term investment strategies to reduce institutional resistance and financial uncertainty. This finding contrasts with studies that primarily interpret financial limitations as resource scarcity, revealing that strategic confidence and governance capability are equally important adoption determinants.

The Technology pillar reflects the technical and infrastructural readiness required for AI-BIM integration. [Table 2](#) indicates that interoperability limitations, inadequate digital infrastructure, and restricted access to advanced technologies remain significant barriers. These findings align with the Technology–Organisation–Environment (TOE) framework ([Tornatzky and Fleischer, 1990](#)), which identifies technological compatibility and organisational readiness as critical adoption factors ([El-Gazzar, 2014](#)). However, the findings reveal that technological barriers in the Ethiopian context are increased by institutional and human-capacity constraints. This suggests that technological implementation cannot be analysed independently from governance structures, workforce capability, and

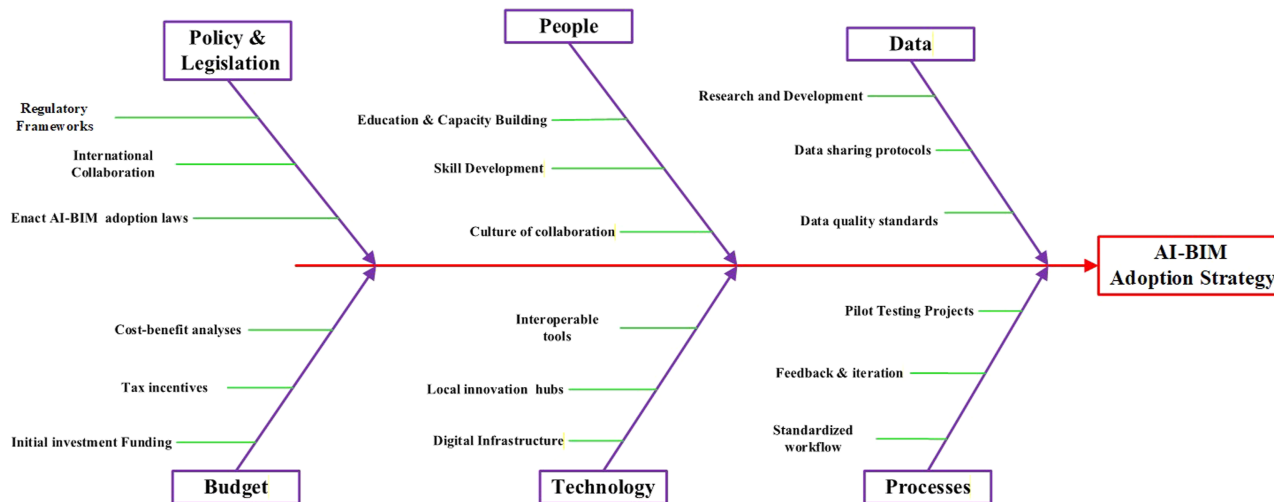


Figure 4. AI-BIM adoption strategic framework for RIM in Ethiopia. Source: Authors' own work

organisational maturity. In contrast to studies that treat interoperability as primarily a technical challenge, this study demonstrates that interoperability limitations also reflect fragmented organisational systems and weak cross-departmental coordination.

The People pillar emphasises the human and organisational dimensions of AI-BIM adoption. Empirical findings show that skill shortages, limited awareness, and resistance to organisational change significantly affect implementation readiness. While these findings support the Technology Acceptance Model (TAM), which highlights perceived usefulness and ease of use as key adoption drivers (Davis, 1989), which highlights perceived usefulness and ease of use as key drivers of adoption (Sheehan and Foss, 2017), the results suggest that adoption challenges extend beyond individual user acceptance. Specifically, the findings indicate that organisational culture, leadership commitment, and inter-organisational collaboration strongly influence digital transformation capacity. This expands existing adoption discussions by demonstrating that technical training alone is insufficient without broader organisational learning and change-management strategies.

The Data pillar emerged as a cross-cutting component influencing all other framework dimensions. Respondents consistently identified poor data quality, lack of standardisation, fragmented information systems, and limited accessibility as major barriers to AI-BIM implementation. While previous studies emphasise the importance of data for intelligent infrastructure management, the findings indicate that data-related weaknesses also undermine policy implementation, technological interoperability, and process optimisation. The DIKW hierarchy provides a useful analytical lens for understanding how fragmented raw data limits the generation of actionable knowledge (Barney, 2001; Kero and Bogale, 2023). From a broader analytical perspective, the findings suggest that the effectiveness of AI-BIM integration is fundamentally dependent on the maturity and governance of the underlying data ecosystem.

The Process pillar addresses operational and workflow-related transformation requirements. Findings from Table 2 indicate that fragmented workflows, a lack of standardised procedures, and limited pilot implementation hinder effective digital integration. Although Agile and Kaizen principles support iterative improvement and continuous optimisation, the findings demonstrate that process inefficiencies are deeply embedded within existing organisational practices (Priem and Butler, 2001). This suggests that digital technologies alone cannot resolve operational inefficiencies if traditional, fragmented workflows remain unchanged. In contrast to studies that primarily focus on technology implementation, the present findings indicate that process transformation is equally critical for achieving sustainable AI-BIM integration. Consequently, the framework highlights that successful digital transformation requires simultaneous advancement in technological capability, institutional governance, workforce readiness, data management, and operational restructuring.

4.4 Contribution and implications of the study

This study contributes to the growing body of knowledge on AI-BIM adoption and digital transformation in road infrastructure management by providing a context-specific perspective from a developing-country public-sector context. Theoretically, it extends existing technology adoption literature by demonstrating that successful AI-BIM implementation depends not only on technological readiness but also on the alignment of institutional capacity, governance structures, organisational readiness, financial resources, workforce competencies, data governance, and operational processes. By integrating these factors into a six-pillar strategic framework, the study offers a holistic understanding of the organisational and institutional conditions required for digital transformation in a limited resource context. Practically, the study develops an evidence-based strategic framework that supports policymakers and practitioners in planning and implementing AI-BIM adoption. The framework directly addresses key barriers identified through the empirical findings, including skilled manpower shortages, budget limitations, fragmented governance, and regulatory challenges. Through a phased

implementation approach, it provides actionable guidance for strengthening institutional readiness, improving decision-making, enhancing lifecycle coordination, and promoting more efficient and sustainable road infrastructure management. Although developed within the Ethiopian context, the framework offers broader relevance for public-sector infrastructure agencies facing similar institutional and resource constraints. Methodologically, the study demonstrates the value of combining a systematic narrative review with empirical survey data to develop a context-sensitive strategic framework. The clear linkage between empirical evidence and framework components enhances methodological transparency, strengthens the validity of the proposed model, and provides a replicable approach for future research on AI-BIM adoption and digital transformation in infrastructure management.

4.5 Limitations and future research

This study provides context-specific insights with acknowledged limitations. The empirical scope is limited by a relatively small sample size and a focus on selected road sectors, which may limit the generalisability of the findings. In addition, the cross-sectional design captures perceptions at a single point in time and does not reflect the dynamic nature of the technology adoption process. Furthermore, the study focuses primarily on AI-BIM adoption, without fully incorporating other emerging technologies that are increasingly relevant to digital infrastructure management. As a result, the broader technological ecosystem may not be comprehensively represented. Future research should address these limitations by expanding the empirical scope across multiple sectors and countries to enhance generalisability and comparative analysis. Longitudinal studies are particularly needed to examine how adoption evolves in response to policy and institutional changes. Additionally, pilot implementations and case-based validation of the proposed framework are essential to assess its practical feasibility and real-world impact. Finally, further investigations into the integration of complementary technologies, such as IoT and digital twins, would provide a more comprehensive understanding of digital transformation pathways. Such research would strengthen the adaptability and scalability of AI-BIM frameworks for sustainable infrastructure management in developing contexts.

5. Conclusions

This study develops a context-sensitive strategic framework to guide AI-BIM adoption in Ethiopia's road infrastructure management, addressing the gap between global technological advances and local implementation realities. By integrating empirical evidence with established theoretical perspectives, it offers a coherent and practical framework relevant for digital transformation in a developing country context. The findings highlight that AI-BIM is widely perceived as beneficial for enhancing decision-making, sustainability, stakeholder coordination, and life-cycle cost efficiency. However, its adoption is constrained by institutional, financial, and human capacity limitations, as well as inadequate policy support. By explicitly linking these barriers to a targeted strategic response within the framework, the study provides an analytical and actional foundation for implementation. Theoretically, this study contributes to the AI-BIM adoption literature by providing a context-sensitive understanding of digital transformation within public-sector road infrastructure management. The study demonstrates that AI-BIM adoption is influenced by the combined effect of governance arrangements, organisational capacity, technological readiness, workforce development, data governance, and operational integration. The proposed six-pillar framework synthesises these dimensions into a coherent structure, contributing to a broader understanding of the opportunities and challenges associated with AI-BIM adoption in developing-country infrastructure contexts. Methodologically, the study combines a systematic literature review with empirical survey data to develop a multi-dimensional framework. This explicit evidence of framework linkage enhances methodological rigour and

ensures that the model is grounded in real-world conditions. Practically, the framework provides a structured roadmap for policymakers and infrastructure managers, emphasising phased implementation through regulatory reform, capacity building, digital investment, and improved data governance. This approach supports more efficient, transparent, and sustainable infrastructure management. While the framework is conceptually transferable, its implementation must be adapted to local conditions. Future research should therefore focus on pilot applications and longitudinal studies across different contexts to further validate and refine its applicability.

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