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Empirical Research Paper

Driving digital transformation in construction: Strategic insights into building information modelling adoption in developing countries

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A R T I C L E I N F O

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A B S T R A C T

The construction industry in developing countries faces significant challenges, including limited resources, infrastructure constraints, and varying levels of technological readiness, which hinder the adoption of Building Information Modelling. Despite the recognized benefits in enhancing project efficiency, reducing costs, and improving collaboration, there is a lack of comprehensive understanding and tailored strategies for Building Information Modelling implementation in these contexts. This study aims to address these gaps by systematically reviewing Building Information Modelling adoption literature from 2013 to 2023 and developing a model specifically designed to guide its integration in developing nations. It categorizes nations by demographic and economic parameters and employs thematic analysis to explore benefits, challenges, and strategies. The study develops a tailored Building Information Modelling adoption model, by highlighting the dynamic interplay between adoption, contextual and strategic factors, technological advancement and socio-economic development and synthesizing key insights from academic literature and empirical findings. It offers strategic recommendations for nations at different Building Information Modelling integration stages, addressing their unique socio-economic and environmental contexts. The study identifies trends in utilization and highlights significant gaps, particularly in empirical, educational and strategic initiatives on digital construction transformation.

1. Introduction

The construction industry plays a key role in the economic and sociological progress of nations worldwide. However, the industry is confronted with several obstacles that necessitate the development of creative strategies in order to guarantee its long-term viability and expansion. The digitization of the construction projects has become a significant driver in recent years, referred to as "digital transformation" (Marnewick and Marnewick, 2022). Digital transformation involves the integration of digital technologies into all areas of construction, fundamentally changing how projects are planned, designed, constructed, delivered and maintained (Musarat et al., 2021).

Central to this digital transformation is the adoption of Building Information Modelling (BIM), which entails a collaborative and data-intensive methodology for the creation, production, and administration of constructed assets (Papadonikolaki et al., 2019). BIM serves as the focal point of the construction industry's digital revolution, facilitating collaboration across diverse professional entities (Stojanovska--Georgievska et al., 2022). BIM has the capacity to significantly transform the manner in which construction projects are conceptualized, implemented, and maintained (Banihashemi et al., 2022b). This is achieved through the provision of a collaborative digital competence and platforms that encompasses all individuals and entities participating in construction projects endeavor (Liu et al., 2024).

The implementation of BIM has exhibited notable advantages in construction industries globally, including increased project management, augmented stakeholder cooperation, and informed decision-making. Although several countries have adopted BIM as a crucial instrument for enhancing their construction industries, the effective integration of this process continues to pose a significant obstacle in developing countries. In this study, we focus explicitly on developing countries and their challenges in adopting BIM. Developing countries face unique obstacles in implementing BIM compared to more developed nations, stemming from factors such as limited resources, infrastructure constraints, and varying levels of technological readiness (Takyi-Annan and Hong, 2023; Stojanovska-Georgievska et al., 2022; Zhou et al., 2019). By examining the current status, benefits, drivers, challenges, implementation status, and strategies of BIM adoption in

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developing countries, this study aims to shed light on the specific needs and considerations of these countries in embracing BIM technologies for construction and development projects.

In fact, a study conducted by Bui et al. (2016a,b) has confirmed that researchers in several developing countries have just been exploring various aspects of BIM. In their research findings, it indicated a scarcity of studies conducted in the majority of developing countries (Bui et al., 2016a,b). The absence of research in this area is a noteworthy aspect of this study, underscoring the necessity for investigation in a domain that has yet to be thoroughly examined in relation to the adoption of BIM and its consequences. It is imperative to embrace this process in order to align with developed nations, given the generally recognized advantages, enduring digitalization, and global provision of solutions offered by BIM methodologies.

According to the findings of Babatunde et al. (2020a,b), construction industry in developing countries frequently encounters challenges related to fragmentation, which may be attributed to insufficient documentation and inefficient practices in information management. The phenomenon of fragmentation leads to a decrease in output and a general lack of efficiency within the organization. Olatunji and Sher (2010) have emphasized the issues resulting from design flaws and estimating limitations, since they prevent the proper distribution of information across different phases of building projects. Given the aforementioned concerns, BIM presents itself as a potentially viable remedy. According to Eastman et al. (2011), BIM has the potential to facilitate effective communication and cooperation among many stakeholders within the building industry.

The present construction methodology is frequently characterized as a modelling technique, which encompasses a range of methodologies for generating, evaluating, and conveying project models. Furthermore, BIM has the capacity to improve the effectiveness of design and construction procedures, therefore making a valuable contribution to the overall performance of the sector, as emphasized by Abubakar et al. (2014). The use of BIM holds significant potential in enhancing the efficiency of the design, building, and maintenance processes of various structures.

Moreover, BIM offers a complete and readily available depiction of a structure, providing enhanced levels of detail and current information. The research conducted by Yori (2011) and Yusuf et al. (2016) highlights the significant impact of BIM on improving the quality, efficiency, and competitiveness of the construction industry. Therefore, BIM can be commonly defined as a collaborative process that involves the generation and management of digital representation of physical and functional characteristics of built assets throughout their lifecycle.

Recent studies by Ariono et al. (2022a,b) and Georgina Esi Takyi-Annan and Hong (2023) have delved into various aspects of BIM adoption and its barriers within the developing world. Ariono et al. (2022a,b) emphasized the identification of drivers, barriers, and enablers of BIM innovation through interpretive structural modelling, shedding light on the intricacies of BIM adoption dynamics in developing nations. On the other hand, Takyi-Annan and Hong (2023) conducted a bibliometric analysis to discern the implementation barriers of BIM in the developing world, highlighting the persistent challenges and proposing strategic frameworks for mitigation. Saka and Chan (2023) also highlighted key obstacles to the adoption of BIM across different settings, and a comparative analysis brought out the variations in perceptions. These findings highlight a pronounced digital gap in BIM adoption between small and medium enterprises (SMEs) and larger corporations, as well as an increasing disparity between developed and developing nations.

In contrast to these studies, our research endeavors to offer a comprehensive understanding of the BIM adoption landscape in three different levels of developing countries by synthesizing insights from a wide array of sources. In fact, in the construction industry, projects serve as the fundamental units of organizational operations and strategic execution. By examining BIM adoption through the lens of project delivery, this study seeks to elucidate how digital transformation impacts project outcomes, thereby contributing to the field of project management. The centrality of projects in construction means that advancements in BIM adoption directly influence project management practices, offering insights into enhanced project delivery mechanisms, resource optimization, and stakeholder engagement.

The aim is to go beyond mere identification of barriers or drivers through developing a tailored BIM adoption model, incorporating thematic analysis and strategic deployment methods. The study adopts PICO (Population, Intervention, Comparator and Outcome) framework (Amir-Behghadami and Janati, 2020) to formulate objectives and questions the review addresses, expressed in terms of a relevant question formulation framework.

- **Population:** Construction industries in developing countries.
- **Intervention:** The adoption of BIM process.
- **Comparator:** Traditional construction methods without BIM.
- **Outcome:** Improvements in project delivery and efficiency.

Therefore, the study seeks to answer the following objectives and questions.

1. Observed Benefits and Enhancements:
   - What specific improvements in project delivery, including project timelines, cost efficiency, and stakeholder collaboration, have been observed in the construction processes of developing countries following the adoption of BIM processes? How do these improvements align with the broader objectives of project management in enhancing project outcomes and achieving strategic goals?
2. Barriers and Challenges:
   - What are the primary technological, organizational, and cultural barriers and challenges that impede the adoption and implementation of BIM in the construction industry of developing countries?
3. Strategic, Contextual, and Adoption Factors:
   - How do strategic, contextual, and operational factors influence the integration of BIM in developing countries, and what tailored adoption model can be developed based on these influences?

By contextualizing the findings within the broader scope of existing literature, we seek to elucidate the novel contributions of this study in informing strategic decision-making for BIM implementation in developing nations. Applying meticulous examination and comparative analysis, the endeavor is to pinpoint the distinctive factors influencing BIM adoption within varying socio-economic contexts, thereby enriching the discourse on construction digital transformation practices globally.

2. Theoretical background

BIM has emerged as a transformative process in the architecture, engineering, and construction (AEC) industry, revolutionizing the way construction projects are planned, designed, and managed. In project management, BIM facilitates enhanced project delivery by integrating data and processes across the project lifecycle, enabling better coordination, reduced rework, and improved decision-making (Oraee et al., 2019). This section explores the theoretical underpinnings of BIM adoption, focusing on its impact on project delivery, cost control, and stakeholder collaboration within construction projects. BIM encompasses the creation and management of digital representations of physical and functional characteristics of places, facilitating collaboration, data exchange, and decision-making throughout the project lifecycle (Sacks et al., 2018).

Several previous studies have investigated the adoption and implementation of BIM in developing countries, shedding light on the unique challenges and opportunities faced by these countries. For instance, Zhou et al. (2019) conducted a study focusing on BIM adoption in China, highlighting strategic suggestions such as government involvement, legal frameworks, financial support, and cooperation among stakeholders. Stojanovska-Georgievska et al. (2022) examined the status of BIM in North Macedonia, proposing a comprehensive roadmap for adoption tailored to the country's specific needs.

In fact, the rapid advancement of BIM has the potential to significantly enhance the efficiency and productivity of construction projects worldwide. However, the adoption and integration of BIM processes in developing countries face unique challenges that necessitate systematic exploration (Bui et al., 2016a,b). This systematic literature review study aims to address these challenges by evaluating the effectiveness of BIM processes in developing countries settings. The study employs the PRISMA framework to ensure a rigorous and transparent review process, providing clear objectives and a structured methodological approach to evaluate the impacts of BIM adoption. While previous reviews have provided valuable insights into BIM implementation in developing countries, the current study aims to fill a specific research gap.

Unlike existing reviews, this study focuses explicitly on analyzing BIM adoption experiences across three development levels of countries: upper-middle-income, low-middle-income, and low-income countries. This theoretical exploration delves into how BIM supports project management objectives and addresses common project-related challenges in developing countries. By categorizing countries based on their economic status, the study aims to provide a nuanced understanding of the challenges and strategies associated with BIM adoption in diverse socioeconomic contexts. This study contributes to the existing literature by offering a comprehensive analysis of BIM adoption and implementation experiences in developing countries, encompassing contextual, strategic, and adoption factors. By synthesizing lessons learned from representative countries across different economic levels, the study presents a roadmap for BIM adoption tailored to the unique challenges and opportunities faced by developing countries. Additionally, by highlighting the research gaps identified in previous reviews, this study lays the groundwork for future research endeavors aimed at advancing our understanding of BIM implementation in diverse global contexts.

3. Review methodology

This study employs a systematic literature review approach that rigorously follows the guidelines set out by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Sarkis-Onofre et al., 2021). The study was conducted through a thorough review of the current body of literature pertaining to developing countries. The primary objective of this systematic literature review is to investigate the experiences of developing nations in the adoption of BIM.

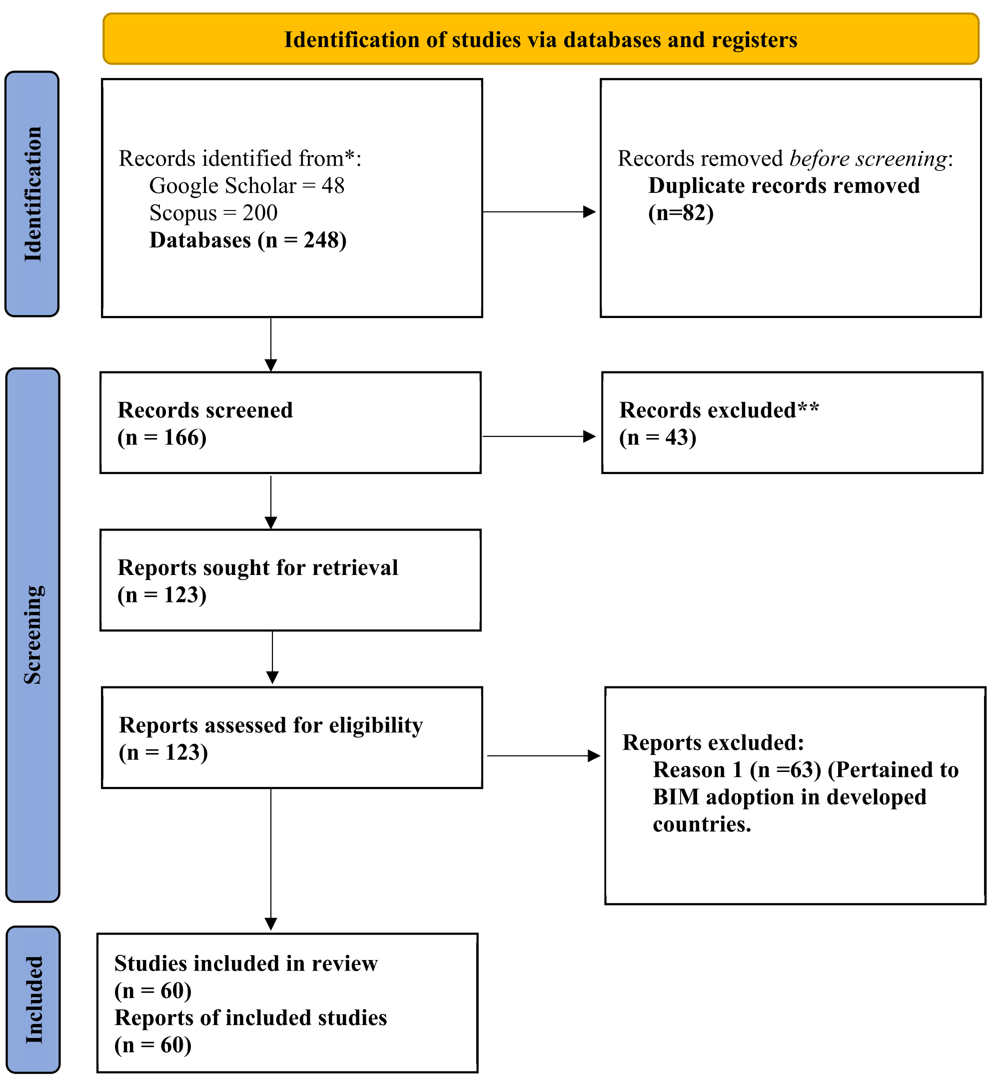

Fig. 1. PRISMA flow diagram of the study.

The methodology utilized for the review and data gathering from academic articles is outlined in the workflow illustrated in Fig. 1. The first stage of the study encompassed the development of an all-encompassing search strategy, involving the thorough selection of keywords to define the boundaries and constraints of the search. We expanded the search strategy to include variations of keywords commonly used in literature. This involved incorporating synonyms, alternative terms, and related concepts into the search string to ensure a more comprehensive retrieval of relevant studies. For example, in addition to "challenges," terms such as "barriers," "obstacles," and "constraints" were included. Similarly, alternative terms for "developing countries," such as "emerging economies," "low-income countries," and "less developed nations," were included to capture a wider range of relevant literature. The search technique employed in this study was carefully developed to locate high-quality academic research articles published between 2013 and 2023. This period was chosen to capture relevant studies that reflect the current state of BIM implementation and address contemporary challenges and strategies. In determining the appropriate timeframe for this systematic literature review, the period from 2013 to 2023 was selected based on several pivotal considerations. This decade marks a significant phase in the evolution of BIM, characterized by rapid technological advancements and an increasing rate of adoption in developing countries.

Firstly, the selection of the year 2013 as the starting point is aligned with the global recognition of BIM as a transformative force within the construction industry. This year is often cited as a turning point when several developing countries began formalizing policies and initiatives to promote BIM adoption, influenced by the success observed in developed economies. For example, studies such as those by Hardi and Pittard (2015) and Liao et al. (2021) highlight how governmental mandates in countries like the UK and Singapore served as a model for similar policies in regions such as Southeast Asia and Latin America. Furthermore, the technological advancements in BIM software and methodologies from 2013 onwards have significantly lowered barriers to adoption, making these tools more accessible and applicable to the specific challenges faced by developing countries. The literature documents an enhanced focus on customization and scalability of BIM solutions to meet diverse infrastructural needs, which is critical in varied developmental contexts (El Hajj et al., 2023). The year 2023 serves as the endpoint for the search period, providing a full decade of data and allowing for a comprehensive analysis of the most recent developments and their impacts. This recent focus is crucial, as the latest studies provide insights into the current state of BIM technology and its adoption, reflecting ongoing innovations and the increased integration of BIM into mainstream construction practices in developing countries.

The search was done in December 2023. The selection process prioritized scientific articles, review and conference papers that met our inclusion requirements, namely those published solely in the English language. The main and equivalent keywords that were discovered to guide the search are shown in Table 1.

The search for the literature was conducted focused, purposefully selecting only literature that discussed the topic this project intends to examine. The inclusion criteria are.

Table 1
Keywords search of the study.

Topic keywords	Geographical keywords
• Building Information Modeling/BIM • BIM adoption • BIM challenges/barriers/obstacles/constraints • BIM benefits/impacts/outcomes • BIM drivers	• Developing countries • Developing nations • Developing economies • Emerging economies • Low-income countries • Less developed nations

- Peer-reviewed articles published from January 2013 to December 2023.
- Articles that explicitly discuss BIM adoption and implementation in the context of developing countries.

While, the applied exclusion criteria are.

- Non-peer-reviewed literature, grey literature, and unpublished works.
- Articles not written in English.
- Studies that do not directly address the intersection of BIM adoption and implementation in developing countries.

The systematic review methodology employed in this study utilized BOOLEAN connectors or operators to refine search queries and enhance the precision and relevance of the literature search process (Scells et al., 2020). The rationale for employing BOOLEAN connectors lies in their ability to construct complex search queries by combining multiple search terms and criteria (Atkinson and Cipriani, 2018). By using operators such as "AND" and "OR", we were able to specify relationships between search terms and control the scope of the literature search. The use of BOOLEAN connectors allowed for the creation of comprehensive search strings that encompassed a wide range of relevant literature.

Below is the full search string used for the search strategy.

("Building Information Modeling" OR "BIM") AND ("implementation" OR "adoption") AND ("challenges" OR "barriers" OR "obstacles" OR "constraints") AND ("benefits" OR "impacts" or "outcomes") AND ("developing countries" OR "emerging economies" OR "low-income countries" OR "less developed nations") (Table 1).

The search was conducted in the *Scopus, and Google Scholar* digital databases available through the University of Canberra Library. Scopus is recognized for its extensive collection of scientific texts, including areas pertinent to this research like engineering, environmental science, and urban studies. It contains peer-reviewed articles and conference papers, guaranteeing the reliability and scholarly merit of the resources consulted (Burnham, 2006). Scopus's sophisticated search capabilities enable the construction of complex strategies for literature retrieval. Additionally, its detailed citation analysis tools are invaluable for identifying foundational works and evaluating their relevance to the topic under study (Hardi and Pittard, 2015).

Google Scholar compiles a broad array of scholarly materials, including dissertations, books, summaries, and publications from academic entities, professional bodies, online archives, and higher education institutions. Accessible at no cost and often linking directly to full-text content, Google Scholar is particularly useful when specific articles are not available in subscription-based databases (Martín-Martín et al., 2017). The platform's strength lies in its ability to capture interdisciplinary works spanning construction, digital transformation, and the circular economy, among others (Hardi and Pittard, 2015).

Therefore, conducting a comprehensive systematic literature review demands a cross-disciplinary array of high-quality sources, combining the strengths of both Scopus and Google Scholar (Moed et al., 2016). This approach ensures the study encompasses a wide range of publications, from impactful journals to all available online materials, offering an extensive perspective on the subject of BIM adoption and application within developing nations.

The analysis yielded an overall 200 articles sourced from Scopus, alongside an additional 48 articles acquired from Google Scholar. The initial examination consisted of removing any duplicate entries, resulting in a collection of 166 unique data that may be further evaluated. In the succeeding step, a thorough review of publication titles was conducted, resulting in the exclusion of 43 records that were found to be unrelated to the topic of BIM adoption in developing nations.

After the first screening process, 123 articles were selected for more in-depth study in the succeeding step. During this second phase, a thorough evaluation was conducted on the 123 articles to determine their relevance and alignment with the primary objectives of the study. The articles were classified according to the UN (World Population Review, 2022) categorization of developing countries as shown in Appendix A. In this phase, 63 documents that were relevant to the adoption of BIM in developed countries were excluded.

The rigorous screening procedure yielded a final group of 60 records that closely adhered to the predetermined criteria and were highly pertinent to the research aims of the study. The collection of 60 papers shown here is the fundamental dataset for the systematic literature review. This dataset is subjected to comprehensive analysis in order to extract meaningful insights and draw relevant conclusions.

In conducting the analysis, a qualitative approach was employed, focusing on thematic analysis (Hamel et al., 2021). This approach was chosen for its suitability in identifying and exploring recurring themes and patterns across the selected literature, providing a deeper understanding of the drivers, challenges, strategies, etc. associated with BIM adoption in developing countries. The decision to employ thematic analysis was informed by the need to systematically organize and interpret the diverse range of findings extracted from the literature, facilitating the extraction of meaningful insights and the formulation of relevant conclusions.

4. Descriptive analysis

The systematic literature review involved a thorough analysis of published articles and reviews that discussed the adoption of BIM and related studies in developing countries. The review analysis has shown a comprehensive overview of BIM research trends in the context of developing countries. During the span of ten years from 2013 to 2023, the academic community witnessed a diverse range of scholarly pursuits emerging from several nations. Based on the results of this comprehensive analysis, it is evident that Nigeria has emerged as a significant addition to the existing body of knowledge on BIM within the context of developing nations. Specifically, 14 articles originating from Nigeria were identified and analyzed in this study. Furthermore, a lot of different nations, such as China, Malaysia, Iran, Pakistan, Ghana, Egypt, Indonesia, Vietnam, Jordan, Iraq, Yemen, and India, have accomplished noteworthy scientific advancements in this particular domain, with the quantity of published works ranging from one to nine. To manage this heterogeneous group of developing nations, they were categorized into three levels based on the UN World Population Review for the year 2022. Fig. 2 presents a comprehensive overview of the quantity of published papers of BIM adoption across all categories of emerging

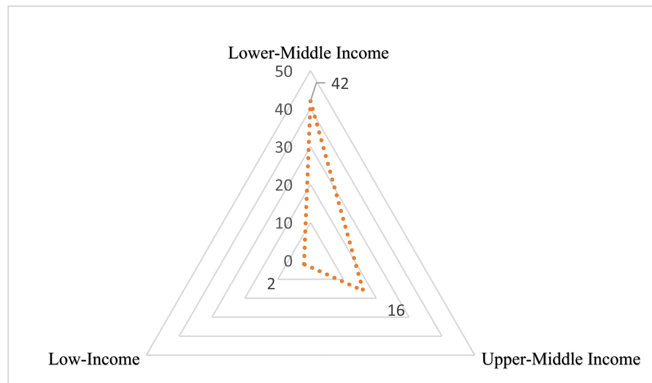

Fig. 3. Bim research trend in developing countries.

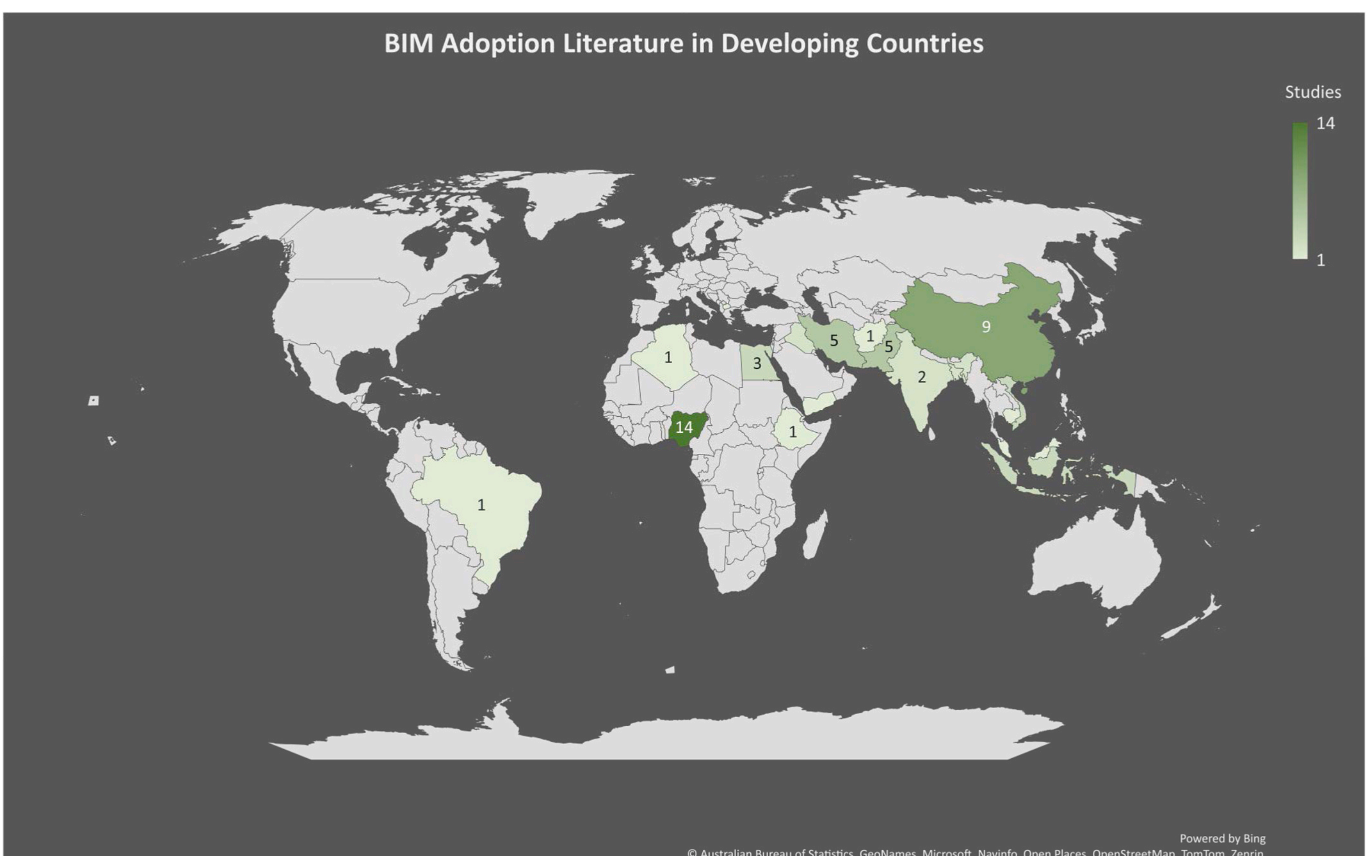

Fig. 2. BIM adoption literature in developing countries.

nations. Furthermore, Fig. 3 provides a visual representation of the aforementioned research trend, effectively emphasizing the allocation of research endeavors pertaining to BIM within the construction industry throughout the three levels of emerging nations. The provided visual depiction provides significant insights on the level of digitalization attained via the use of BIM across the building sectors of emerging nations. The primary objective of this descriptive analysis is to provide the groundwork for future research endeavors pertaining to the adoption of BIM and its possible ramifications within developing economies.

5. Thematic analysis

In framing the theoretical framework for this review, inspiration was drawn from the work of Aghimien et al. (2022). The collected publications were methodically grouped into various themes based on various criteria, including the current state of developing nations, the benefits and challenges of BIM, the drives and strategic methods, and the takeaways and suggestions for execution (Table 3). In addition, Table 3's references were carefully placed chronologically, starting with the most recent publications and going all the way back to the oldest ones, in accordance with the classification of developing countries. This categorization approach proved instrumental in identifying the primary themes that formed the foundation for the subsequent thematic analysis in this literature review. The recurring themes that emerged prominently included the examination of BIM's benefits and barriers, the identification of driving forces and strategic approaches, the assessment of the current state of BIM adoption, and the formulation of recommendations for its effective integration. This systematic review facilitated a comprehensive exploration of the existing body of literature, allowing for a coherent and insightful examination of the various dimensions of BIM adoption in developing countries.

5.1. Trend and status of BIM in developing countries

The construction industry in developing countries experiences heightened complexity due to prevalent inefficiencies and ineffectiveness (Isa et al., 2013; Mbamali and Okotie, 2012). BIM implementation refers to the systematic efforts undertaken to facilitate the widespread adoption of BIM within the construction industry. This entails the establishment of official protocols or standards that mandate or endorse the use of BIM as a recognized and accepted operational framework within the construction sector (Arayici et al., 2011; Eadie et al., 2013; Smith, 2014). The drives and challenges connected with BIM are influenced by the particular industrial setting and must be examined within the specific natural context of a country or firm (Arayici et al., 2011; Poirier et al., 2015). The development of a specific BIM implementation model for developing countries has significance due to the pressing need to align with prevailing BIM implementation trends. This alignment may result in the replication of BIM implementation initiatives established in developed countries. The replication of BIM implementation strategies employed by developed countries is not a viable approach for implementing BIM in developing countries due to the disparities in organizational structure, cultural norms, and market conditions between the two contexts (Gu and London, 2010; Miller et al., 2013; Silva et al., 2016; Cao et al., 2017). Therefore, the effective adoption of BIM in developing countries necessitates the utilization of a comprehensive BIM implementation model.

The aforementioned statement suggests that the BIM implementation model in developing countries should possess multiple dimensions. It should have the ability to promote BIM adoption at the industry, organization, and project levels. Additionally, it should accommodate the needs of small and medium-sized construction organizations. Furthermore, contextual, theoretical, and empirical justifications, as stated by Miettinen and Paavola (2014) and Bui et al. (2016a,b) should support the model.

Studies on the adoption of BIM have indicated that the successful implementation of BIM inside organizations necessitates substantial expenditures in terms of both time and financial resources. The extent to which BIM is implemented in developing countries such as Nigeria, China, India, Indonesia, Sri Lanka, Vietnam, and Pakistan exhibit notable variations, with the degree of adoption being shaped by a range of factors including governmental regulations, levels of awareness, cultural barriers, and industry-specific circumstances. Table 2 provides an overview of BIM trend or status in different developing countries. Bew and Richard's BIM maturity model (2008) was utilized as a theoretical framework to infer and categorize the levels of BIM implementation in developing countries. This model categorizes BIM implementation into distinct levels of maturity.

- **BIM Level 0:** Characterized by unmanaged CAD (Computer-Aided Design) with 2D drawings and a lack of collaboration.
- **BIM Level 1:** Involves managed 3D BIM model formats using common data environments, but collaboration between disciplines is still limited.
- **BIM Level 2:** Features collaborative working across different disciplines using nD BIM models, but not fully integrated or interoperable.
- **BIM Level 3:** Represents full collaboration between all disciplines using a shared model on a single project model repository, enabling integrated and interoperable workflows.

Table 2 provides an overview of the BIM trend or status in different developing countries based on this maturity model, offering insights into the varying levels of BIM adoption and implementation.

Although several developing nations have noted low rates of BIM adoption in their areas, they also acknowledge the advantages of this technology as per the study conducted by Ismail et al. (2017).

5.2. Benefits of BIM adoption

The utilization of BIM in the construction industry of developed economies has garnered significant attention, owning to the multitude of advantages that have been identified via its adoption (Eastman et al., 2011). The use of BIM in project planning, design, building, and maintenance stages has been shown to provide several advantages. These benefits encompass resource conservation, heightened productivity (Azhar, 2011), and the enhancement of overall quality (Ashcraft, 2008; Chen and Luo, 2014).

As known, this implementation has a substantial influence on the reduction of construction waste during the design and pre-contract phases (Banihashemi et al., 2018). This is achieved by minimizing errors in design and documentation, enhancing specification and quality, improving estimating and site investigation, optimizing work planning, and enhancing procurement processes (Eze et al., 2022). However, the effectiveness and influence of BIM in emerging economies can be distinctly characterized by their specific social, economic, and environmental priorities. This differentiation arises from the unique challenges and opportunities these economies face, requiring a tailored approach to BIM implementation and utilization (Khanzadi et al., 2018).

a) Upper-Middle Income

The urgency to accomplish economic decarbonization on a worldwide scale by the year 2050 imposes new requirements on the AEC sector (Ariono et al., 2022a,b). The AEC industry, with the build environment sectors, collectively contribute to around 40% of carbon emissions on a worldwide scale (Robinson et al., 2021). In this context, developing countries have the formidable task of allocating significant resources towards the establishment of novel infrastructure. Countries such as India and China are anticipated to undertake the construction of over 100 million new housing constructions in the coming decade in order to accommodate their growing populations. Nevertheless, the

Table 2
Trend and status of BIM in developing countries.

Country/ Region	BIM Trend or Status	Level of Implementation	References
Nigeria	Limited adoption primarily involving basic 2D and various 3D technologies.	BIM Level 1	Olugboyega and Aina (2018)
China	Notable progress, expanding from design to construction stages. Lack of national mandate.	BIM Levels 2 and 3	Cao et al., 2015
India	Relatively slow adoption, mainly driven by private sector mandates. BIM utilized for visualization purposes, namely for 3D modelling and client presentations.	BIM Levels 1	Sawhney et al. (2014) Mohanta and Das (2022)
Indonesia	Significant awareness but limited practical application. BIM employed for 3D modelling & visualization during design and engineering stages.	BIM Level 1	Hanifah, 2016 Wilis et al. (2017)
Sri Lanka	Nascent stage with limited usage in construction projects.	BIM Level 0	Gunasekara and Jayasena (2013)
Vietnam	Significant awareness but limited practical application.	BIM Level 2	Ismail et al. (2017)
Pakistan	Relatively lower adoption with limited familiarity among professionals.	BIM Level 1	Abbas et al. (2016)
Iraq	Reliance on traditional methods with limited BIM usage.	BIM Level 0	Zaia et al. (2023)
Iran	Limited adoption and slow progression. BIM seen as tool for 3D display.	BIM Level 1	Hosseini et al. (2016)
North Macedonia	Early stages of adoption with growing interest among professionals.	BIM Level 1	Stojanovska-Georgievska et al., 2022
Malaysia	Significant awareness and progressive adoption	BIM Levels 1 and 2	Munianday et al. (2023)
Brazil	Progressive adoption with established roadmap for future integration.	BIM Levels 1 and 2	Arrotéia et al., 2021
Algeria	Embracing BIM for 3D modeling but limited comprehensive integration.	BIM Level 1	Bouguerra et al. (2020)
Egypt	High awareness but low adoption due to various challenges.	BIM Levels 0 and 1	Othman et al. (2021)
Yemen	Limited adoption with reliance on 2D CAD.	BIM Level 0	Sarkis-Onofre et al., 2021

current matter of concern revolves around the imperative to alleviate the substantial carbon emissions linked to these forthcoming constructing endeavors (Ariono et al., 2022a,b). The significance of BIM in this particular context may be emphasized as it presents a prospective resolution to tackle the environmental obstacles presented by these expansive construction endeavors. By utilizing BIM technology, these nations may attain several advantages, including collaborative planning processes, effective resource management strategies, comprehensive lifecycle analysis, and adherence to environmentally friendly standards (Ferdosi et al., 2022). The use of BIM offers several benefits that allow developing nations to link their building endeavors with international decarbonization objectives. This approach not only enhances efficiency and reduces carbon emissions but also leads to cost savings. BIM has emerged as a highly significant technology in the endeavor to achieve digital and integrated infrastructures (Khoshamadi et al., 2023).

In China, the construction sector has benefited greatly from the use of BIM technology, bringing about a great deal of ease, claimed by Cao and Li (2021). As evidenced by a significant increase in organizational efficiency, the authors stress that BIM technology is essential in lowering the need for labour force and staff workloads. Additionally, the study highlights how BIM helps optimize resources by guaranteeing that labour and materials can be wisely utilized. Applying BIM is emphasized as a means of producing well-organized and scientific design drawings, which in turn, raises the standard of construction work as a whole (Yarnold et al., 2021). This all-inclusive strategy complements the organizational-level benefits of BIM, demonstrating its beneficial influence on resource optimization, workflow management, and the general quality of building projects in the context of the organization (Tabejamaat et al., 2024).

The utilization of digital technology, particularly Heritage BIM, in the recording of constructed heritage of Jordan, is emphasized in the research carried out by Aburamadan et al. (2022). Using this program, 3D parametric models can be created that are useful for communicating important aspects like the historical background, the state of conservation, and specifics about the materials and building methods. This emphasizes the BIM technology's technical advantages in the Jordanian setting. The focus on the technical side of creating 3D parametric models for efficient documentation and communication illustrates how BIM may provide technical benefits in the field of building and heritage conservation (Hajirasouli et al., 2021).

Although reaching high BIM maturity levels in developing nations may take some time, adopting BIM can nevertheless have positive, instantaneous effects. An illustration of this situation is provided by a case study carried out by Arrotéia et al. (2021) at a major Brazilian construction company. Though BIM maturity levels may have been lower, using 3D models in particular to visualize project interferences and components has been a beneficial outcome of BIM deployment. Building operations were optimized in part because of this improved visualization. Remarkably, the authors emphasized the strategic integration of BIM into the company's planning, highlighting its role as a fundamental aspect of the strategic agenda for the subsequent three years (from 2018 to 2020). This incremental and strategic approach in adopting BIM highlights how upper middle-income developing countries, such as Brazil, can strategically leverage BIM for immediate gains while aiming for continued improvements over time (Zhang et al., 2023).

b) Low-Middle Income

The benefits that were identified in the study conducted in Vietnam by Toan et al. (2022) fall under a number of different BIM benefit categories. The advantages of "minimized conflicts/changes" and "improved quality of design drawings" for structural and architectural design units are indicative of technical benefits that lead to better design outputs and fewer mistakes. The benefits of "easy planning and resource mobilization" and "convenient project data management" in facility management units complement organizational benefits by improving operational effectiveness and resource utilization. Contractors emphasize a combination of technical and economic benefits, stressing mistake reduction and financial efficiency (Sompolgrunk et al., 2021). They also gain from "minimized construction errors" and "construction cost savings." Furthermore, owners who report "maximized project performance" and "easier investment option selection" are likely to gain strategic benefits through better project results and informed decisions.

Hossain and Ahmed (2022) pioneered a groundbreaking BIM-based safety rule checking approach in the Bangladeshi construction industry, introducing an automated fall safety checking system. This innovation holds substantial technical and organizational benefits for developing countries. The automated system, implemented during the planning phase, significantly reduces fall hazards, providing a crucial enhancement to safety measures. The adoption of BIM technology (3D Revit) in this context offers technical advantages, such as the consistent application of safety rules and the mitigation of human errors, particularly in managing large models (Golizadah et al., 2023). Additionally, the system allows for the early identification and reduction of potential design errors or unsafe designs, aligning with organizational benefits.

Table 3
Commonalities of BIM adoption barriers across developing countries.

Barrier Type	China Zhou et al. (2019)	Jordan Hyarat et al. (2022)	Brazil Arrotéia et al., 2021	Iraq Youkhanna Zaia et al., 2023	Malaysia Munianday et al. (2023)	Nigeria Olanrewaju et al. (2021)	Vietnam Huong et al. (2021)	Cambodia Durdyev et al. (2021)	Indonesia Van Roy and Firdaus, 2020	Ethiopia Belay et al. (2021)	Afghanistan Al-sarafi et al., 2022	South Africa Calitz and Wium (2022)	Pakistan Farooq et al. (2020)	Ghana Chan et al. (2018)
Technological	x	x	x	x		x	x	x	x	x	x			
Organizational	x	x	x	x	x	x	x	x	x		x		x	x
Economic	x	x	x	x	x	x		x	x		x	x		x
Regulatory	x	x	x				x			x	x	x	x	x
Cultural	x		x		x							x		
Educational/Knowledge										x		x	x	x
Human Resource											x		x	

This notion underscores the transformative potential of BIM in bolstering safety practices and improving decision-making processes, contributing to the overall advancement of the construction industry in developing nations like Bangladesh.

The highlighted studies in the work by Rani et al. (2023) shed light on various categories of BIM benefits in the context of the Indonesian construction industry. In Indonesia, BIM has emerged as a transformative technology with diverse benefits across the construction industry. Notably, the application of BIM in asset management has proven invaluable, exemplified by the creation of a 3D BIM model through laser scanners and BIM software (Saptari et al., 2019). This approach underlines the technical benefits of enhanced visualization and data richness, facilitating efficient management of buildings and assets, thereby contributing to informed decision-making and improved asset maintenance practices. Additionally, studies comparing bridge design methods between conventional approaches and BIM highlight strategic advantages, such as the elimination of design clashes and the enhancement of structural safety (Utomo et al., 2021). Furthermore, the use of BIM alongside laser scanners for simulating fire disaster evacuation underscores the social and environmental benefits, emphasizing enhanced safety measures and disaster response capabilities within the Indonesian built environment (Yoga et al., 2022; Sukmono et al., 2021). Collectively, these findings highlight the multifaceted advantages of BIM in addressing various challenges and optimizing different facets of construction projects in the context of Indonesia.

In a groundbreaking case study conducted by Hasan et al. (2022) in Pakistan, the application of BIM technology highlighted significant technical benefits. The study focused on optimizing operational energy consumption by analyzing a 3D parametric BIM model of a sixteen-story high-rise building during the design stage. The results demonstrated that leveraging virtual technology for simulating energy usage patterns allows construction professionals to make informed decisions, leading to energy-efficient building designs. Such innovative approach not only contributes to energy savings throughout the building's life cycle but also addresses environmental concerns by reducing the operational carbon footprint (Banihashemi et al., 2022).

c) Low Income

The research conducted by Belay et al., in 2021 highlighted the primary advantages of implementing BIM in Ethiopia. According to their findings, the most notable benefits include enhanced communication among project stakeholders, early coordination across various disciplines, and the promotion of a positive working environment among professionals. The study revealed that a majority of respondents did not consider clash detection of BIM models and quality assurance issues as significant factors in the current construction business environment. This perception is attributed to the early stages of BIM implementation in the Ethiopian construction industry, suggesting a growing awareness and utilization of BIM practices.

5.2.1. *Comparative analysis of benefits of BIM adoption*

In this section, we conduct a comparative analysis of the benefits of BIM adoption across various countries and income groups, highlighting common themes and unique advantages observed in different contexts. Fig. 4 illustrates the comparative analysis of the key benefits observed in different levels of developing countries.

Common Themes across all Income Groups.

1. Improved Project Efficiency: Across all income groups, BIM adoption leads to enhanced project efficiency through streamlined processes, reduced errors, and optimized resource utilization. This results in cost saving and faster project delivery (Sompolgrunk et al., 2022).
2. Enhanced Collaboration: BIM facilitates better collaboration among project stakeholders, enabling smoother communication,

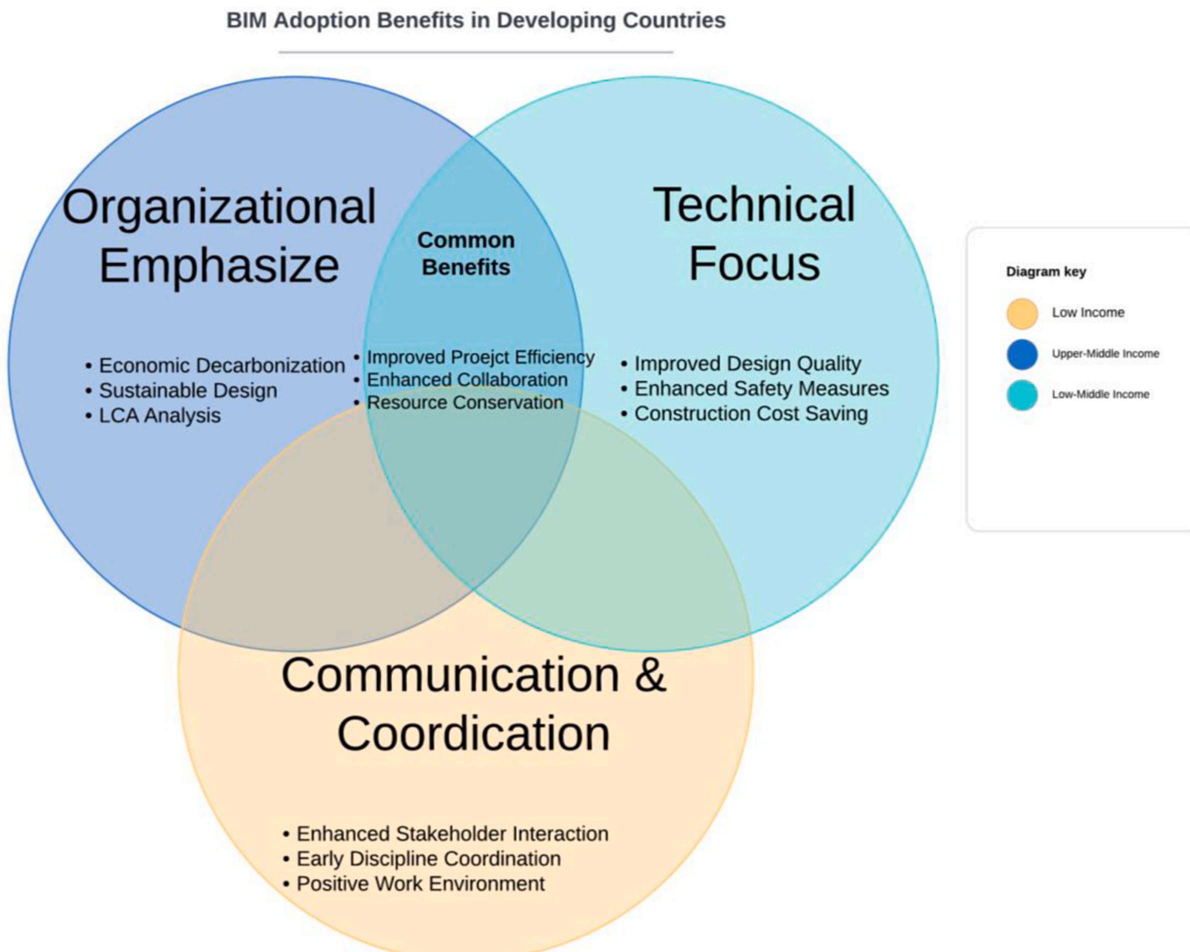

Fig. 4. Dominant and common BIM adoption benefits in developing countries.

coordination, and collaborative approach to construction projects (Oraee et al., 2017).

3. Resources Conservation: By minimizing errors in design and documentation, BIM contributes to resource conservation, particularly in terms of materials and energy. This aligns with global efforts towards environmentally responsible buildings (Banihashemi et al., 2022).

Unique Advantages in Different Contexts.

a) Organizational Emphasis: Upper-middle-income countries like China (Jin et al., 2015) and Brazil (Arrotéia et al., 2021) place a strong emphasis on organizational benefits such as improved efficiency and construction standards, while low-income countries like Ethiopia focus more on improved communication and coordination among stakeholders.
b) Technical Focus: Low-middle-income countries like Vietnam (Huong et al., 2021) and Bangladesh (Hossain and Ahmed, 2022) prioritize technical benefits such as improved design quality and safety measures, leveraging BIM for better design outputs and enhanced safety practices.
c) Strategic Integration: Low-middle-income countries like Indonesia (Rani et al., 2023) and Pakistan (Bhatti et al., 2018) strategically integrate BIM into their planning processes, utilizing it for asset management and energy-efficient building designs, indicating a strategic approach to BIM adoption.

Cross-Case Analysis.

The cross-case analysis reveals the dominant and common benefits of BIM adoption across different income groups. While upper-middle-income countries focus on efficiency, resource optimization, and organizational integration, low-middle-income countries emphasize technical advancements, safety enhancements, and strategic gains. In contrast, low-income countries prioritize communication, coordination, and stakeholder engagement, laying the groundwork for future BIM-driven improvements. Despite contextual differences, BIM adoption emerges as a transformative process with the potential to address diverse challenges including improved project efficiency, enhanced collaboration and resource conservation across income groups as the common and overlapped benefits (Fig. 4).

5.3. BIM implementation barriers and challenges

BIM adoption in developing countries suffers from several barriers that prevent its smooth integration. Studying the barriers preventing the adoption of BIM in developing countries revealed a complicated series of challenges, from technological limitations to regulatory and cultural challenges. These observations highlight the complex landscape in their pursuit of incorporating BIM methodology into construction practices. Therefore, it becomes evident that understanding these challenges is essential for formulating effective strategies. Table 3 presents the literature summary and synthesize on the commonalities of BIM implementation barriers in developing countries, according to the identified barriers, categories and relevant references. A thorough review of relevant studies revealed technological, oarganizational, economic, regulatory, cultural, educational and knowledge, and human resource as major categories into which the highlighted challenges are classified

(Table 3). These barriers add to the complexity of adopting BIM in these countries' particular settings. On the other hand, Table 4 outlines the unique or particularly emphasized barriers in each country, illustrating the specific challenges faced due to different contexts.

5.4. Drivers and strategies for BIM adoption

Developing nations, acknowledging the potential benefits of BIM, are progressively investigating ways to integrate this technology widely. While this study extensively discussed the barriers to BIM adoption in the previous section, it is crucial to equally understand the drivers propelling this technological shift and the strategies used for its effective incorporation. This part of study explores the motivations, catalysts, and strategic frameworks driving BIM adoption in developing countries. To provide a comprehensive overview of the research landscape, the study has compiled a detailed summary in Table 5, highlighting findings from previous studies on drivers and BIM adoption in specific developing countries. It can provide valuable insights for practitioners, policymakers, and researchers committed to advancing technological progress in the construction sector of developing countries.

5.4.1. Analysis of similarities and differences

When discussing the driving forces and adoption strategies of BIM among the developing countries, the study highlights both notable similarities and contrasts. A number of similar drivers emerge across Nigeria (Olanrewaju et al., 2021), Cambodia (Durdyev et al., 2021), Indonesia (Rani et al., 2023), Iran (Khanzadi et al., 2020), Turkey (Kalfa, 2018), South Africa (Calitz and Wium, 2022), Algeria (Bouguerra et al., 2020), China (Zhou et al., 2019), and Ethiopia (Belay et al., 2021), highlighting the potential and problems that are universal to the implementation of BIM. Notably, across these varied circumstances, factors like increased project efficiency, improved teamwork and communication, and a focus on productivity are common. The pursuit of financial gains, such as cost containment and possible competitive advantages, also sticks out as a common incentive. Furthermore, a common feature across several nations is the impact of government intervention, whether in the form of financial subsidies, policy revisions, or regulatory development.

5.4.1.1. *Differences in strategic approaches.*

1. Government Involvement:

Countries like Nigeria, Iran, and Algeria demonstrate strong government involvement, indicating a proactive approach to fostering BIM adoption through policies, incentives, or direct participation. Ethiopia, while noted for government involvement, does not mark presence in other categories, suggesting that its approach may be more narrowly focused or in earlier stages of development.

2. Strategic Approaches:

Indonesia prioritizes academic integration and experimental efforts, while South Africa and Turkey focus on performance development without specific strategies outlined in the studies. Algeria places a high priority on awareness and government aid, contrasting with Iran's and China's focus on standardizing contracts and defining model development clearly.

3. Economic Drivers:

Many countries, including Indonesia, Iran, China, Cambodia, South Africa, Ethiopia and Algeria, recognize the economic benefits of BIM, such as cost savings, efficiency, and competitive advantages in the construction sector. In a more detailed analysis, Iran cites profit

Table 4
Distinctions of BIM adoption barriers across developing countries.

Barrier Type	China Zhou et al. (2019)	Jordan Hyarat et al. (2022)	Brazil Arrotéia et al., 2021	Iraq Youkhanna Zaia et al., 2023	Malaysia Munianday et al. (2023)	Nigeria Olanrewaju et al. (2021)	Vietnam Huong et al. (2021)	Cambodia Durdyev et al. (2021)	Indon Esia Van Roy and Firdaus, 2020	Ethiopia Belay et al. (2021)	Afghanistan Al-sarafi et al., 2022
Technological	Lack of applicability	Software costs	Lack of 3D model info	Lack of BIM experts	Human resources	Lack of tech skills	Lack of awareness	Resistance to change	Lack of IT facilities	Insufficient IT infra	Limited tech infra
Organizational	Resistance to change	Lack of guidelines	Subcontractor issues	Lack of awareness		Regulatory issues	Project delivery	Weak support	Lack of experience		Organizational readiness
Economic	High cost of application	Training costs	Short design time	Traditional methods	Financial resources	High cost	Investment shortage	High implementation cost	High acquisition cost	High implementation cost	
Regulatory	Lack of standards	BIM standards needed	Shared model issues			Lack of regulations	Lack of standards			Lack of courses	
Cultural	Insufficient motivation		Client disinterest								
Educational/ Knowledge										BIM courses needed	

Table 5
Drivers and strategies for BIM adoption.

Developing Country	Key Drivers of BIM	Strategies for Adoption	References
Nigeria	- Construction planning and monitoring. - Process digitalization and economic benefits. - Efficiency gains. - Visualization and productivity improvements.	- Promote BIM concept among academia, government, and industry stakeholders. - Influence public attitudes positively. - Advocate for government involvement and policy amendments.	Olanrewaju et al. (2020)
Cambodia	- Reduction in project timescale. - Improvement in visualization. - Future of project information.	No strategies for BIM adoption discussed in this study.	Durdyev et al. (2021)
Indonesia	NA	- Incorporate BIM into academic curriculum. - Provide implementation guidelines. - Establish BIM digital transformation plan. - Initiate experimental projects. - Create BIM –connected contract framework.	Rani et al. (2023)
Iran	- Profit increase. - Competitiveness enhancement. - Client demand - BIM mandates	- Collaboration between government and construction associations. - Promote BIM in large projects. - Fund research projects. - Utilize knowledge dissemination mechanisms.	Hosseini et al. (2016)
Turkey	- Corporate performance improvement. - Project performance improvement. - Client and government requirements. - Design and construction productivity improvement. - Health, safety, and environmental activities improvement.	No strategies for BIM adoption discussed in this study.	Karacigan et al. (2023)
South Africa	- Performance improvement goals. - Visualization for enhanced understanding. - Budget simulation for cost efficiency. - Construction sequencing optimization.	- Raise awareness and provide education. - Promote pilot projects. - Develop standards. - Update procurement systems. - Develop software. - Government initiatives.	Olugboyega and Windapo, 2022 Calitz and Wium (2022)
Algeria	NA	- Awareness of BIM advantages. - Government assistance. - Strong communication and cooperation plan.	Bouguerra et al. (2020)
China	- Absorptive capacity. - Environment/green building. - Regulations/ government. - Client and contractor demands.	- Standardize contracts. - Legal establishment of obligations. - Define model development clearly. - Flexibility in adjusting legal aspects.	Ariono et al. (2022) Fan (2020)
Ethiopia	NA	- Develop sector-specific BIM policies and laws. - Create standard contract forms. - Establish project-specific rules. - Conduct competence evaluation. - Organize BIM trainings. - Provide financial assistance. - Incorporate BIM-related courses.	Belay et al. (2021)

increase, competitiveness enhancement, and client demand as drivers, whereas Algeria emphasizes awareness of BIM advantages and government assistance. Ethiopia highlights financial assistance programs and sector-specific policies, while China mentions absorptive capacity, green building, regulations, and client demands.

5.4.1.2. Overlaps in key drivers.

1. Economic Considerations:
   - Several countries, including Nigeria, Iran, Algeria, China, South Africa, Indonesia and Ethiopia, cite economic drivers such as cost control, increased profit, and gaining a competitive advantage.

2. Government Influences:
   - Government involvement, through policy amendments, regulatory development, and financial subsidies, is highlighted across multiple countries, including Nigeria, Iran, Algeria, China, and Ethiopia.

3. Green Building Focus:
   - The integration of green building standards emerges as shared drivers in countries like Iran, Algeria, and China.

4. Education and Awareness:
   - Education and awareness initiatives, including raising awareness, training, and incorporating BIM-related courses into academic curricula, are emphasized in several countries, such as Iran, Indonesia, and South Africa.

Table 6 illustrates the above analysis of each identified themes and offers a critical analysis of the differences and similarities between different countries. The developed comparative matrix outlines the presence or absence of various themes or drivers related to BIM adoption across different developing countries. This representation offers a quick and easy way to visually compare the differences and similarities of key themes or drivers across different countries.

In order to effectively assist BIM adoption in the various contexts of developing countries, policymakers, practitioners, and researchers must have a thorough understanding of both the similarities and differences. This will ensure that tailored solutions are implemented to meet each country's particular obstacles.

Table 6
Comparative matrix of BIM adoption drivers across developing countries.

Developing Country	Government Involvement	Strategic Approaches	Economic Drivers	Green Building Focus	Education and Awareness
Nigeria	X	X	X	X	X
Cambodia			X		
Indonesia	X	X	X		X
Iran	X	X	X	X	X
Turkey		X			
South Africa	X	X	X	X	X
Algeria	X	X	X	X	
China	X	X	X	X	X
Ethiopia	X		X		

Table 7 provides a succinct summary of the similarities and differences between developing nations and provides a concise summary of the main takeaways from the discussion on BIM adoption.

On the other hand, the study revealed lower levels of integration technology and collaboration processes and modeling policy. In addition, government efforts towards implementing BIM were observed to be low. The study suggested developing an incentive governmental strategy to encourage BIM implementation, for example, tax breaks for projects using BIM or even facilitating the building permit process (Marzouk et al., 2022).

5.5. *Lessons/recommendations in BIM adoption*

This section presents the experiences and lessons learned from BIM adoption and implementation in three levels of developing countries. It is intended to highlight the similarities and differences within the study's context and present a framework of the lessons and recommendations for the next adopters of developing economies.

5.5.1. *Upper-Middle Income countries*

Zhou et al. (2019) presented several strategic recommendations for enhancing BIM adoption in China's AEC industry. Key strategies include.

1. **Government Involvement:** Advocating for increased governmental and academic support through pilot BIM projects and seminars to foster clear adoption guidelines.
2. **Legal Frameworks:** Collaboration between government and academic entities to establish BIM-specific legal responsibilities and contract templates for project clarity.
3. **Financial Support:** Proposing the creation of a BIM Fund, similar to Singapore's model, to assist with the costs associated with BIM implementation, including software and hardware.
4. **Government Mandates:** Suggesting the emulation of successful BIM policies from the UK and Singapore, initially mandating BIM for large government projects, with a view to broader application.
5. **Cooperation and Collaboration:** Developing standardized BIM systems and manuals across various government levels, along with a collaborative work platform, taking cues from UK practices.

Table 7
Key findings of the drivers and strategies of BIM adoption in developing countries.

No.	Key Findings	Explanations
1	**Universal Drivers**	Common motivations for BIM adoption include improved project efficiency, enhanced collaboration, economic benefits, and productivity consideration.
2	**Government Influences**	Government involvement, through policy amendments, regulatory development, and financial subsidies, plays a crucial role in driving BIM adoption across countries.
3	**Economic Considerations**	Economic drivers such as cost control, increased profit, and gaining a competitive advantage are central to BIM adoption in diverse developing countries.
4	**Diverse Strategies**	While common drivers exist, the strategies employed to address them vary significantly, emphasizing the need for tailored approaches based on unique country contexts.
5	**Green Building Focus**	The integration of green building standards emerges as shared drivers, reflecting a global trend in aligning BIM with environmental goals.
6	**Education and Awareness**	Education and awareness initiatives, including raising awareness, training, and incorporating BIM-related courses into academic curricula, are crucial components of BIM adoption strategies.

Stojanovska-Georgievska et al. (2022) proposed a comprehensive roadmap tailored to North Macedonia's specific needs for BIM adoption, aiming to advance the digitization of the national construction sector. The roadmap highlights the importance of public sector leadership and recommends several strategic actions.

1. **Public Sector Leadership and Incentives:** Introducing incentives designed to motivate stakeholders in public projects, fostering the integration of BIM methodologies throughout project lifecycles.
2. **Centralized Authority:** Establishing a central body with appointed leaders to oversee BIM implementation, ensuring streamlined decision-making and coordination.
3. **BIM Education and Training:** Developing a BIM certification program and incorporating BIM into educational curricula to build a skilled workforce, supported by scholarships and mandatory participation of trained professionals in government projects.
4. **Adoption of International Standards:** Strengthening collaboration with international entities to adopt global and European standards, supporting structured data use and enhancing interoperability.
5. **Open BIM and Stakeholder Engagement:** Promoting open, internationally recognized information standards through stakeholder consultations to improve industry-wide collaboration.
6. **Central Digital Resource Platform:** Creating a platform for digital resources and developing national protocols for BIM to standardize and facilitate consistent implementation across projects.
7. **Cross-Sectional Collaboration Platform:** Establishing a knowledge hub for sharing experiences and linking with international BIM platforms to foster continuous improvement in BIM practices.

5.5.2. *Low-middle income countries*

Dao and Nguyen (2021) explored the outcomes of a BIM pilot project in Vietnam, providing significant insights and lessons on challenges and effective strategies for BIM adoption in construction. The key findings and strategic recommendations include.

1. **Regulatory and Standardization Challenges:** The study highlights a lack of comprehensive guiding documents, standards, and technical laws specific to BIM in Vietnam. This gap leads to inconsistencies in the application of BIM terminologies and understanding of its objectives and benefits.

2. **Organizational and Cultural Barriers:** The organizational structure and culture within stakeholder groups were found to impede BIM adoption. Issues include the scarcity of skilled personnel and conflicts between specialized activities and BIM responsibilities.
3. **Resource and Experience Shortages:** Initial phases of BIM implementation faced hurdles due to the lack of prior experience and adequately trained personnel, which is common in early BIM adoption stages.
4. **Financial and Technological Constraints:** Significant costs associated with BIM software and hardware, along with inadequate technological preparedness, restrict broader application of BIM in project management.
5. **Information Sharing Difficulties:** The case study points to challenges in information sharing among stakeholders and the integration of existing data into BIM systems.

From these challenges, the study derived several strategies for successful BIM integration.

- **Clear Goals and Leadership:** Establishing clear objectives and fostering leadership understanding of BIM's benefits are crucial for successful implementation.
- **Assessment of Influencing Factors:** It is important to recognize and evaluate factors that could impact project success, facilitating the anticipation and mitigation of potential challenges.
- **Stakeholder Engagement and Coordination:** Initiating BIM requires engaging all project stakeholders, ensuring effective coordination, and aligning project goals through regular meetings.
- **Unified Approach:** Close cooperation among various organizations and departments is essential, with coordinated efforts and well-defined procedures to ensure project success.

Girginkaya Akdag and Maqsood (2020) investigated the challenges and advancements in the BIM adoption within Pakistan's education and professional sectors. The study identifies key areas of concern and strategic recommendations.

1. **Educational Limitations in BIM:** BIM instruction is primarily confined to civil engineering departments in Pakistan, with architecture programs lagging significantly. There is a noted deficiency in BIM competencies among Architecture, Engineering, and Construction (AEC) professionals, largely attributed to inadequate domestic educational provisions in BIM. Many architects proficient in BIM have been trained internationally, highlighting a gap in local expertise.
2. **Need for Enhanced BIM Curriculum:** The study emphasizes the critical need for a broader integration of BIM education within academic curricula. This includes more comprehensive training involving interactive discussions and practical sessions led by industry experts. Such initiatives aim to improve the understanding and application of BIM among future professionals.
3. **Development of a Decade-Long Roadmap:** The research proposes a decade-long roadmap for educational and training institutions, focusing on a systematic approach to address the knowledge deficit in BIM. This roadmap is intended to ensure that future AEC professionals are well-versed in BIM technologies and applications.
4. **Supportive Institutions for BIM Implementation:** The study suggests the establishment of supportive entities at both governmental and private levels to promote BIM adoption comprehensively across the AEC sectors. These institutions should focus on creating policies, roadmaps, plans, and guidelines tailored to the specific needs and conditions of Pakistan. This approach underscores the importance of multidisciplinary collaboration in BIM processes.

5.5.3. *Low-income countries*

Belay et al. (2021) analyzed barriers to BIM adoption in Ethiopia's construction industry and offer strategies to overcome these challenges through targeted interventions across various dimensions.

1. Legal and Contractual Frameworks:
   - Development of industry-specific BIM policies and standard contracts including BIM protocols to address claims and disputes.
   - Ensuring compatibility with international standards to streamline BIM integration.
2. Process Enhancements:
   - Creation of project-specific BIM guidelines and use of BIM-compatible procurement and delivery methods to enhance collaboration and efficiency across the project lifecycle.
   - Implementation of pre-and post-BIM capability assessments to evaluate and improve BIM strategies, providing insights into performance and areas for improvement.
3. Cultural and Organizational Development:
   - Regular BIM training, seminars, and workshops organized by the government in collaboration with academic and professional institutions to boost knowledge and understanding.
4. Government Initiatives and Infrastructure:
   - Developing comprehensive strategies for BIM deployment in public and private sectors, including enhancing IT infrastructure and fostering public-private partnerships (PPPs) to bolster technological capabilities.
   - Establishment of financial support mechanisms, such as loan programs, to help manage the high initial costs of BIM implementation, making it more accessible.
5. Educational and Workforce Preparation:
   - Encouraging universities to incorporate BIM-focused research projects and courses into their curricula to equip students with practical skills and align education with industry demands, thus fostering a proficient future workforce.

Sarkis-Onofre et al. (2021) outlined strategic recommendations to enhance the BIM adoption in Yemen, addressing specific local challenges and leveraging global best practices.

1. Tailored BIM Adoption Model:
   - Development of a BIM adoption model specifically designed for Yemen that could potentially extend to include operations and demolition stages, with the feasibility of this model's application in other countries also being explored.
2. Curriculum Enhancement:
   - Urgent revision and enhancement of Yemen's postsecondary education curriculum within the built environment fields to integrate BIM education, aiming to cultivate a workforce proficient in BIM practices.
3. Regulatory Incentives:
   - Encouragement for the Yemeni government to mandate the use of BIM in all construction projects through building regulations, mirroring practices in more developed nations, to promote widespread BIM adoption.
4. Financial Support Mechanisms:
   - Proposal for a government-backed financing program to support construction firms in affording the high initial costs of BIM technology, alleviating financial barriers to adoption.
5. Global Adoption Analysis:
   - Recommendation to conduct comprehensive studies on BIM adoption rates and strategies in both developed and developing countries to identify effective practices and benchmark data that could help overcome global and local challenges in BIM adoption.

6. BIM Adoption Model for Developing Countries

This study develops a framework model by analyzing the key lessons and developing tailored recommendations from the BIM adoption experiences in representative countries across three developmental levels (Fig. 5). The model is meticulously constructed through a multi-layered analysis of the data gleaned from our systematic review. The key elements from the literature were categorized into three intersecting domains – strategic factors, contextual factors, and adoption factors – which encompass a comprehensive set of interrelated components critical to BIM adoption. The presented BIM Adoption Model is a comprehensive one, designed to guide developing countries through the intricate process of integrating BIM into their construction and development sectors. This model is underpinned by a multi-dimensional approach that recognizes the varying economic, educational, and infrastructural landscapes across developing countries.

6.1. Contextual factors

The model begins by acknowledging the Contextual Factors, which are pivotal in setting the groundwork for BIM adoption. It recognizes the necessity of tailoring strategies to the economic capabilities of countries, categorized as upper-middle, low-middle, and low-income. For instance, upper-middle-income countries might be more prepared to offer scholarships for BIM education and mandate skilled BIM professionals for government projects. Conversely, low-income countries may focus on developing BIM goals that align closely with their urgent economic development needs. Providing standard forms and templates for BIM execution plans is also a critical strategic element, ensuring consistency and quality in BIM implementation. For the low-middle income countries, it includes the development of clear BIM goals, evaluation of phased BIM development, and the cultivation of BIM knowledge through education and training.

6.2. Strategic factors

At the heart of the model are Strategic Factors that act as the driving force behind adoption strategies. Internationalization entails collaboration with international entities and the adoption of international standards, enabling interoperability and global competitiveness. Nation-wide Initiatives include central platforms and digital resource banks, ensuring accessibility and standardization across the nation. Cross-sectional Collaboration encourages the sharing of knowledge and resources between different sectors, fostering a community of practice that supports continuous learning and adaptation.

6.3. Adoption factors

The outer layer of the model encapsulates Adoption Factors, which are essential components that must be addressed to ensure successful BIM adoption. Government Engagement is crucial, requiring active participation, spearheading pilot projects, and developing BIM adoption roadmaps. Government bodies must take the lead in demonstrating BIM's value and fostering an environment conducive to its adoption. A Legal Framework ensures that BIM adoption is supported by appropriate policies and regulations. This includes government-academia collaboration, defining legal responsibilities for BIM, and standardizing contracts for BIM projects. Financial Support is a key facilitator, encompassing the establishment of BIM adoption funds and the encouragement of public-private partnerships. These financial mechanisms can alleviate the cost burden of adopting BIM technologies and processes. Education and Training should be embedded into academic curricula to cultivate a workforce skilled in BIM. National accreditation and certification for BIM training can uphold the quality of education and assure industry readiness (Fig. 5).

7. Discussion

The proposed BIM Adoption Model for Developing Countries (Fig. 5) is not just a strategic plan but a call for an orchestrated effort across various sectors, with a particular emphasis on improving project delivery outcomes. This model underscores the pivotal role of projects as organizational vessels that drive strategic and contextual factors influencing BIM adoption. By focusing on project-based insights, this study

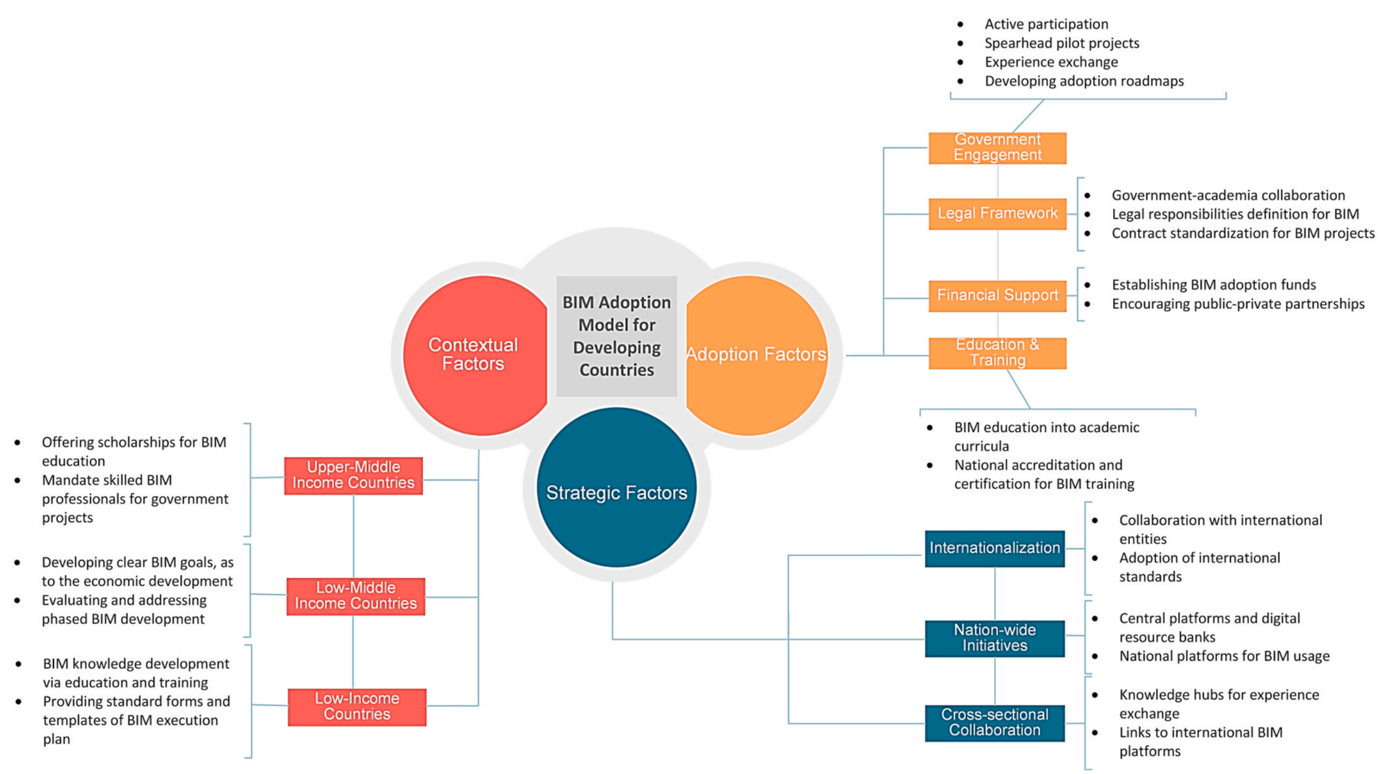

Fig. 5. Conceptual model of BIM adoption for developing countries.

highlights how BIM can transform project management practices in developing countries, leading to enhanced project efficiency, reduced costs, and better alignment with strategic goals. Its effectiveness lies in the recognition that successful BIM adoption is not solely a technological transition but a holistic change involving cultural and procedural transformation that affects multiple stakeholders. Government engagement emerges as a crucial factor in driving BIM adoption. As evidenced by studies such as Zhou et al. (2019), Stojanovska-Georgievska et al. (2022) and Nair Subramanian and Banihashemi (2024), the recommendations for government-led initiatives, such as pilot programs, defined guidelines, stakeholder incentives and modern leadership styles adopted in the engineering sectors, highlights the critical role of governmental support in advancing BIM integration.

Financial support, as highlighted by Girginkaya Akdag and Maqsood (2020) and Belay et al. (2021), is essential driver of the BIM adoption Roadmap, particularly in resource-constrained environments. By prioritizing funds and incentives for BIM adoption, stakeholders can reduce the perceived risk and encourage investment in BIM technologies. Education and training are also fundamental to the success of BIM integration, with Sarkis-Onofre et al. (2021) emphasizing that integrating BIM education into academic curricula and providing professional development opportunities can ensure a skilled workforce ready to leverage BIM technologies effectively.

The emphasis on internationalization, as recommended by Belay et al. (2021), underscores the importance of aligning with global standards to facilitate participation in the international market and adoption of best practices. Furthermore, nation-wide initiatives and cross-sectional collaboration, as suggested by Sarkis-Onofre et al. (2021), emphasize the importance of shared infrastructure and knowledge exchange in democratizing BIM benefits and fostering a culture of collaboration and innovation.

8. Practical implications

The findings and developed model (Fig. 5) offer several practical implications for project managers, policy-makers, and leaders in developing countries who are interested in leveraging digital transformation through BIM adoption.

8.1. For project managers

1. Enhanced Project Delivery: The Adoption Model emphasizes the integration of collaborative digital platforms that improve communication and coordination among stakeholders. By using BIM, project managers can streamline workflows, reduce rework, and ensure adherence to project timelines. This model supports the adoption of BIM Level 2 and 3 practices, which facilitate full collaboration and interoperability across project phases, leading to more efficient project delivery.
2. Resource Optimization: The model highlights the importance of resource management through accurate cost estimation, materials tracking, and labor allocation facilitated by BIM. Project managers can leverage these capabilities to optimize resources, minimize waste, and ensure projects are completed within budget. The strategic factors of the model encourage the use of BIM for detailed resource planning and management, which is crucial for achieving cost efficiency.
3. Risk Management: The advanced simulation and modeling capabilities of BIM, as outlined in the adoption model, allow project managers to foresee potential issues and mitigate risks proactively. This approach to risk management is supported by the model's emphasis on technological and strategic factors, which ensure that potential problems are identified and addressed early in the project lifecycle, leading to more successful project outcomes.

8.2. For policy-makers

1. Policy Development: Insights from the BIM Adoption Model can guide policy-makers in developing national standards and guidelines that promote BIM adoption. The model's contextual factors highlight the need for supportive regulatory frameworks that mandate BIM use in public sector projects, driving industry-wide adoption. Policy-makers can reference the model to create policies that align with international standards and local needs.
2. Financial Incentives: The model suggests implementing financial incentives, such as tax breaks, grants, or subsidies, to encourage BIM adoption. These incentives can help reduce the initial costs associated with BIM implementation, making it more accessible for organizations. By providing financial support, policy-makers can stimulate widespread BIM integration in the construction industry, as recommended by the model's financial support strategies.
3. Infrastructure Development: Investment in digital infrastructure, such as high-speed internet and data storage facilities, is crucial for effective BIM implementation. The adoption model underscores the importance of developing robust infrastructure to support digital transformation in construction. Policy-makers should prioritize these infrastructural developments to ensure that the necessary technological foundation is in place for BIM adoption.

8.3. For leaders in the construction industry

1. Strategic Planning: Industry leaders can use the BIM Adoption Model to incorporate BIM into their strategic planning processes. By integrating BIM into their business models, companies can improve project outcomes, enhance client satisfaction, and increase profitability. The model provides a framework for leaders to align their strategic goals with BIM adoption, ensuring that digital transformation initiatives are effectively implemented.
2. Workforce Development: The model emphasizes the need for training and development programs to build a workforce proficient in BIM technologies. Leaders should invest in educational initiatives and partner with academic institutions to offer BIM certification programs and continuous professional development opportunities. This approach ensures that the workforce is equipped with the necessary skills to leverage BIM effectively.
3. Collaboration and Innovation: Encouraging a culture of collaboration and innovation is a key component of the BIM Adoption Model. Leaders should promote interdisciplinary collaboration and support innovative practices that leverage BIM's full potential. By fostering an environment that values collaboration, organizations can enhance their BIM adoption efforts and achieve better project outcomes.

In a nutshell, the BIM Adoption Model provides a strategic and nuanced framework that can guide developing countries through the complex process of BIM integration. By addressing contextual, strategic, and adoption factors in tandem, this model proposes a pathway that is not only strategic but also practical and applicable. It is a call to action for governments, industry, academia, and international partners to collaborate in harnessing the transformative power of BIM for the future of construction and development.

9. Gaps and future research directions

The reviews and analysis revealed several significant gaps in the current understanding and adoption of BIM adoption in developing countries. These gaps highlight the complexity of BIM implementation across diverse socioeconomic contexts and underscore the need for a more nuanced approach in future research.

9.1. Current research problems and gaps identified

1) Interplay of Contextual, Strategic, and Adoption Factors:
   - Problem: While existing studies have explored various facets of BIM adoption such as governmental roles, legal frameworks, and financial support, they often treat these elements in isolation.
   - Gap: There is a notable deficiency in studies that synthesize these elements to assess their combined effect on BIM adoption outcomes. This gap limits the ability to understand how these factors interact dynamically within different developmental contexts.
2) Disconnection Between Thematic Frameworks and Contextual Realities:
   - Problem: The categorization of countries into three development levels and the identification of key influencing factors are well-intentioned; however, they remain somewhat disconnected from the practical realities and contextual peculiarities of these nations.
   - Gap: This results in a lack of research that bridges theoretical frameworks with practical implementations, hindering the development of effective, context-specific BIM adoption strategies.

9.2. Recommendations for future research

Based on the identified gaps, the following future research directions are proposed.

1) Holistic Analysis of BIM Adoption Factors:
   - Future Research Direction: Conducting comprehensive studies that integrate contextual, strategic, and adoption factors in a single analytical model. This research should aim to develop a holistic understanding of how these factors collectively influence BIM adoption, using mixed-methods approaches to capture both quantitative and qualitative insights.
   - Supporting Reference: Skare and Soriano (2021) suggest that multi-factorial analyses provide deeper insights into the systemic challenges and opportunities within technology adoption in emerging markets.
2) Empirical Studies on Thematic Frameworks:
   - Future Research Direction: Implementing empirical studies that test the applicability of the thematic frameworks presented in the literature within real-world settings. These studies should aim to validate or revise the theoretical constructs based on empirical evidence from diverse developmental contexts.
   - Supporting Reference: Kogler (2015) emphasize the need for empirical validation of theoretical models to ensure their relevance and applicability across different geographic and economic settings.
3) Development of Context-Specific BIM Adoption Models:
   - Future Research Direction: Focusing on developing tailored BIM adoption models that account for the specific challenges and resources of each development level. This should involve collaborative research involving local stakeholders to ensure that the models are grounded in local realities and needs.
   - Supporting Reference: Rhee et al. (2022) argues for the necessity of localized solutions in technology adoption, highlighting the successful digital transformation in Southeast Asia.

By addressing these research directions, future studies can bridge the current gaps between theoretical understanding and practical implementation of BIM in developing countries. This approach will not only enhance academic literature but also provide actionable insights for policymakers and industry practitioners, leading to more effective BIM adoption strategies tailored to the unique challenges of developing nations.

10. Conclusion

The systematic literature analysis has provided an extensive overview of the status quo regarding the adoption and implementation of BIM in developing countries. The evaluation indicates that although BIM adoption has become increasingly popular in a number of developing countries, a significant gap remains in holistic research on BIM adoption within this socioeconomic segment, thereby highlighting the special characteristics of this study setting. Also, the research delineates various scenarios of BIM adoption across different developing countries, marked by variations in levels of implementation, motivations, obstacles, and approaches employed.

The literature revealed a number of recurring themes, such as an analysis of the advantages and challenges of BIM, motivations and tactical methods, an evaluation of the adoption of BIM to date, and suggestions for its successful integration. Adoption of BIM has clear advantages, including lower costs, higher quality, and productivity. The literature also highlights a number of difficulties, such as management, cultural, financial, and technical obstacles. However, further study is necessary to comprehend the long-term effects of BIM adoption on the development of the construction sector, innovation, and economic growth in emerging nations, even though studies frequently concentrate on the short-term benefits. Research on obstacles unique to emerging nations, such as infrastructure, legal systems, and political stability, is also lacking.

10.1. Novel contributions

1. Conceptual Contributions:
   - Our research introduces a novel conceptual framework that integrates contextual, strategic, and operational factors affecting BIM adoption. This framework is the first of its kind to holistically combine these dimensions within the unique context of developing countries, offering a nuanced perspective that previous studies have overlooked.
2. Methodological Contributions:
   - We have employed a robust methodological approach using the PICO and PRISMA frameworks to ensure a systematic and reproducible review process. This methodological rigor enhances the reliability of our findings and sets a precedent for future studies in construction technology adoption in similar socioeconomic settings.
3. Empirical Contributions:
   - Although primarily a literature review, our study proposes empirical pathways based on identified gaps, such as the need for targeted studies on BIM's long-term impacts on construction sector development, innovation, and economic growth in emerging nations. These proposals lay the groundwork for future empirical research, guiding scholars to explore under-researched areas that are critical for the advancement of BIM in developing contexts.

Theoretical Implications: Our findings contribute to the theoretical understanding of technology adoption in emerging economies by highlighting the importance of a multi-faceted approach that considers local challenges and opportunities. The study enriches BIM adoption theory by adapting it to the complexities of developing countries, where factors such as infrastructure, legal systems, and political stability play a significant role in shaping technology integration strategies.

Future Research Directions and Practical Implications: The results of this systematic review highlight the necessity of more study in a number of important areas. Primarily, there is a pressing necessity for studies that examine the implementation of BIM within different income levels of developing countries. The BIM adoption model proposed by this research, while conceptual, requires a meticulous analysis and assessment to refine and validate its applicability and effectiveness within the intended study context. Furthermore, in order to address the deficiencies in BIM-related education and training in underdeveloped nations, more thorough research is needed. Research on how BIM adoption might support green building practices and environmental mitigation is required, as environmental concerns get more attention. Finally, an in-depth examination of the obstacles unique to emerging nations can provide insightful information on how to get beyond roadblocks pertaining to stability, legislation, and infrastructure.

In conclusion, this study provides a significant contribution to the body of knowledge by delineating the intricate interplay of factors that influence BIM adoption in developing countries. It advances the theoretical framework of technology adoption, offers a methodological blueprint for similar systematic reviews, and proposes practical measures for enhancing BIM implementation. These contributions are vital for policymakers, industry stakeholders, and academic researchers who are engaged in fostering technological advancements in the construction sectors of emerging economies.

CRediT authorship contribution statement

Sonam Rinchen: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Saeed Banihashemi:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Conceptualization. **Suhair Alkilani:** Writing – review & editing, Validation.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT in order to improve language and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Appendix

Appendix A. Assessing BIM objectives and implementation in developing countries

Reference	Developing Countries	Current Status/Level	BIM Benefits & Barriers	Drivers and Strategies	Lessons/Recommendations
Oladimeji et al. (2023)	Nigeria				
(Youkhanna Zaia et al., 2023)	Iraqi				
Rani et al. (2023)	Indonesia				
Kineber et al. (2023)	Egypt				
Toyin and Mewomo (2023)	Nigeria				
Hatami and Rashidi (2023)	Iran				
Toan et al. (2022)	Vietnam				
(Stojanovska-Georgievska et al., 2022)	North Macedonia				
Sood and Laishram (2022)	India				
Olugboyega and Windapo (2022)	South Africa				
Okwe et al. (2022)	Nigeria				
(Nafe Assafi et al., 2022)	Bangladesh				
Marzouk et al. (2022)	Egypt				
Hyarat et al. (2022)	Jordanian				
Hossain and Ahmed (2022)	Bangladesh				
Hasan et al. (2022)	Pakistan				
Eze et al. (2022)	Nigeria				
Ariono et al. (2022)	China				
Aburamadan et al. (2022)	Jordanian				
Calitz and Wium (2022)	South Africa				
(Sarkis-Onofre et al., 2021)	Yemen				
Aghimien et al. (2022)	South Africa				
Olanrewaju et al. (2021)	Nigeria				
Manzoor et al. (2021)	China				
Huong et al. (2021)	Vietnam				
Durdyev et al. (2021)	Cambodia				
Dao and Nguyen (2021)	Vietnam				
Cao and Li (2021)	China				
Babatunde et al. (2021)	Nigeria				
Belay et al. (2021)	Ethiopia				
(Arrotéia et al., 2021)	Brazil				
Alfalah et al. (2021)	China				
Aka et al. (2021)	Nigeria				
Al-sarafi et al., 2022	Afghanistan				
Olanrewaju et al. (2020)	Nigeria				
(Van Roy and Firdaus, 2020)	Indonesia				
Trillo et al. (2020)	Jordanian				
Saka et al. (2020)	Nigeria				
Khanzadi et al. (2020)	Iran				
Farooq et al. (2020)	Pakistan				
(Fan, 2020)	China				
Bouguerra et al. (2020)	Algerian				
Babatunde et al. (2020)	Nigeria				

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(*continued*)

Reference	Developing Countries	Current Status/Level	BIM Benefits & Barriers	Drivers and Strategies	Lessons/Recommendations
Babatunde et al. (2020)	Nigeria				
Zhou et al. (2019)	China				
Olugboyega and Windapo (2019)	Nigeria				
Olawumi and Chan (2019)	China				
Amin and Abanda (2019)	Egypt				
Akdag and Maqsood (2019)	Pakistan				
Telaga (2018)	Indonesia				
Olapade and Ekemode (2018)	Nigeria				
Ogunmakinde and Umeh (2018)	Nigeria				
Bhatti et al. (2018)	Pakistan				
(Amuda-Yusuf, (2018))	Nigeria				
Ismail et al. (2017)	China				
Sahil (2016)	India				
Hosseini et al. (2016)	Iran				
Kiani et al. (2015)	Iran				
Tang et al. (2015)	China				
Hosseini et al. (2015)	Iran				
Masood et al. (2014)	Pakistan				
Sistani and Rezaei (2012)	Iran				

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