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An integrated decision support system for BIM level 3 implementation

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The Architecture, Engineering, and Construction (AEC) sector accounts for 39% of greenhouse gas emissions, 40% of solid waste, and 12% of potablewater usage globally, underscoring the need for sustainable, efficient practices. Building Information Modeling (BIM) offers a digital framework to address these challenges through lifecycle management, collaboration, and efficiency gains. However, most organizations remain at BIM Level 2 maturity, which limits their potential for full integration. This study proposes a comprehensive Decision Support System (DSS) to facilitate the adoption of BIM Level 3, with an emphasis on collaboration, sustainability, and data interoperability. The DSS integrates Structural Equation Modeling (SEM), Analytical Hierarchy Process (AHP), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to identify and prioritize key drivers—including political, economic, socio-cultural, technological, legal, and environmental factors. The framework is validated through case studies, demonstrating its ability to align organizational strategies with sustainable practices. Organization (A) highlighted several essential components, ensuring a comprehensive assessment of BIM level 3 implementation within the organization. On the other hand, organization (B) stressed the importance of comparing the predicted environmental performance outcomes generated by the DSS with actual performance data collected during the building's occupancy phase to validate the system's predictive capabilities. These findings offer a practical pathway for achieving BIM Level 3 maturity, enhancing efficiency, supporting digital transformation, and advancing sustainability in the AEC industry.

KEYWORDS

building information modeling (BIM), BIM level 3 maturity, decision support system (DSS), integrated project delivery (IPD), analytical hierarchy process (AHP), techniquefor order preference by similarity to ideal solution (TOPSIS), structural equation modeling (SEM)

1 Introduction

Technological advancements have occurred across the Architecture, Engineering, and Construction (AEC) industry over the last few decades, with Building Information Modeling (BIM) emerging as a highly imperative tool to address various challenges faced by the industry. BIM is a model-oriented, collaborative digital platform that enables the management of the entire lifecycle of construction initiatives, promoting more sustainable and efficient practices (Azhar et al., 2012; Sacks, 2020). BIM is an integrated framework that encompasses all policies, practices, and technologies related to the digital management of building data, facilitating smooth communication and interoperability among different stakeholders in a project. There is evidence that the implementation of BIM reduces the costs and time spans of projects while simultaneously increasing the productivity and quality of construction activities (Bryde et al., 2013; Suermann and Issa, 2009). BIM is the backbone of Construction 5.0 because it facilitates the digital transformation of the sector's activities, making it even more efficient and innovative to execute in the construction field.

BIM is a multi-dimensional approach that allows extra data dimensions to be linked to a model (Awwad et al., 2022; D'Amico et al., 2020a). As more information (e.g., cost and schedule) can be added, it provides a fuller understanding of the project/asset. According to (D'Amico et al., 2020a; D'Amico et al., 2020b; Koutamanis, 2020), the levels are the procedures that enable other knowledge areas, such as construction project management, scheduling and planning, cost estimation and control, construction safety, and sustainability parameters, to be embedded in BIM software to provide a single source of information for all project stakeholders. These areas are interrelated with the levels of BIM maturity in terms of BIM dimensions.

In Level 1, managed CAD drawings (in 2D or 3D) are used, and industry standards, like commercial data and cost management packages, are implemented (Adekunle et al., 2023; Adekunle et al., 2022b; Adekunle et al., 2021; Alankarage et al., 2023; Alankarage et al., 2022). Level 2 involves basic collaborative modeling; however, the 3D environment is maintained in separate, discipline-specific tools and is not shared in the cloud environment. The 4D in level 2 is a 3D representation of an asset that includes the element of time, enabling schedules and critical path simulations (Adekunle et al., 2023; Alankarage et al., 2022; Almashjary et al., 2020). The 5D within BIM level 2 is a 3D representation of an asset with the elements of cost included and linked to enable cost estimation, commercial management, and earned value tracking to take place (Abubakar et al., 2014; Charef et al., 2018; D'Amico A. et al., 2020). Finally, Level 3 represents an open and interoperable process, including data integration enabled by Industry Foundation Classes (IFC). The TA collaborative model server manages data and information (Giel and Issa, 2013; Succar, 2010; Succar and Kassem, 2015). Level 3, sometimes called iBIM, involves sharing information in a cloud-based, collaborative environment (Abdalla and Eltayeb, 2018; Almashjary et al., 2020). At this stage, a new dimension (6D BIM) has evolved and been developed to address sustainability needs (Charef et al., 2018; Kaewunruen et al., 2020; Montiel-Santiago et al., 2020).

Many organizations have yet to achieve BIM Level 3 maturity, which involves an integrated workflow that spans all stakeholders and project phases. The key issues include fragmented construction processes, interoperability between systems, and the lack of robust evaluation frameworks to measure BIM adoption within organizations (Chen et al., 2023; Gbadamosi et al., 2018). Maturity models, such as the BIM Scorecard and the NBIMs ICMM, can be used for assessing implementation, but they typically rely on project-centric measures that do not encompass many organizational and strategic considerations necessary for complete integration into an organization (Dakhil et al., 2015; Smits et al., 2017). The multitude of data formats and the lack of standardization further complicate the AEC sector's implementation of an integrated BIM strategy.

The demand for BIM Level 3 introduces additional complexity to the system, given stringent organizational objectives, sustainability considerations, and the practical information requirements of stakeholders. Most of these diverse demands cannot be fulfilled well by current BIM frameworks. Hence, most BIM applications tend to be disintegrated as they cannot fulfill the actual promises of BIM's implementation in most organizations (Olanrewaju et al., 2020; Olanrewaju et al., 2022). Moreover, earlier literature suggests that scalable and effective decision-making tools are required for pre-planning the demand in terms of BIM.

This study aims to address the existing gaps in the design and validation of a holistic Decision Support System (DSS) method tailored for BIM Level 3 implementation. This DSS shall integrate Structural Equation Modeling (SEM), the Analytical Hierarchy Process (AHP), and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). SEM is a multivariate statistical technique that allows for the testing of relationships among latent variables (AbuMoeilak et al., 2023; Kock, 2015). AHP is a multi-criteria decision-making tool for ranking alternatives based on weighted priorities (Chen and Li, 2015; Saaty, 1980). TOPSIS is a method that evaluates alternatives against ideal and worst-case benchmarks to identify optimal solutions (Lai et al., 1994; Li et al., 2022). The Analytical Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) form a solid basis for evaluating and facilitating BIM adoption (Dehdasht et al., 2020). More precisely, the DSS would identify which key drivers of BIM adoption should be prioritized and weighted from both internal and external perspectives, informing an organization's strategy and implementation plan. Among its objectives, the study will review current BIM frameworks, identify the most critical drivers of BIM Level 3, rank those using more rigorous methodologies, and develop a rating tool for assessing readiness and maturity in the organizational use of BIM. Realistic case studies are then applied to test the DSS, demonstrating in practice how effective it would be in conducting construction projects where integration and collaboration issues frequently arise.

2 Literature review

Available and reported BIM frameworks rarely address these multidimensional demands. Therefore, by reducing fragmentation in current BIM adoption practices, this research provides a pathway to achieve BIM Level 3 maturity through seamless collaboration, interoperability, and integration of sustainability. The proposed DSS will theoretically fill some gaps in understanding how BIM implementation should work by providing practical solutions to overcome challenges in the AEC industry. The findings contribute to the global body of BIM knowledge, providing valuable insights that researchers, practitioners, and policymakers can use to improve efficiency, sustainability, and digital transformation in the industry. In the context of strategic BIM adoption, the study highlights the potential of BIM Level 3 to transform construction practices, reduce environmental impacts, and support the AEC industry's shift toward a more sustainable future.

2.1 BIM level 3 and integrated project delivery (IPD)

Several maturity models can be used to assess BIM adoption in the AEC industry, each with distinct levels and measurement criteria (Adekunle et al., 2022b; Azhar, 2011; Eastman et al., 2011). The most common models include the BIM Capability Maturity Model (BIM-CMM), the BIM Execution Planning (BEP) Maturity Model, and the Building Information Modeling Maturity Index (BIMMI) (Azhar et al., 2012; Pan and Zhang, 2022). Such models typically outline stages from BIM adoption to more advanced levels of practice. They often lack a comprehensive set of tools to achieve the highest maturity level, particularly BIM Level 3. Existing models tend to prioritize specific project components over organizational-wide integration, which is essential at higher levels of maturity (Smits et al., 2017). Furthermore, their incapacity to evaluate real-time collaboration, interoperability, and the integration of multiple stakeholders explains a substantial gap in current BIM maturity models. Recent research has expanded the scope of BIM maturity frameworks to include global and regionally specific contexts. For example (Schery et al., 2023), proposed a framework for identifying and prioritizing critical success factors for BIM adoption in public sector projects, applying fuzzy multi-criteria decision-making (MCDM) techniques. This work highlights the growing emphasis on structured decision-making methods for evaluating BIM maturity, particularly in developing countries. Table 1: summarises the most cited maturity models in the literature. BIM Level 3 is considered to be the peak of digital integration in the construction industry, and at this level, integration consists of interoperability, sustainability considerations, and robust collaboration (Arayici et al., 2018; Glasgow and Dakhil, 2017; Glema, 2017). In this scenario, all project stakeholders, including designers, engineers, contractors, and clients, utilize a single web-based platform to exchange information in real time. The centralization of data ensures that all critical project information is readily available at all times, thereby improving coordination and reducing errors (Giel and Issa, 2013). Furthermore, Level-3 integration incorporates sustainability parameters directly into the project lifecycle, such as energy and resource conservation (De Schutter et al., 2018). This integrated approach leads to more informed decision-making and smoother project delivery.

The IPD system is a major driver of BIM Level 3 integration, promoting collaboration among all project stakeholders (Bui et al., 2016; Merschbrock and Munkvold, 2014). The IPD promotes the sharing of goals, resources, and risks, leading to a collaborative effort to enhance project outcomes. (Khosrowshahi, 2017). This approach encourages improved accountability, productivity, and transparency by allowing stakeholders with expertise in related subjects to contribute to the brainstorming and decision-making process, thereby solving problems in real-time (Sacks, 2020). The practice of BIM at Level 3 significantly enhances the efficiency of the IPD, as everyone on the team is aligned with the project's goals and strategies (Chen and Lu, 2019; Zhang et al., 2022).

2.2 BIM Implementation Drivers and attributes

Government regulations and interventions are key drivers of BIM adoption. National regulations—such as mandating BIM in public sector projects and establishing BIM standards and guidelines—have been crucial in driving its widespread deployment (Kim S. et al., 2020; Wang et al., 2021). Countries such as the United Kingdom and South Korea have implemented regulatory frameworks that promote BIM implementation, demonstrating the level of government support required for BIM adoption. Table 2 describes BIM drivers.

In addition, the role of governance and institutional frameworks has become increasingly crucial for advancing BIM implementation. Tran and Huynh, 2025 examined government involvement in public–private partnership (PPP) infrastructure delivery in Vietnam, emphasizing how legal frameworks, institutional capacity, and regulatory mechanisms shape the successful digitalization of construction practices. These findings reinforce the importance of the political and economic dimensions considered in this study's DSS framework and demonstrate how policy-driven environments in Asia are accelerating BIM maturity at both organizational and national levels.

The implementation of BIM involves considerable upfront costs, primarily due to expenses related to software, training, and deployment (Capobianco et al., 2021). In contrast, the long-term benefits of BIM are usually greater than the cost of investment, including cost savings through improved efficiency, enhanced project outcomes, and reduced errors (Du et al., 2014; Kim S. et al., 2020). The ROI from implementing BIM is a significant driver for its uptake, especially in competitive marketplaces where financial benefits are regarded as critical determinants (Wang and Feng, 2022).

Successful BIM adoption requires a shift in organizational culture towards greater innovation and collaboration (Shafiq, 2021). Effective implementation of BIM also requires engagement and trust among stakeholders because it demands an integrated approach to project management (Lu W. et al., 2021). Cultural factors encompass the attitudes of individuals toward technology and their willingness to adopt new tools, which can significantly impact an organization's adoption of BIM(Liu et al., 2022; Tan et al., 2022).

Studies such as (Schery et al., 2023; Vempati, 2024) illustrate how AI-enabled decision-making and digital twins are reshaping construction management and sustainability practices. This evolution demonstrates the need for DSS that can integrate both technological innovation and organizational factors, as proposed in the current research.

The successful implementation of BIM is dependent primarily on the availability of BIM-compatible software, along with a robust IT infrastructure. Organizations should invest in powerful computing systems and advanced software to benefit fully from BIM(Wang and Feng, 2022). Furthermore, software interoperability across various platforms used by diverse stakeholders is critical to ensuring the smooth flow of data and collaboration throughout the project's lifetime.

BIM adoption requires legal frameworks that provide clarity regarding intellectual property and data security. The ownership rights to digital models and the protection of sensitive data must

TABLE 1 Summary of the most cited maturity models.

Model	Developer	Key elements	Shortcomes	References
BIM Maturity Model (BMM) – (iBIM)	Bew-Richards (2008)	- BIM process-based model 3 Levels - Clear guidelines for United Kingdom construction industry	- Apply to some organizations or industries	(Adekunle et al., 2022b; Dakhil et al., 2016; Kim I. et al., 2020; Peralta Lagos, 2019; Succar and Kassem, 2015)
BIM Maturity Model (BIM3)	Bilal Succar (2010)	- BIM field-based model - Based on 12 (KMAs) Comprehensive evaluation framework	- Does not adequately consider potential financial benefits of BIM.	(S. Adekunle et al., 2022; Chen and Li, 2015; Ferraz et al., 2020; Succar, 2010)
Capability Maturity Model- (CMM)	National Institute of Building Sciences (NIBS)	- Organizational, cultural, leadership, training, and communication aspects of BIM.	- High subjectivity, limited measurement scope	Banawi et al. (2019), Chen and Lu (2019), McCuen et al. (2012), Sun et al. (2022)
Dutch construction industry BIM Quick Scan	Sebastian and Van Berlo (2010)	- Identify areas for improvement in BIM processes - Clear and structured approach for innovation through BIM.	- Implementation may require a significant amount of time and resources	(Banawi et al., 2019; Lu W. et al., 2021; Siebelink et al., 2021; Sun et al., 2022)
Information Modeling Cloud Score (BIMCS)	Du, Liu, and Issa (2014)	- Based on a set of BIM stages of the construction lifecycle - Provides a roadmap for organizations to improve their BIM capabilities	- Implementation may require a significant amount of time and resources	Alankarage et al. (2022), Feng et al. (2021), Kassem et al. (2020), Siebelink et al. (2021), Sun et al. (2022)
BIM Proficiency Index	The Indiana University (IU)- (2012)	- Widely accepted BIM capabilities - Provides a clear and structured approach for organizations	- Apply to some organizations or industries	(Chen et al., 2023; Morlhon et al., 2014; Siebelink et al., 2018)

be clearly defined to mitigate regulatory risks (Ahmad et al., 2021; Arensman and Ozbek, 2012). Legal considerations regarding data usage, particularly in collaborative environments, must be addressed promptly to facilitate effective BIM implementation and compliance with industry standards (Eadie et al., 2015).

The BIM supports sustainable practices by incorporating energy-efficient designs and environmental assessments during the early stages of the project's procedure (De Schutter et al., 2018). BIM can be applied to better manage the environmental impact of buildings by optimizing resource use, reducing waste, and ensuring energy-efficient designs (Glasgow and Dakhil, 2017). The advantage of BIM is that it enables one to model environmental conditions and simulate energy use during building construction, ultimately creating more sustainable structures. Table 1 summarizes the most cited BIM Implementation Drivers.

3 Materials and methods

In this study, a mixed-methods research approach is employed, combining qualitative (interviews) and quantitative (SEM, AHP, and TOPSIS) techniques to answer the research questions and test the hypotheses regarding the implementation of BIM Level 3. The combination of these methods enables a complete study of BIM adoption, which combines both the subjective aspects of experts' opinions and objective statistical information. This study employs methodological triangulation, which involves the use of multiple theories, methods, observations, and experimental materials to mitigate the biases and limitations that might otherwise arise from a single approach. Triangulation enhances research outcomes, especially in areas such as BIM implementation. Figure 1 provides a detailed overview of the research methodology.

3.1 Questionnaire design

The first phase in the survey construction outlined the purpose of the research. It established a target population of Subject Matter Experts (SMEs) with BIM knowledge across various segments of the AEC industry. It was essential to gather precise expert opinions, which could only be obtained from SMEs. After this, a pilot phase was conducted with the primary goal of testing the initial survey questions. This paper employed an expert panel in the pilot phase to refine the survey questions, ensuring they elicited the critical factors influencing BIM Level 3 (McBride and Sigler, 2019). We refined our questions based on expert feedback to improve clarity and relevance.

TABLE 2 BIM implantation drivers summary.

Dimension		Attributes	Definition	References
1	Political	Government Regulations and Mandates	Refers to regulations and requirements set by government bodies that mandate or encourage the adoption of BIM in construction projects	Al-Mohammad et al. (2023), Almeida et al. (2023), Atkinson et al. (2014), Jiang et al. (2022), Winfield (2020)
		Government Funds and Budget allocations	The government's availability and allocation of financial resources to support BIM implementation in the AEC industry	Al-Ashmori et al. (2023), Almeida et al. (2023), Kim S. et al., 2020, Wang and Feng (2022)
		Trade Policies and International Standards	Refers to regulations and rules set by governments to govern international trade in the context of BIM, such as established norms and guidelines	Charef et al. (2019), Ganah and Lea (2021), Simon Elias (2019)
		Government Intervention	Government intervention involves the active role of authorities in promoting, regulating, or incentivizing the adoption of BIM in the AEC industry	Atkinson et al. (2014), Withers (2012), Yuan and Yang (2020)
2	Economic	Cost of Implementation	The total expenses associated with adopting and integrating BIM into construction processes	Babatunde et al. (2019), Fazeli et al. (2021), Khahro et al. (2021), Parsamehr et al. (2023)
		Financial Considerations	Evaluation of the long-term financial benefits and savings resulting from the implementation of BIM.	Al-Ashmori et al. (2023), Farouk et al. (2023), Hill and Lee (2012), Inyim et al. (2015), Kotler and Alexander Rath (1984)
		Competitive Advantage	The strategic benefit organizations gain through the effective use of BIM in terms of project efficiency, quality, and competitiveness	Abdalla et al. (2023), Awwad et al. (2022), Madanayake et al. (2021), Porwal et al. (2023)
		Skills and Training Cost	The expenses related to training personnel to effectively use BIM tools and methodologies	Hartmann et al. (2008), Tang et al. (2019), Al Hattab and Hamzeh (2018)
		Return on investment (ROI)	Measuring the financial gains or benefits obtained relative to the costs incurred in implementing BIM.	Arslan et al. (2020), Kim I. et al. (2020)
		Global Economic Conditions	External economic factors that can influence the adoption and success of BIM implementation on a global scale	Al-Yami and Sanni-Anibire (2021), Chen et al. (2018), Abbasnejad et al. (2021), Eilifsen et al. (2020)
3	Socio-cultural	Culture and Values	Organizational culture and values that may impact the acceptance and integration of BIM within a company	Adekunle et al., 2022b, Al-Ashmori et al., (2022), Alankarage et al. (2023), Tan et al. (2022)

(Continued on the following page)

TABLE 2 (*Continued*) BIM implantation drivers summary.

Dimension		Attributes	Definition	References
		Leadership and Change Management	The effectiveness of leadership and change management practices in facilitating the transition to a BIM-enabled workflow	Abd Jamil and Fathi (2019), Ahmed et al. (2017), Al-Ashmori et al. (2023), Azhar, 2011; Olugboyega (2023)
		Employee Attitudes and Beliefs	The perceptions and acceptance levels of employees toward BIM, which can affect its successful implementation	Al-Ashmori et al. (2023), Alankarage et al. (2022), Elhendawi et al. (2019), Olanrewaju et al. (2022), Olugboyega (2023)
		Labor Market Conditions	The availability and expertise of skilled labour in the market proficient in BIM methodologies	Al-Mohammad et al. (2023), Liu et al. (2022), Tan et al. (2022)
		Human Resources and Skills Development	Education, training, certification, ongoing professional development, collaborative learning, research, and promotion efforts	Al Hattab and Hamzeh (2018), Al-Mohammad et al. (2023), Awwad et al. (2022), Olugboyega (2023)
		Collaborative Practices	The extent to which BIM encourages and facilitates collaborative work practices among project stakeholders	Lu Y. et al. (2021), Al Hattab and Hamzeh (2018)
		Generational Differences	Variances in attitudes and approaches towards technology, including BIM, across different age groups within the workforce	Celoza et al. (2021), Stepanenko et al. (2019), Alwash et al. (2017), Awwad et al. (2022)
		Effective Communication and Information Sharing	The ability of organizations to communicate and share information efficiently through BIM processes	De Schutter et al. (2018), Du et al. (2014)
4	Technological	Availability of BIM Software	The accessibility and variety of BIM software solutions in the market.	Awwad et al. (2022), Chan et al. (2019), Ma et al. (2022)
		Interoperability Platforms	The compatibility and seamless integration of different BIM tools and software platforms	Awwad et al. (2022), Huang et al. (2023), Kadhim (2022), Mutis and Mehraj (2022), Tang et al. (2019)
		IT Infrastructure	The strength and adequacy of an organization's IT infrastructure to support BIM implementation	Huang et al. (2023), Pan and Zhang (2022), Porwal et al. (2023)
		Data Management and Data Standardization	Strategies and systems in place for the effective organization, storage, and retrieval of BIM-related data	Huang et al. (2023), Pan and Zhang (2021), Simon Elias (2019), Szép and Károlyfi (2021)
		Machine Learning and AI Technologies	Integration of machine learning and artificial intelligence technologies to enhance BIM capabilities	Chauhan et al. (2021), Chen et al. (2023), Marchinares and Aguilar-Alonso (2020), Pan and Zhang (2022), Wang and Feng (2022)

(Continued on the following page)

TABLE 2 (*Continued*) BIM implantation drivers summary.

Dimension		Attributes	Definition	References
5	Legal	Intellectual Property	Legal considerations regarding ownership and protection of intellectual property related to BIM models and data	Celoza et al. (2021), Stepanenko et al. (2019)
		Liability and Risk Allocation	Determination of responsibilities and risks associated with BIM implementation among project stakeholders	Alwash et al. (2017), Dao et al. (2020)
		Contractual obligations	Legal agreements outlining BIM-related responsibilities and requirements between parties involved in a construction project	Ahmad et al. (2021), Alwash et al. (2017), Arensman and Ozbek (2012), Arshad et al. (2019)
		Dispute Resolution Mechanisms	Procedures in place to resolve disputes that may arise during the course of BIM-enabled projects	Alwash et al. (2017), Arensman and Ozbek (2012), Arshad et al. (2019), Ma et al. (2020)
		Information Exchange Protocols	Agreed-upon standards and protocols for exchanging BIM-related information among project participants	Sansa et al. (2021), Hill and Lee (2012), Inyim et al. (2015), Kotler and Alexander Rath (1984)
6	Environmental	Sustainability and Green Building Initiatives	Integration of BIM in projects focused on sustainable and environmentally friendly construction practices	Glasgow and Dakhil (2017), Inyim et al. (2015), Siebelink et al. (2021)
		Environmental Awareness	Consideration of environmental impact and sustainability goals in BIM-enabled projects	Liu et al. (2022), Wang and Feng (2022)
		Sustainability Policies	Organizational policies and guidelines related to sustainable construction practices	Ahmad et al. (2021), Al-Ashmori et al. (2023)
		Sustainability Tools	BIM tools and features designed to support and assess the sustainability aspects of construction projects	De Schutter et al. (2018), Du et al. (2014)
		Local Environmental Regulations	Adherence to and compliance with local regulations pertaining to environmental standards in construction projects	Abd Jamil and Fathi (2019), Ahmed et al. (2017), Sansa et al. (2021)

In the second phase of the survey design, we conducted semi-structured interviews with SMEs to validate the factors identified in the reported literature and to explore new BIM adoption drivers that had not been previously covered. Table 3 presents the profile of the expert panel engaged in the semi-structured interviews, comprising four professionals with diverse expertise in digital transformation, BIM modeling, project management, and technical specification. Their varied job roles, years of experience (6–15), and geographic representation (United Kingdom, UAE, KSA) ensured balanced and credible input for validating the survey. The data collection included flexible, semi-structured interviews, which enabled the researchers to explore new and emerging factors, as well as refine existing ones based on expert insights. Following the identification of a research gap in the literature, semi-structured interviews were conducted with SMEs to gather qualitative data, validate the research findings, and gain an in-depth understanding of the factors influencing the adoption of BIM Level 3.

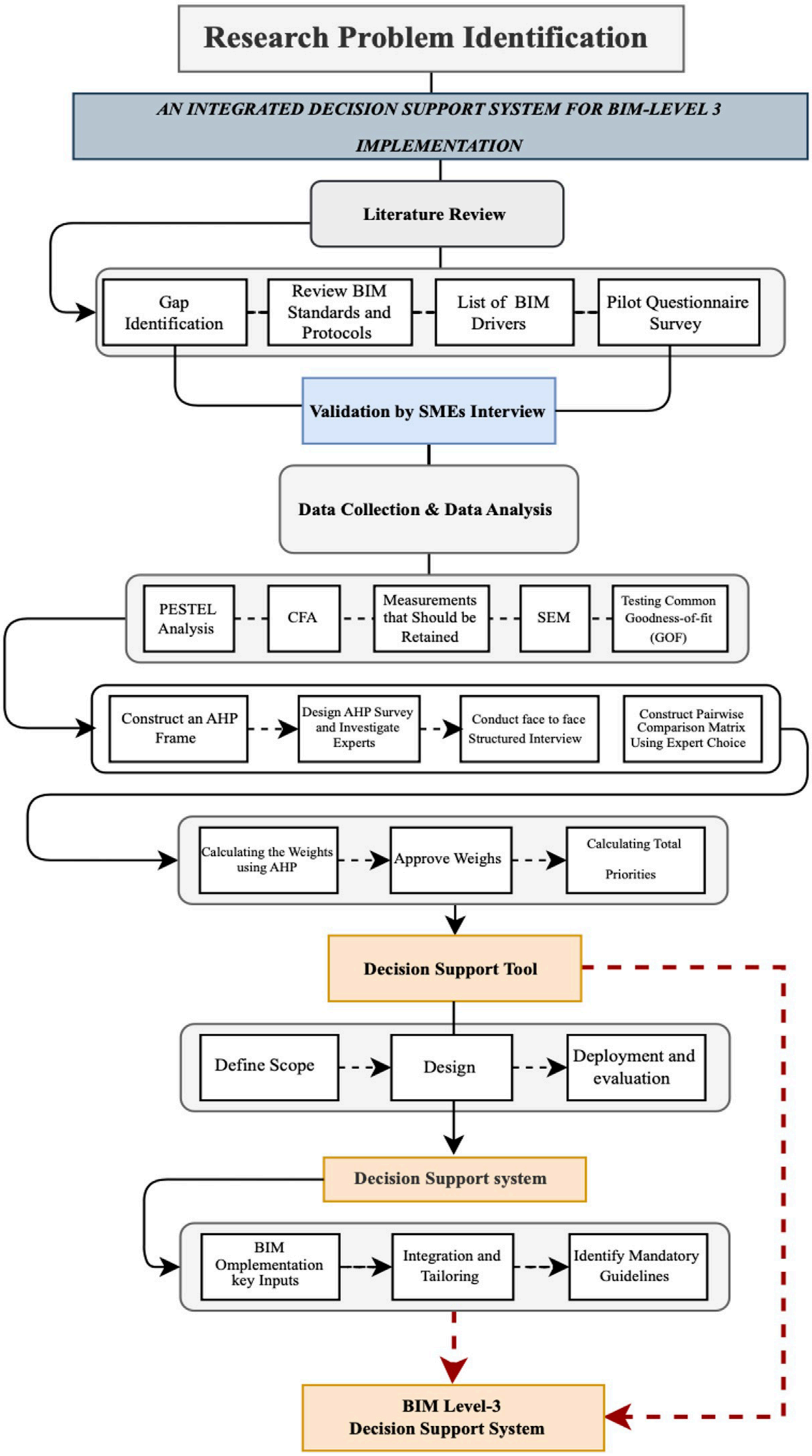

FIGURE 1
Research methodology.

A set of interviews was conducted to explore the current status of BIM implementation at Level 3 and the barriers that influence its successful adoption at this level. Kuada (Kuada, 2012) argued that interviews can be used to gather valuable insights into the subjective experiences of participants, which are often essential for understanding the complex problems associated with BIM

TABLE 3 Interviewees profiles.

No	Interviewee	Expert 1	Expert 2	Expert 3	Expert 4
1	BIM Specialization	Academia – Digital Transformation	BIM Modelling	Project Management	Technical Specification
2	Job Designation	PhD/BIM Coordinator	Senior BIM Architect	Project Manager	Senior Engineer
3	Years of Experience	6	9	15	7
4	Country	United Kingdom	UAE	UAE	KSA

implementation. The data collected from these interviews were then used to corroborate questions about the survey and to provide a comprehensive understanding of the drivers and the limitations of BIM adoption.

3.2 Data collection and analysis

3.2.1 Structural Equation Modeling (SEM) – EFA and CFA

A statistical technique known as SEM was used to analyze the relationship between drivers of BIM Level 3 implementation. SEM is suitable for studying complex topics, such as BIM implementation, because it enables the analysis of both latent and measured variables and supports the modeling of various BIM drivers. Before applying SEM, the study employed Exploratory Factor Analysis (EFA) to identify the latent constructs underlying the collected survey data. EFA is a widely accepted technique for reducing dimensionality and exploring factor structures in the early stages of model building (Hair et al., 2019; Mei et al., 2022). The dataset's suitability for factor analysis was confirmed using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity. The KMO value exceeded 0.90, indicating excellent sampling adequacy, while Bartlett's test was significant ($p < 0.05$), confirming that the correlation matrix was appropriate for factor extraction (Cohen, 2013; Garson, 2012; Majumdar and Schehr, 2014). Following the EFA, the model structure was validated through Confirmatory Factor Analysis (CFA), and the reliability of the identified factors was assessed consistent with the literature. Then, SEM was used to explore the relationship between these factors and their influence on users' perceptions, which became an exogenous dimension of the model (Kim and Jung, 2016). SEM enabled us to evaluate several hypothesized relationships simultaneously, grasp the intricacies of BIM Level 3 implementation, and empirically identify the most influential drivers.

3.2.2 AHP and TOPSIS

The AHP method was used to rank the various factors that affect BIM adoption. AHP is a MCDM tool that enables decision-makers to evaluate multiple alternatives against a set of criteria, where the weight of each criterion varies. It consists of structuring the decision problem, collecting data, normalizing the weights, and deriving a final ranking of the decision criteria. BIM drivers are particularly important for decision-making, so AHP is a highly convenient tool for assigning relative importance to various BIM drivers (Saaty, 2001).

The TOPSIS method was employed to evaluate and prioritize alternative solutions based on their proximity to an ideal solution. Intrinsically, this methodology assesses how each alternative performs compared to an ideal and a worst-case scenario, providing a comprehensive evaluation of each alternative's effectiveness (Akram et al., 2019). The application of TOPSIS in BIM implementation enhances decision-making by determining the best alternatives based on multiple criteria, and it improves BIM Level 3 adoption strategies (Tan et al., 2021).

An online questionnaire, developed in Google Forms, was sent to experts through LinkedIn and other professional networks, and circulated to 11 experts within the AEC sector worldwide. A total of 11 responses, deemed representative, were collected and subsequently analyzed for this study.

The data implies that this demographic comprises a diverse pool of BIM professionals with varying experience levels. The presence of highly experienced individuals and those with fewer years of experience suggests a broad spectrum of expertise. A significant majority (58%) of individuals in this demographic have 11–20 years of experience in BIM. This suggests that a substantial portion of the group comprises seasoned professionals who have been working with BIM for a considerable period. Another noteworthy observation is that a significant segment (25%) of respondents has more than 21 years of experience in BIM. This group can be considered highly experienced and potentially includes BIM pioneers who have been involved in the technology's early adoption. Furthermore, the data indicate that most organizations in this context belong to the private sector, accounting for 55%, while the government sector is less prominent in this dataset, yet still significant at 45% (Figure 2).

4 Results and discussion

4.1 Respondents profile

To collect data from BIM stakeholders worldwide, this study used an online survey that included a wide range of sectors and professional backgrounds. The survey was conducted on 12 December 2023, and remained open for 2 weeks, resulting in 270 responses, with 259 complete responses included in the analysis. The demographic data showed that most respondents (61.8%) were male, reflecting the fact that engineering and construction are mainly male-dominated fields. This highlights the need for increased gender diversity in these industries, as shown by the 38.2% female participants.

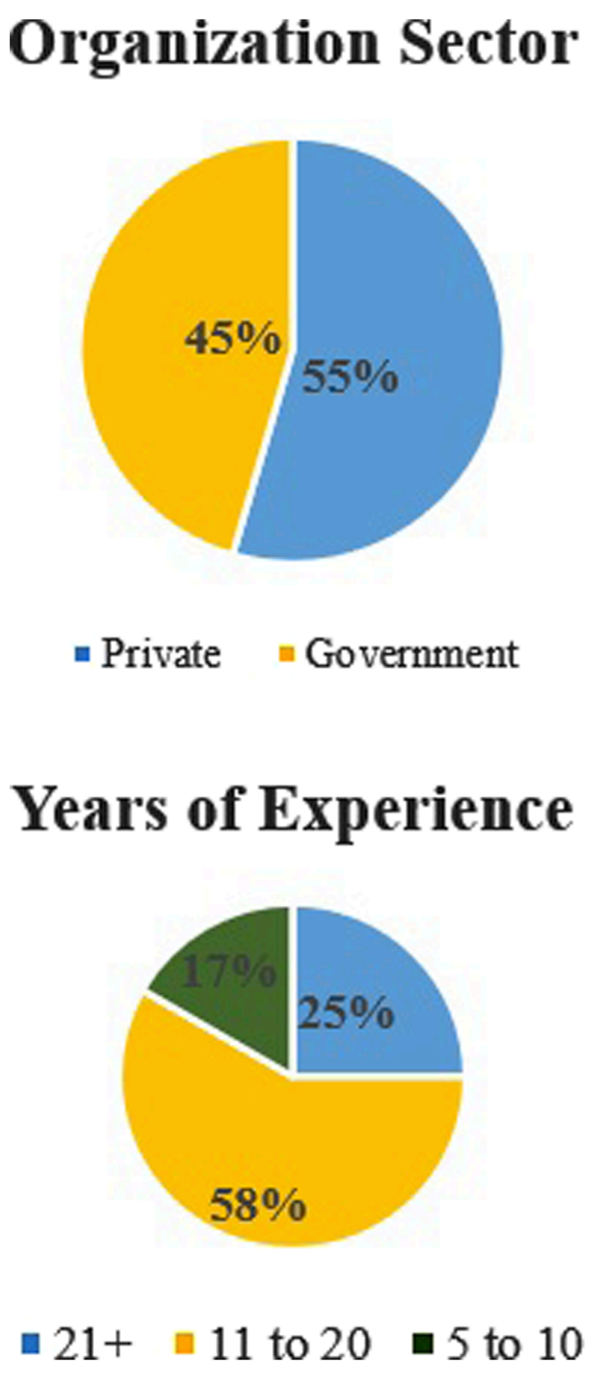

FIGURE 2
Two pie charts. The first chart shows the organizational sector. The second chart shows years of experience.

Half of the respondents (52.9%) held managerial positions, while 35.5% were analysts/associates, and the smallest group (9.3%) were the C-suite executives. There was an even distribution of experience levels, with 36.7% of people having between 5 and 10 years of experience, offering ample evidence of contributions from both mid-career professionals and senior experts. 20.8% of participants reported adopting BIM between 2010 and 2019, highlighting a period of accelerated uptake within the industry. The primary organizational focus included construction management (21.2%), consultancy (18.5%), and owners/developers (15.1%), illustrating the diverse application of BIM practices across sectors. This demographic diversity ensures a comprehensive representation of perspectives on BIM implementation.

4.2 Exploratory and confirmatory factor analyses

The study used EFA, supported by KMO measure of sampling adequacy and Bartlett's Test of Sphericity, which was conducted. A KMO value above 0.9 indicates excellent suitability for factor analysis, and Bartlett's significance ($p < 0.05$) confirms that the correlation structure is appropriate for extraction (Hair et al., 2019). EFA was utilized to identify the underlying latent constructs in the data. Key measures of sample adequacy were met, with a KMO value exceeding 0.90 and significant results from Bartlett's Test of Sphericity ($p < 0.05$), indicating the dataset was suitable for factor analysis. EFA extracted nine distinct factors, explaining a significant portion of the variance, with eigenvalues greater than 1. Factor loadings exceeded 0.4, and no cross-loadings were present, confirming the appropriateness of the factor structure (Table 4). The measured dimensions were (PD = Political Dimension; ECO = Economic; SCD = Socio-Cultural Dimension; TD = Technological Dimension; LD = Legal Dimension; ENV = Environmental; IPDA = Integrated Project Delivery Attributes; SPA = Sustainability Practices Assessment; BIMIL = BIM Implementation Level).

CFA was conducted to assess the reliability and validity of the constructs (Figure 3). The measurement model demonstrated a strong fit to the data ($\chi^2/df = 1.816$, RMSEA = 0.056, CFI = 0.927, and TLI = 0.919). Internal consistency was established with Cronbach's alpha values exceeding 0.7 for all constructs, while Composite Reliability (CR) values further validated scale reliability. Convergent validity was confirmed with Average Variance Extracted (AVE) values >0.5, and discriminant validity was established as Heterotrait-Monotrait (HTMT) values were below 0.85. These findings confirm that the data structure is robust and the measurement scales are both reliable and valid.

4.3 Integrated AHP and TOPSIS

Building on the CFA results, this study used the AHP and TOPSIS methods to prioritize and rank the drivers of BIM implementation.

AHP was used to assign weights to six primary drivers: socio-cultural, technological, legal, environmental, economic, and political. The highest weight (17.57%) was given to technological drivers, emphasizing the need for robust IT infrastructure, software interoperability, and skill development in BIM implementation. The second-ranked (16.69%) legal considerations included contractual clarity, intellectual property protection, and regulatory compliance. A weighted set of these drivers was used to rank project delivery systems using the TOPSIS method. IPD was ranked highest and aligns with BIM's shared risk framework through its emphasis on collaboration. Construction Management at Risk (CMAR) was

TABLE 4 EFA communalities.

Code	Initial	Extraction PCA method	Code	Initial	Extraction
PD1	1	0.73	TD5	1	0.763
PD2	1	0.834	TD6	1	0.737
PD3	1	0.854	ENV1	1	0.823
PD4	1	0.818	ENV2	1	0.806
ECO1	1	0.738	ENV3	1	0.84
ECO2	1	0.806	ENV4	1	0.801
ECO3	1	0.777	ENV5	1	0.774
ECO4	1	0.757	LD1	1	0.81
ECO5	1	0.733	LD2	1	0.817
ECO6	1	0.773	LD3	1	0.806
SCD1	1	0.776	LD4	1	0.75
SCD2	1	0.736	LD5	1	0.761
SCD3	1	0.728	BIMIL1	1	0.847
SCD4	1	0.685	BIMIL2	1	0.801
SCD5	1	0.689	IPDA1	1	0.852
SCD6	1	0.794	IPDA2	1	0.851
SCD7	1	0.738	SPA1	1	0.745
SCD8	1	0.658	SPA2	1	0.746
TD1	1	0.823	SPA3	1	0.704
TD2	1	0.83	SPA4	1	0.748
TD3	1	0.819	SPA5	1	0.714
TD4	1	0.709	SPA6	1	0.771

second, followed by Design-Build (DB) and Design-Bid-Build (DBB). The resulting hybrid AHP-TOPSIS approach offered a nuanced prioritization framework that enabled decision-makers to synthesize strategies with project-specific requirements and resource availability (Figure 3).

5 Proposed framework

5.1 Framework development

A structured methodology for evaluating and guiding organizations toward a complete collaboration and integration of information across the lifecycle of built assets has been represented by the BIM Level 3 DSS (Figure 4).

5.1.1 Identification of drivers

The proposed BIM Level 3 DSS was developed based on the holistic identification of key drivers affecting BIM implementation in the AEC industry. The main structure of this phase involved an extensive review of previous literature, industry reports, and case studies to develop a robust framework comprising seven primary dimensions. The political dimension examines government policies, regulations, and funding allocation related to supporting BIM adoption. The economic aspect addresses the financial aspects of BIM implementation, including a cost-benefit analysis and return on investment metrics. Organizational culture, workforce skills, and collaboration with external stakeholders are all social factors that emphasize the role of these factors in the effective adoption of new initiatives. These pursuits require BIM Level 3 maturity, which encompasses software interoperability,

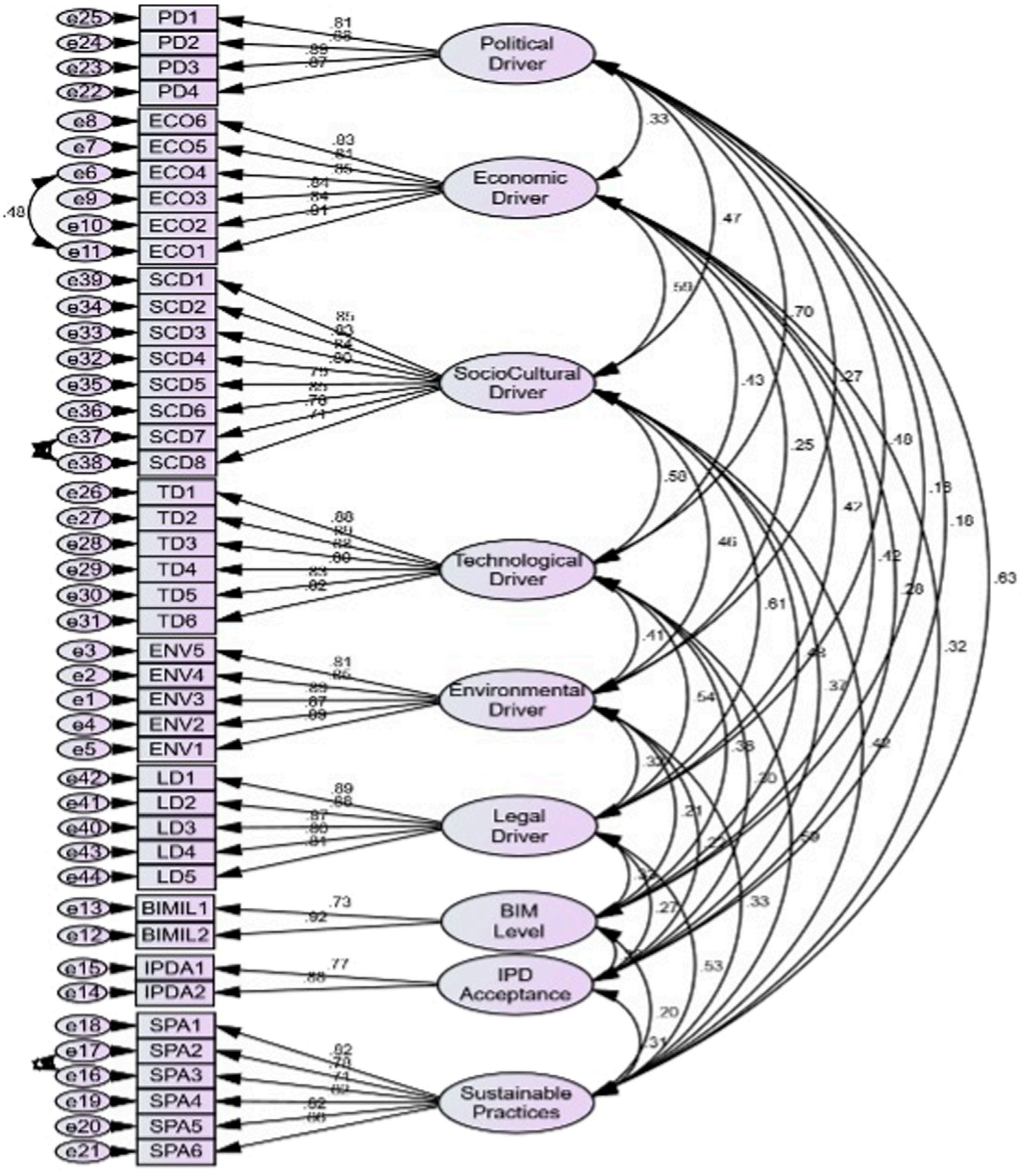

FIGURE 3
CFA diagram.

robust IT infrastructure, skill development, and technological considerations.

The third dimension of the view is the environmental dimension, comprising tools such as green building standards, lifecycle assessment, and generally environmentally responsible practices, all of which are duly supported by BIM. The legal aspects are related to questions regarding the clarity of contractual frameworks, liability administration, and the protection of intellectual property based on trust, as well as the effectiveness of risk mitigation in projects. The dimension of collaborative delivery methods that include IPD is based on the principles of shared risks and rewards inherent in BIM. These three dimensions become an overall frame of reference for a common understanding and grading of readiness for BIM Level 3 implementation. They address both external and internal factors, providing the drivers for evaluating the maturity and integration of BIM practices in an organization. The DSS is a multidimensional approach that encompasses all the challenges and opportunities associated with the digitalization of the construction industry.

5.1.2 Measuring drivers using SEM

The relationships and causal linkages among the identified drivers were quantified using SEM. The SEM method facilitates understanding the direct and indirect effects of these factors and the nuances of interdependencies among them, which are crucial for

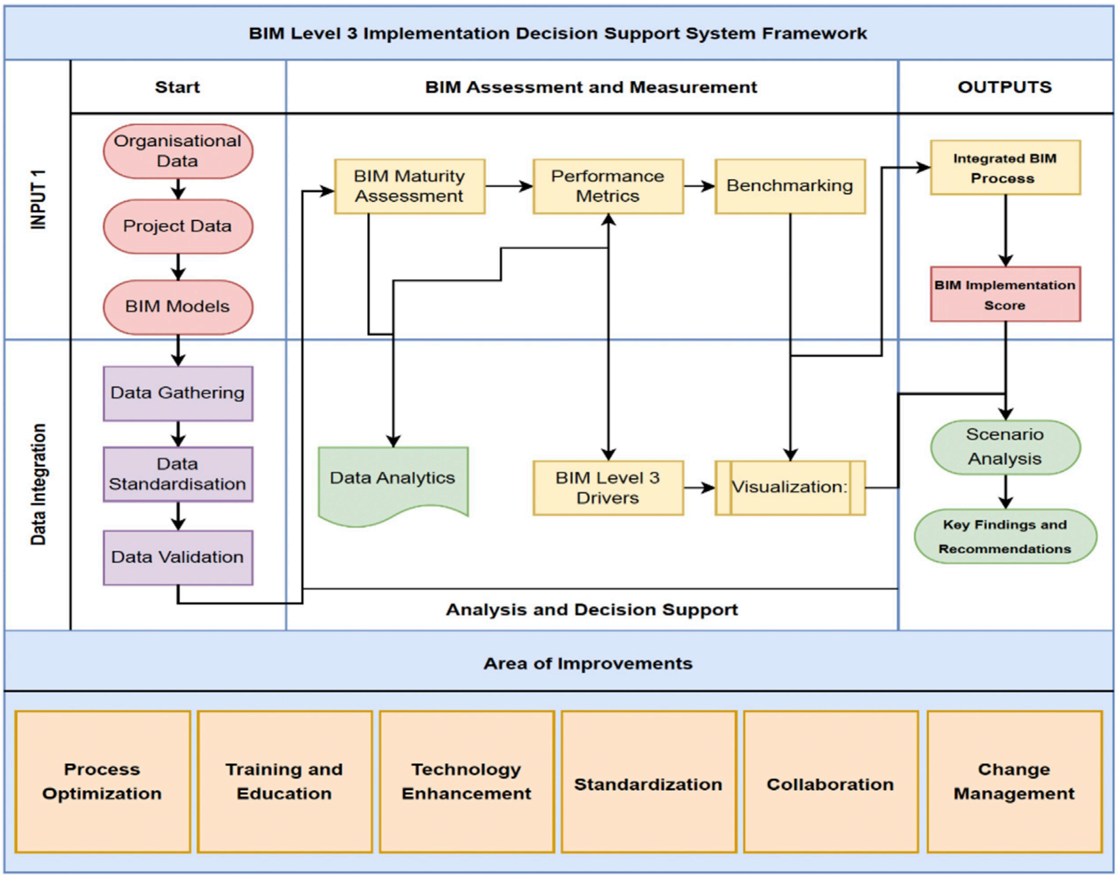

FIGURE 4
DSS conceptual framework.

comprehending their role in BIM implementation. The significant mediators and moderators of the adoption process were identified through SEM analysis, and the statistical indices, as indicated by the RMSEA and CFI methods, ensured the robustness of the SEM model. Figure 5 illustrates the SEM analysis path diagram.

5.1.3 Assigning weights using AHP

This study used the AHP method to determine the relative importance of the drivers based on expert opinions and to present data-driven findings. This step facilitated the systematic prioritization of drivers based on their importance in achieving BIM Level 3 maturity. Subsequent ranking and decision-making processes were informed by the AHP results, complemented by the TOPSIS, to evaluate the project delivery methods.

5.1.4 Developing the DSS

The measured drivers and their corresponding weights are integrated into a maturity assessment tool using the DSS. The maturity spider tool is a key feature of the system, visually representing an organization's performance across all dimensions. This interactive interface enables stakeholders to identify the strengths and weaknesses of BIM, facilitating appropriate interventions for enhancing BIM readiness.

5.1.5 Validation of the DSS

The DSS method was validated based on practical applications extracted from the case studies of Organizations A and B. Refinements to the accuracy, usability, and relevance of the system were confirmed through these case studies.

5.1.6 Validation

Two private organizations' case studies have been selected to test and validate the DSS. The selection of case studies in this research employed a purposive sampling strategy, focusing on BIM projects that represented diverse scales, complexities, and industry sectors. The goal is to ensure a comprehensive examination of the developed DSS across varied contexts, enabling the identification of common patterns, challenges, and success factors. Table 5 outlines the selected organization's profile. Organization A demonstrated strong sustainability performance, reinforced by effective environmental policies and commendable leadership. The DSS accurately identified areas for improvement, including expanded training programs and the refinement of lifecycle assessment tools. The feedback on the tool's user-friendly interface and its ability to align sustainability practice with strategic objectives was particularly lauded. However, Organization B experienced some difficulties in developing a workforce and achieving interoperability with existing systems. Actionable recommendations to fill these gaps

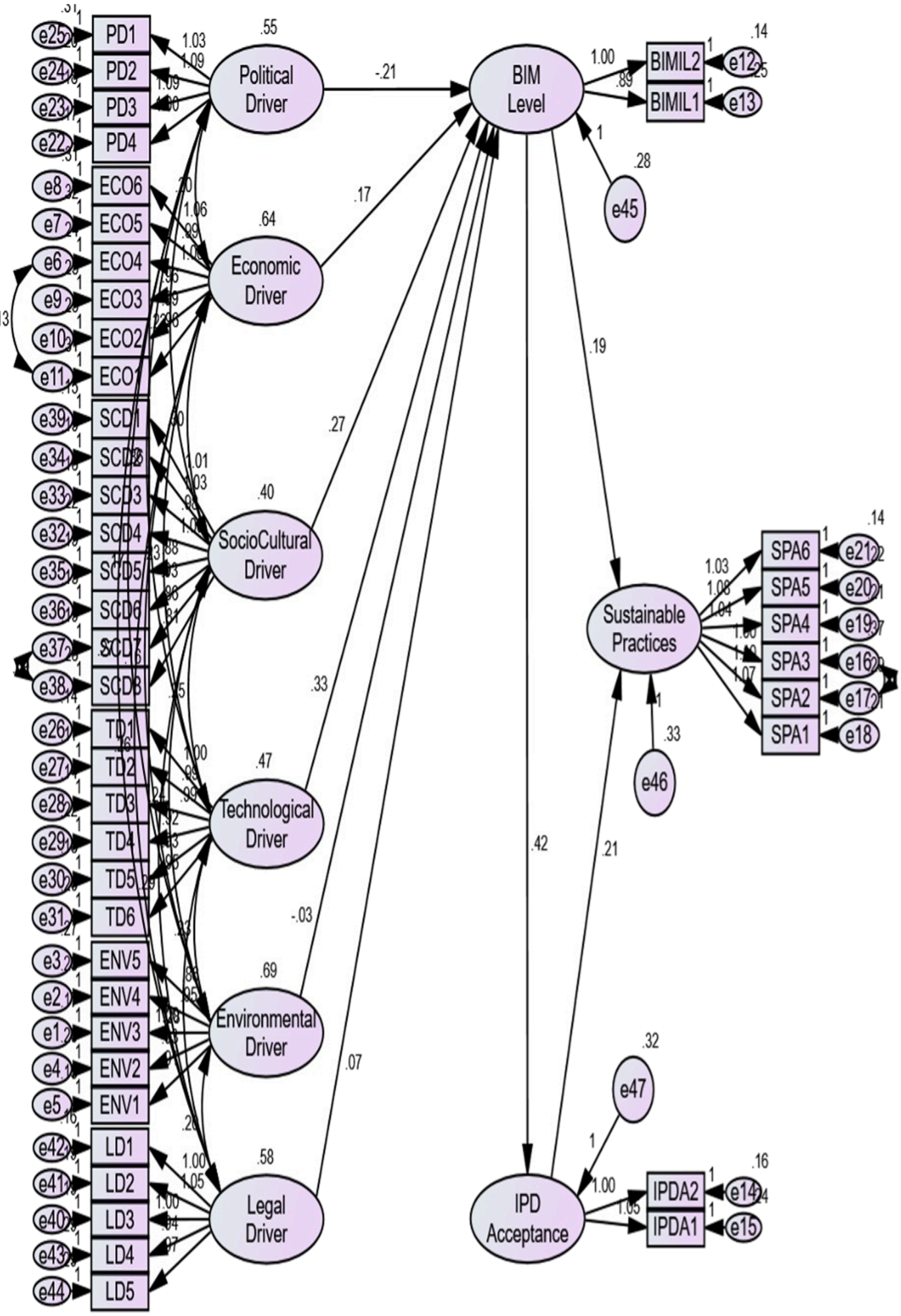

FIGURE 5
SEM path diagram.

TABLE 5 Case studies organizations profiles.

Organizations (private)	Size	Sector	History of BIM	Location	Stockholder (user)	BIM score
A	Medium (100-150)	Construction	Since 2018	UAE	BIM Manager	47% (Level 2)
B	Small (50 -100)	Engineering Management	Since 2021	United Kingdom	Senior Project Manager	63% (Level 2)

included developing new training modules and integrating cloud-based interfaces provided by the DSS. The maturity spider tool also helped the organization visually identify critical areas of underperformance.

Both organizations found the DSS able to deliver valuable insights and support decision-making. While these were generally successful, there were areas for further refinement, such as increased compatibility with other software formats and expanded predictive capability to match the modeled results with real-world performance data.

6 Conclusion and future recommendations

The research undertaken was prompted by a noticeable gap in the existing literature, particularly concerning the absence of dedicated decision support systems capable of effectively measuring the implementation of BIM Level 3 across various project delivery systems within the AEC industry. This gap was identified as a critical void in the current state of BIM research and practice, hindering the industry's ability to assess and advance BIM implementation maturity comprehensively. The lack of a dedicated DSS tailored to measure BIM Level 3 implementation across this spectrum substantially impedes organizations from transitioning seamlessly to advanced BIM practices. Consequently, the research aimed to develop an integrated DSS designed to facilitate BIM Level 3 implementation within the AEC industry effectively.

Traditional DSS models often fail to accommodate the nuanced requirements associated with different project delivery systems, hindering organizations' ability to assess their readiness and progress in adopting BIM Level 3. This consequently inhibits effective decision-making and strategic planning, demonstrating the need for a comprehensive, adaptable, and project-delivery system-specific tools in the industry capable of assessing and guiding the implementation roadmap.

The MCDM techniques, particularly the integration of AHP and TOPSIS, facilitated the systematic evaluation of diverse factors influencing BIM Level 3 implementation. The synergy between qualitative and quantitative data sources ensured a comprehensive exploration of the complex interplay of factors, contributing to a more robust understanding of the research goals. Rooted in a systematic methodology, this mixed-methods approach enabled the triangulation of findings, ensuring a comprehensive and robust exploration of the research goals. Empirical findings of SEM and AHP analysis confirmed the multifaceted nature of BIM Level 3 implementation, emphasizing the pivotal roles played by organizational culture, leadership commitment, technological infrastructure, and collaborativ e practices.

Moving forward, researchers and practitioners should continue exploring and refining tools specifically catered to the diverse landscape of the IPD systems, taking into consideration all the project phases within the AEC industry. This involves ongoing collaboration between academia, industry professionals, and software developers to ensure that DSS are robust, comprehensive, and adaptable to the evolving nature of construction project delivery. This focused approach on the intersection of BIM Level 3 and project delivery systems is vital for fostering a more holistic and effective implementation of BIM within the AEC sector.

6.1 Research limitations

Certain limitations of this study are recognized, which provide valuable context for its findings. The geographic scope of the case studies used to validate the DSS was restricted. The findings were not generalized to regions or contexts outside of the study. Moreover, it also depends on expert opinions to derive weights and priorities of attributes for users in DSS, which may be biased. While they tried to diversify the panel of experts, the results have been interpreted subjectively, colored by the individual's experience.

The BIM dynamic technological landscape represents another limitation. The tools and frameworks developed during the study may need to be continually updated to stay relevant and reflect the latest innovations in BIM practice. The evolution of project delivery systems reinforces the need for periodic refinement of the DSS to accommodate changes in industry practice.

6.2 Future recommendations

Based on this study, some avenues for further investigation and development are proposed. Advanced technologies, including machine learning, offer an excellent opportunity to implement machine learning algorithms in the DSS, extending its engineering capabilities. The system can bring predictive analytics to life, helping it evolve beyond descriptive insights to proactively identify patterns and predict outcomes, supporting more robust decision-making processes. Thus, a more dynamic and adaptive set of tools could be enabled, responding to the complexities and uncertainties of the AEC industry.

Moreover, other case studies should be explored in their geographic scope to generalize the DSS to other regional and cultural contexts in future research. By expanding the scope, the system's adaptability and relevance in different markets and regulatory environments can be further explored. Furthermore, the temporal evolution of BIM Level 3 implementation can be studied through longitudinal studies. It will provide insights into the sustained impacts of critical drivers and the evolution of BIM practices over time.

Future iterations of the DSS must be robust, comprehensive, and aligned with the needs of multiple stakeholders, necessitating collaboration between academia, industry practitioners, and policymakers. Fostering such collaboration would be instrumental to the seamless and standardized adoption of BIM Level 3 across the AEC sector. Furthermore, exploring the possibilities of applying BIM Level 4 frameworks based on findings from this study holds an attractive prospect for the future development of BIM maturity models.

6.3 Executive summary

This study developed a DSS to help organizations successfully adopt BIM Level 3. The framework identifies six critical factors: leadership, culture, technology, collaboration, economic, and environmental considerations that influence readiness and implementation. By applying structured decision-making methods, the DSS provides a practical roadmap for assessing current capabilities and planning future actions. For industry leaders and project managers, the findings highlight the importance of investing in digital infrastructure, fostering collaboration, and embedding sustainability into BIM practices. This tool can support more informed decisions and smoother transitions toward advanced BIM maturity.

This study advances the implementation of BIM Level 3 and highlights the ongoing need for iterative development in both research and practice. The study's limitations may be addressed by implementing the recommended strategies to advance innovative, adaptable, and internationally relevant solutions for BIM adoption and implementation within the dynamic AEC industry.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Institutional Review Board (IRB) of the American University of Sharjah (Protocol #24-058, Exempt approval under 45 CFR 46.104(d)(2)). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

LA: Formal Analysis, Writing – original draft, Validation, Methodology, Conceptualization, Investigation, Supervision, Writing – review and editing, Software. SB: Writing – review and editing, Supervision, Methodology, Validation, Conceptualization. SA: Funding acquisition, Supervision, Resources, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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