technologies

Review

Integrating Building Information Modelling and Artificial Intelligence in Construction Projects: A Review of Challenges and Mitigation Strategies

Ayaz Ahmad Khan [1,2], Abdulkabir Opeyemi Bello [3,4], Mohammad Arqam [5] and Fahim Ullah [6,*]

[1] UniSA Creative, University of South Australia, City West Campus, Adelaide, SA 5000, Australia; ayaz.khan@mymail.unisa.edu.au
[2] IVE: Australian Research Centre for Interactive and Virtual Environments, Mawson Lakes Campus, Adelaide, SA 5095, Australia
[3] Department of Building, Federal University of Technology, P.M.B 65, Minna 920101, Nigeria; abdulkabiropeyemi@gmail.com
[4] Department of Building Technology, SAF Polytechnic, Iseyin 211101, Nigeria
[5] School of Mechanical and Mechatronic Engineering, University of Technology Sydney, Ultimo, NSW 2007, Australia; mohammad.arqam@uts.edu.au
[6] School of Surveying and Built Environment, University of Southern Queensland, Springfield Campus, Ipswich, QLD 4300, Australia
* Correspondence: fahim.ullah@unisq.edu.au

Abstract: Artificial intelligence (AI), including machine learning and decision support systems, can deploy complex algorithms to learn sufficiently from the large corpus of building information modelling (BIM) data. An integrated BIM-AI system can leverage the insights to make smart and informed decisions. Hence, the integration of BIM-AI offers vast opportunities to extend the possibilities of innovations in the design and construction of projects. However, this synergy suffers unprecedented challenges. This study conducted a systematic literature review of the challenges and constraints to BIM-AI integration in the construction industry and categorise them into different taxonomies. It used 64 articles, retrieved from the Scopus database using the PRISMA protocol, that were published between 2015 and July 2024. The findings revealed thirty-nine (39) challenges clustered into six taxonomies: technical, knowledge, data, organisational, managerial, and financial. The mean index score analysis revealed financial (μ = 30.50) challenges are the most significant, followed by organisational (μ = 23.86), and technical (μ = 22.29) challenges. Using Pareto analysis, the study highlighted the twenty (20) most important BIM-AI integration challenges. The study further developed strategic mitigation maps containing strategies and targeted interventions to address the identified challenges to the BIM-AI integration. The findings provide insights into the competing issues stifling BIM-AI integration in construction and provide targeted interventions to improve synergy.

Keywords: artificial intelligence; building information modelling; challenges; construction industry; systematic literature review

Citation: Khan, A.A.; Bello, A.O.; Arqam, M.; Ullah, F. Integrating Building Information Modelling and Artificial Intelligence in Construction Projects: A Review of Challenges and Mitigation Strategies. *Technologies* **2024**, *12*, 185. https://doi.org/10.3390/technologies12100185

Academic Editors: George F. Fragulis and Debopriyo Roy

Received: 17 August 2024
Revised: 17 September 2024
Accepted: 27 September 2024
Published: 2 October 2024

1. Introduction

The tidal waves of digital transformation in the construction industry gained momentum with traction in building information modelling (BIM) [1,2]. BIM is touted as a digital solution to the persistent problems of fragmentation, stakeholder disintegration, collaboration deficit, information islands, frequent change orders, requests for information, and inconsistencies in construction project delivery [3,4]. It encompasses a set of interacting policies, processes, and technologies, translating into a methodology for generating and managing relevant building design and project data in a digital format throughout the lifecycle of an asset [3,5].

BIM simulates the construction project in a virtual environment. It digitally constructs an accurate virtual model of the building, enabling the project team to visualise the proposed asset in a simulated environment [6]. The completed BIM model usually contains precise geometry and relevant non-geometry data required to support the design, procurement, fabrication, construction, operation, maintenance, and end-of-life management of the built asset [3,5]. Thus, BIM supports visualisation, fabrication/shop drawing, code reviews, cost estimation, construction sequencing, clash detection, forensic analysis, and facilities management [6,7].

While BIM may appear as an all-in-one solution to construction problems, it presents novel challenges such as data processing and management. Large volumes of data (big data) are produced and managed in the BIM workflows throughout the asset lifecycle [8]. While the large corpus of data from BIM models conforms to a structured schema and constitutes a centralised machine-interpretable mine [9], prevailing decision support from BIM models draws mainly on the metadata of objects. These metadata are augmented with aggregate functions for the extraction of quantitative information, code reviews, and clash detection based on geometrical inference, parametric design, and documentation [3]. Additionally, BIM models capture data that are not overtly specified but embodied in the interrelation between the entities of a single model or in the interrelation of a large variety of models [9]. Consequently, construction project teams have struggled to mine, process, analyse, and transform the large corpus of implicit and explicit big data from the BIM models into valuable information and insights to inform decision-making throughout the project lifecycle. This is due to the prevailing information and data processing limitations [7].

In contrast, artificial intelligence (AI) provides complementary opportunities, including the computational power to analyse datasets, automate processes, and extract valuable insights from different types and sources of data, including the BIM models [10]. AI refers to algorithms, software, hardware, and systems having the capability to correctly interpret external data, learn from such data, and use those learnings to achieve specific goals and tasks through flexible adaptation [11]. AI leverages machine learning (ML), data analytics, natural language processing, knowledge-based systems, computer vision, robotics, and metaheuristics [12,13]. ML and decision support systems can deploy complex algorithms to learn sufficiently robust data from multiple sources. Such learning and data insights are used to adaptively inform smart decisions [13]. AI techniques offer vast opportunities to transform massive big data into useful knowledge [14].

The integration of BIM-AI enables many possibilities for data handling in construction projects. These include autonomous design modelling, automated code compliance checking, automated progress monitoring, and project performance control [7,13]. BIM-AI integration presents endless opportunities and extends the possibilities of innovations in the design and construction of projects [15,16]. Figure 1 shows the benefits of BIM-AI integration throughout the construction project lifecycle.

However, BIM-AI faces practical, technical, commercial, cultural, and organisational challenges in the construction industry [13]. For an industry among the least digitised in the world, with a long-standing culture of resistance to change, limited automation, and complex structure, BIM-AI integration faces more profound challenges than other industrial counterparts [7]. Therefore, it is increasingly important to explore, identify, and address these challenges if the construction industry aims to reap the benefits of holistic BIM-AI integration. Although there is a growing body of literature focused on understanding and addressing the challenges of BIM-AI integration [14], these challenges are often fragmented, dispersed across various studies, and not thoroughly synthesised for practical application in the construction industry [13]. As a result, these challenges remain poorly understood and difficult to address within industry practice. This presents a gap that is targeted in the current study.

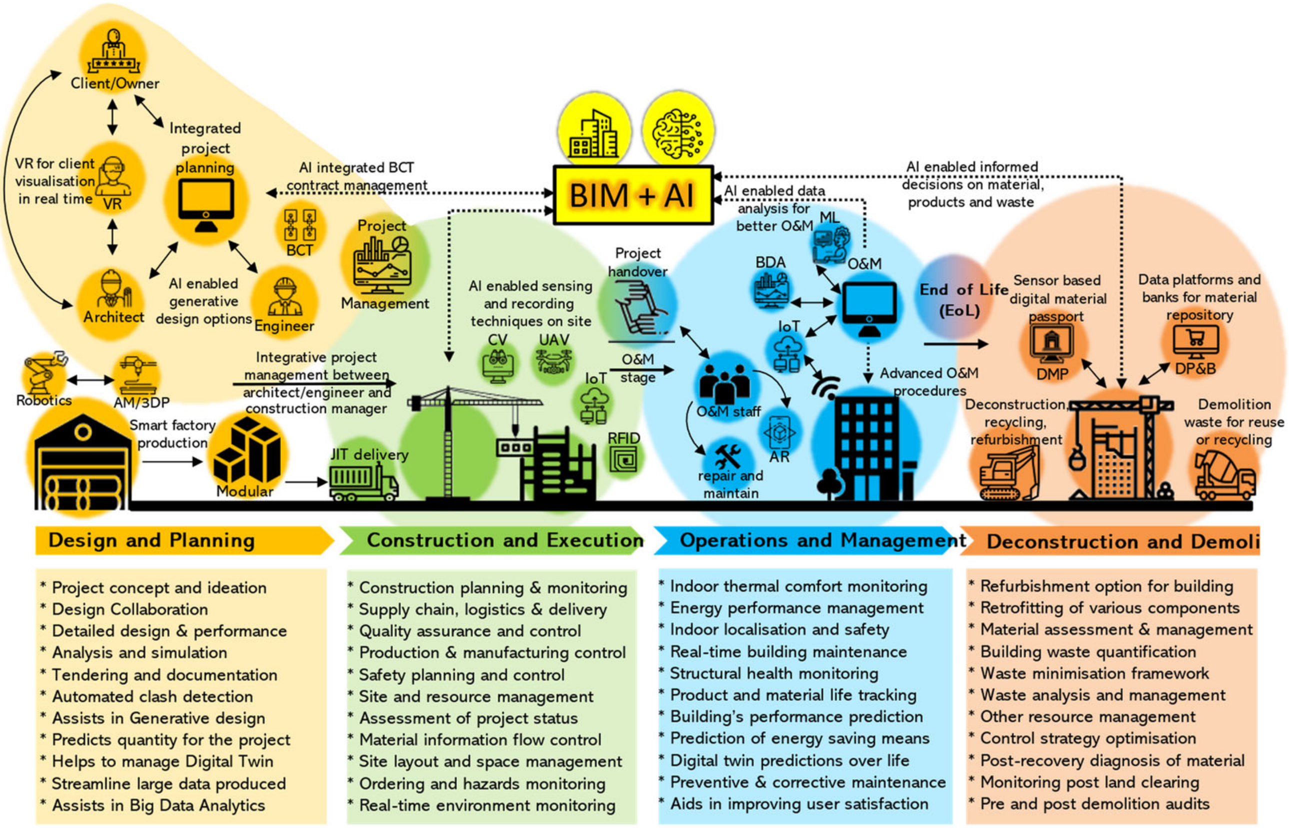


Figure 1. BIM-AI utilisation throughout the construction project lifecycle. VR = Virtual Reality, AM = Additive Manufacturing, 3DP = 3D Printing, BCT = Blockchain Technology, JIT = Just in Time, CV = Computer Vision, UAV = Unmanned Aerial Vehicle, IoT = Internet of Things, RFID = Radio Frequency Identification, BDA = Big Data Analytics, AR = Augmented Reality, DMP = Digital Material Passport, DP&B = Data Platforms and Banks. Note: All icons are from www.freepik.com under free creative common license.

Accordingly, this study aims to investigate the challenges of BIM-AI integration in the construction industry. There are three concomitant objectives:

1. To identify and extract the challenges of the BIM-AI integration;
2. To categorise the challenges of the BIM-AI integration into taxonomies;
3. To prioritise and propose a mitigation strategy map for the vital challenges of BIM-AI integration in the construction industry.

This study uniquely addresses the underexplored challenges of BIM-AI integration by not only categorising and prioritising these challenges, but also proposing practical solutions to mitigate them. The lack of a clear framework for BIM-AI integration has impeded the construction industry from realising its full advantages, such as improved productivity, reduced mistakes, and enhanced decision-making. Through a comprehensive review of the literature, this study brings together current knowledge, recognises gaps, and presents actionable recommendations, enabling the industry to surmount these challenges and seize the opportunities offered by integrated BIM-AI systems.

The following sections of this research are structured in the following manner: Section 2 provides an overview of the methodology employed for the systematic literature review. Section 3 presents the findings, which comprise a Pareto analysis and a mitigation strategy map. Section 4 delves into a discussion of the results, while Section 5 concludes the study with a summary of the most important insights and conclusions.

2. Materials and Methods

2.1. Research Strategy

This study used a systematic literature review (SLR) to identify, prioritise, categorise, and develop mitigation strategies for the challenges of BIM-AI integration in the construction industry. SLR is a transparent, accurate, and robust scientific method for obtaining, analysing, and interpreting the findings of comparable studies to develop new evidence, knowledge, and theory [17,18]. It provides a rigorous methodology for the synthesis of the available evidence [19]. The SLR process involves several stages, including formulating a research question, developing a review protocol, literature sampling, selection of studies, quality assessment, data extraction, data synthesis, and interpreting results [20,21]. Figure 2 shows a flow chart of the research process adopted in the current study.

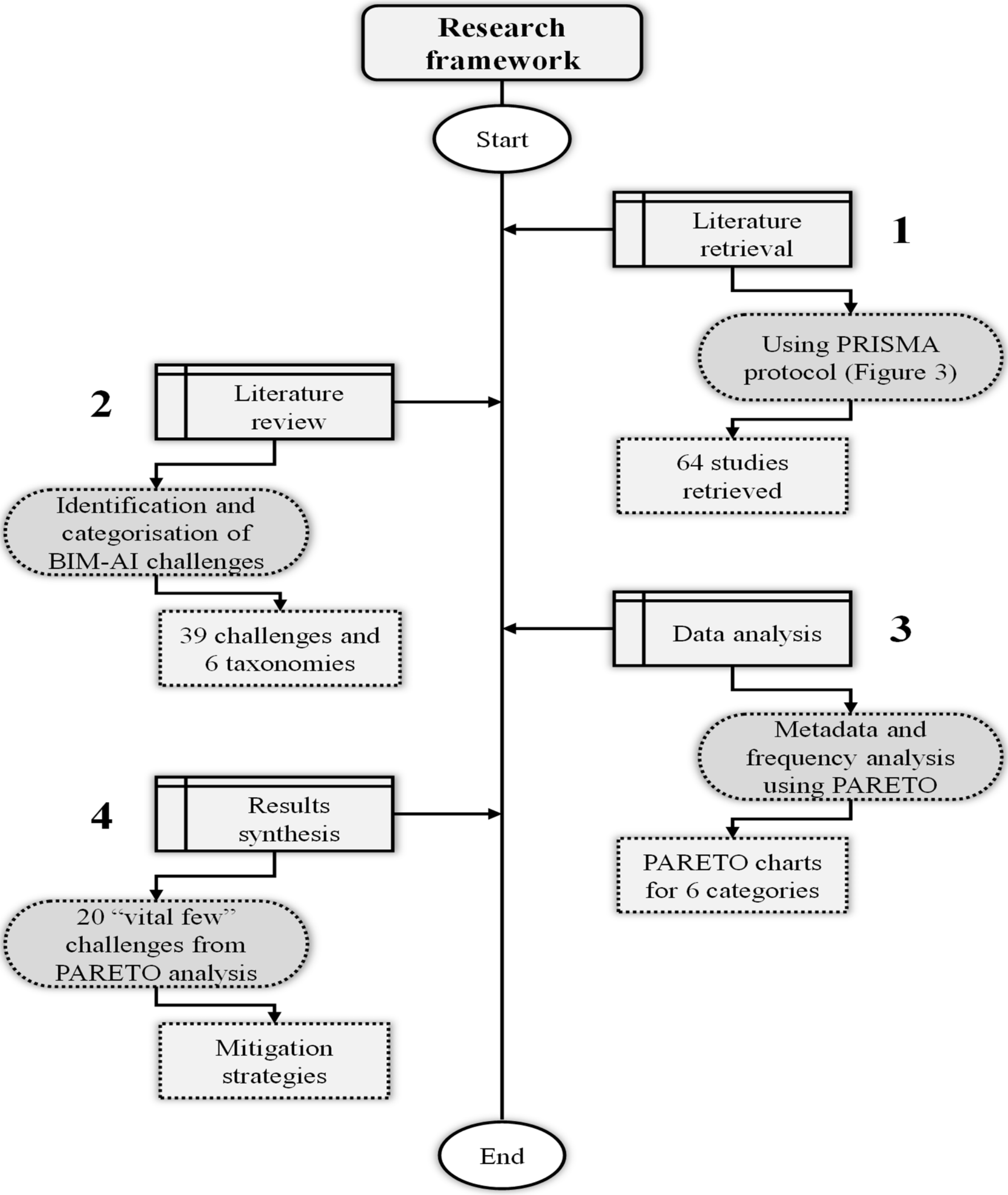


Figure 2. A flowchart of the systematic literature review process in the study.

2.2. Review Protocol

This study developed a written protocol for the review, including a review question, a search strategy, inclusion and exclusion criteria, and a risk of bias assessment following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement protocol. By systematically identifying, screening, and including relevant studies, PRISMA ensures a transparent and comprehensive review process. This methodology enables to extract and synthesise challenges from the literature in a more organised and rigorous manner, reducing ambiguity and providing a clearer understanding of the BIM-AI integration challenges. The primary research questions (RQs) were as follows:

RQ1: What are the challenges of the integration of BIM-AI in the construction industry from existing studies?

RQ2: How can the challenges of BIM-AI integration be categorised into meaningful taxonomies?

RQ3: What strategies can be proposed to mitigate the vital challenges of BIM-AI integration in the construction industry?

The search strategy comprised a selection of literature sources and keywords. The literature sources included the Scopus database complemented with a snowball search (forward and backward snowballing) [22]. Two sets of keywords were used in the literature search to retrieve studies that address the challenges of BIM-AI integration. The eligibility studies (i.e., inclusion and exclusion criteria) included journal articles published in the English language, with full-text access, that addressed the challenges of BIM-AI integration in the construction industry. Articles written in other languages and those without full text were excluded. The study also excluded conference papers and grey literature, including industry and government reports, due to the limited peer review process associated with these sources [23]. The SLR process strictly adhered to PRISMA protocols to minimise the risk of bias and increase scientific validity [18].

2.3. Literature Sampling

The search was conducted on Elsevier's Scopus repository (8 July 2024). Several filters were applied based on the review protocol. The document types were limited to article (ar) and review (re). The language was limited to English, and the source type was limited to journals only. The full search string is given below.

(TITLE (BIM OR "building information model" OR "building information modelling") AND TITLE (ai OR "artificial intelligence" OR "computational intelligence" OR "machine intelligence" OR "machine learning" OR "knowledge-based system" OR "expert system" OR "business intelligence" OR "decision support system" OR "computer vision" OR "digital twin" OR "case-based reasoning" OR "robotics" OR "support vector machine" OR learning OR regression OR "neural network" OR "fuzzy set theory" OR "fuzzy logic" OR algorithm OR "natural language processing")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j")).

The filtered search retrieved 211 articles. After an initial screening of the Titles, Abstracts, and Keywords, 107 potentially relevant articles were identified. These articles were downloaded for full-text evaluation against the inclusion and exclusion criteria. The rigorous full-text evaluation highlighted 37 articles that addressed the challenges of BIM-AI integration. To increase the sample size and achieve a comprehensive coverage of the relevant studies, the 37 relevant articles formed the basis for forward and backward snowball searches [22]. The backward snowballing involved searching the reference lists of the included studies to identify additional relevant articles. The forward snowballing involved using Scopus to track the articles that cited the eligible articles. The new studies identified from the snowballing search became subjects of further forward and backward snowballing until no new studies were found. The snowballing strategy helped gather 27 additional relevant articles, increasing the valid sample size to 64 articles. Figure 3 shows the literature search and selection procedures. Appendix A (Table A1) summarises the references to the reviewed articles.

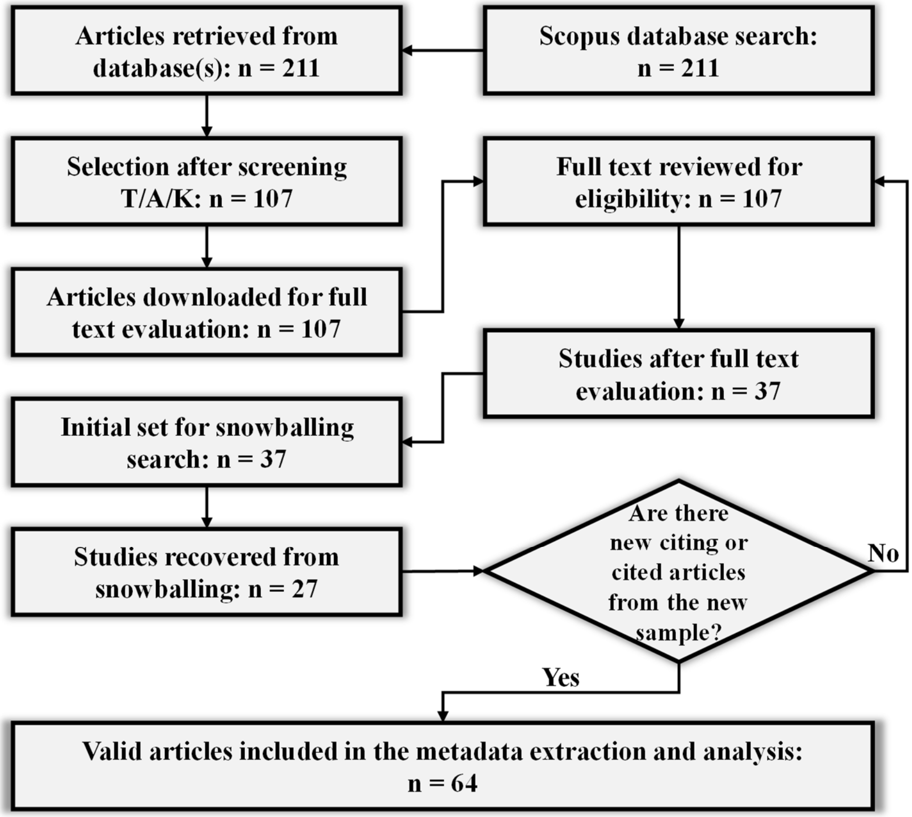


Figure 3. A flowchart of the literature sampling procedure.

2.4. Metadata Extraction and Analysis

The study critically reviewed the eligible articles and extracted relevant metadata, including publication year, research outlet, and the stated challenges of BIM-AI integration. The metadata were recorded in a data summary sheet prepared in Microsoft Excel. The sheet recorded the number of articles that cited each challenge to BIM-AI integration, forming the basis for three levels of analysis: citation frequencies, taxonomies, and prioritisation of challenges. First, the citation frequencies of the challenges were computed from the set of citing articles. The citation frequencies for various challenges were recorded and used as a surrogate indicator to rank the challenges of the BIM-AI integration. Second, the relevant challenges were classified intuitively into taxonomies to generate a structured framework. The mean citation frequencies of the taxonomies of the challenges of the BIM-AI integration were computed using Equation (1).

$$\text{Mean Citation Frequency}\left(\mu_j\right) = \frac{\sum_{j=1}^{n}\left(C_j\right)}{n} \tag{1}$$

where μ_j denotes the mean citation frequency of a taxonomy of the challenges, Cj represents the citation frequency of a challenge in each taxonomy, and n denotes the number of challenges in a taxonomy. The mean citation frequencies were used to rank the taxonomies of the challenges of BIM-AI integration in the construction industry. Lastly, Pareto analysis was conducted to prioritise the vital few challenges in each taxonomy. Pareto analysis ranks data classifications in descending order, from the highest to the lowest citation frequencies [24]. It is based on the heuristic of the "80/20" rule. In a Pareto chart, the total (cumulative) frequency is equated to 100%, such that the "vital few" challenges occupy a substantial amount (80%) and the "trivial many" occupy only the remaining 20% of the cumulative citation frequencies [25]. This study used Pareto charts to identify and develop a conceptual map of the most important challenges of BIM-AI integration in the construction industry. Subsequently, the study developed a mitigation strategy comprising targeted interventions to address the challenges reported in each taxonomy.

3. Results

3.1. Ranking of the Challenges of BIM-AI Integration in the Construction Industry

This study identified thirty-nine (39) challenges to the integration of BIM-AI in the construction industry. Table 1 summarises the frequency of occurrences and ranking of the identified challenges. The top ten most documented challenges are:

1. High cost of software and hardware for integrated BIM-AI solutions;
2. High cost of training and re-engineering for the use of BIM-AI in construction;
3. Resistance to BIM-AI integration in strategic objectives;
4. Shortage of integrated BIM-AI specialists;
5. Inadequate experience in integrating BIM-AI;
6. Limited industry best practice guidelines and standards for BIM-AI integration;
7. Low interest of clients in integrated BIM-AI solutions in construction projects;
8. Interoperability and industry foundation classes issues with integrated BIM-AI solutions;
9. Data quality problems;
10. Unknown return on investment of integrated BIM-AI solutions.

Table 1. Frequency ranking of the challenges of BIM-AI integration.

ID	Challenges	F	Rank
TC	Technical challenges		
TC1	Shortage of integrated BIM-AI specialists	40	4
TC2	Interoperability and industry foundation class issues with integrated BIM-AI solutions	36	8
TC3	Limited compatibility of BIM-AI during the early stages of projects	33	11
TC4	The complexity of the integrated BIM-AI requirements in the project lifecycle	15	28
TC5	Inadequate capabilities to use integrated BIM-AI solutions during design and construction	13	30
TC6	The increased workload required to adopt integrated BIM-AI solutions	13	30
TC7	Difficulties integrating AI with different LODs and dimensions of BIM	6	36
KC	Knowledge-related challenges		
KC1	Inadequate experience in integrating BIM-AI	39	5
KC2	Inadequate training and knowledge of BIM-AI integrated applications in construction projects	31	12
KC3	The unfamiliarity of the project teams and practitioners with BIM-AI integration	19	21
KC4	Poor understanding of BIM-AI requirements in construction projects	17	25
KC5	Insufficient BIM-AI technical knowledge among practitioners	16	26
KC6	Limited understanding of AI models and outcomes among construction professionals	5	38
DC	Data-related challenges		
DC1	Data quality problems	35	9
DC2	Data fragmentation, storage, licensing, and ownership issues	27	14
DC3	Poor BIM-AI data sharing and accessibility in the construction industry	19	21
DC4	Intellectual property rights and data ownership issues	14	29
DC5	Data loss, theft, virus attacks, and cyberattacks	6	36
OC	Organisational challenges		
OC1	Resistance to BIM-AI integration in strategic objectives	43	3
OC2	Lack of support from the top management of the construction organisation	30	13
OC3	Lack of integrated software providers and technological availabilities	26	15
OC4	Incompatibility of industry legacy systems with integrated BIM-AI solutions	20	20
OC5	Inadequate pilot projects and successful business models for integrated BIM-AI solutions	19	21
OC6	Unavailability of BIM-AI integrated software solutions	16	26
OC7	Inadequate network connectivity and power required to handle large data	13	30
MC	Managerial challenges		
MC1	Limited industry best practice guidelines and standards for BIM-AI integration	39	5
MC2	Low interest of clients in integrated BIM-AI solutions in construction projects	38	7
MC3	Lack of legal framework and contractual documents for integrated BIM-AI solutions	26	15

Table 1. *Cont.*

ID	Challenges	F	Rank
MC4	Lack of collaboration among project parties and other stakeholders	25	17
MC5	Extensive managerial changes required to support BIM-AI applications	22	19
MC6	Lack of dispute resolution and litigation protocols for integrated BIM-AI solutions	12	33
MC7	Poor industry risk allocation schemes for integrated BIM-AI solutions	9	35
MC8	Unsupportive project delivery and procurement systems	5	38
FC	Financial challenges		
FC1	High cost of software and hardware for integrated BIM-AI solutions	49	1
FC2	High cost for training and re-engineering for the use of BIM-AI in construction	46	2
FC3	Unknown return on investment of integrated BIM-AI solutions	34	10
FC4	Huge upfront investment costs to adopt integrated BIM-AI solutions	25	17
FC5	Lack of government promotions and financial incentives for integrated BIM-AI applications	18	24
FC6	Unproven project and business benefits of integrated BIM-AI solutions	11	34

3.2. Taxonomies of the Challenges of BIM-AI Integration in Construction

Cluster analysis indicated six taxonomies of the challenges to integrating BIM-AI in the construction industry. These taxonomies are technical, knowledge, data, organisational, managerial, and financial challenges. The labels and clusters assigned to the taxonomies are ultimately subjective and should be treated as conceptual guides rather than discrete categories. These taxonomies form the basis for mean citation and Pareto analyses.

3.2.1. Mean Citation Indices of the Taxonomies of Challenges of BIM-AI Integration

The number and total citation frequencies of the identified challenges facilitate the computation of the mean citation indices of the taxonomies. Figure 4 shows the number (n) of challenges, total citation frequencies (∑), and mean citation frequencies (µ) of the taxonomies, including technical (n = 7, ∑ = 156, µ = 22.29), knowledge (n = 6, ∑ = 127, µ = 21.17), data (n = 5, ∑ = 101, µ = 20.20), organisational (n = 7, ∑ = 167, µ = 23.86), managerial (n = 8, ∑ = 176, µ = 22.00), and financial (n = 6, ∑ = 183, µ = 30.50) challenges.

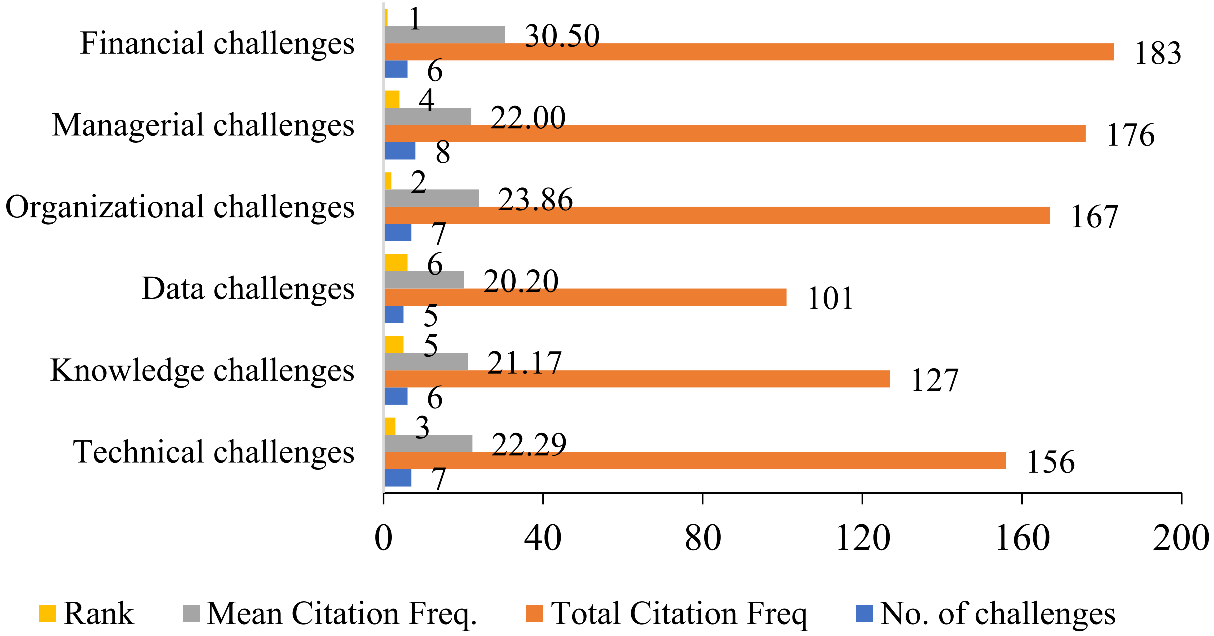


Figure 4. Mean citation ranking of the taxonomies of challenges of BIM-AI integration.

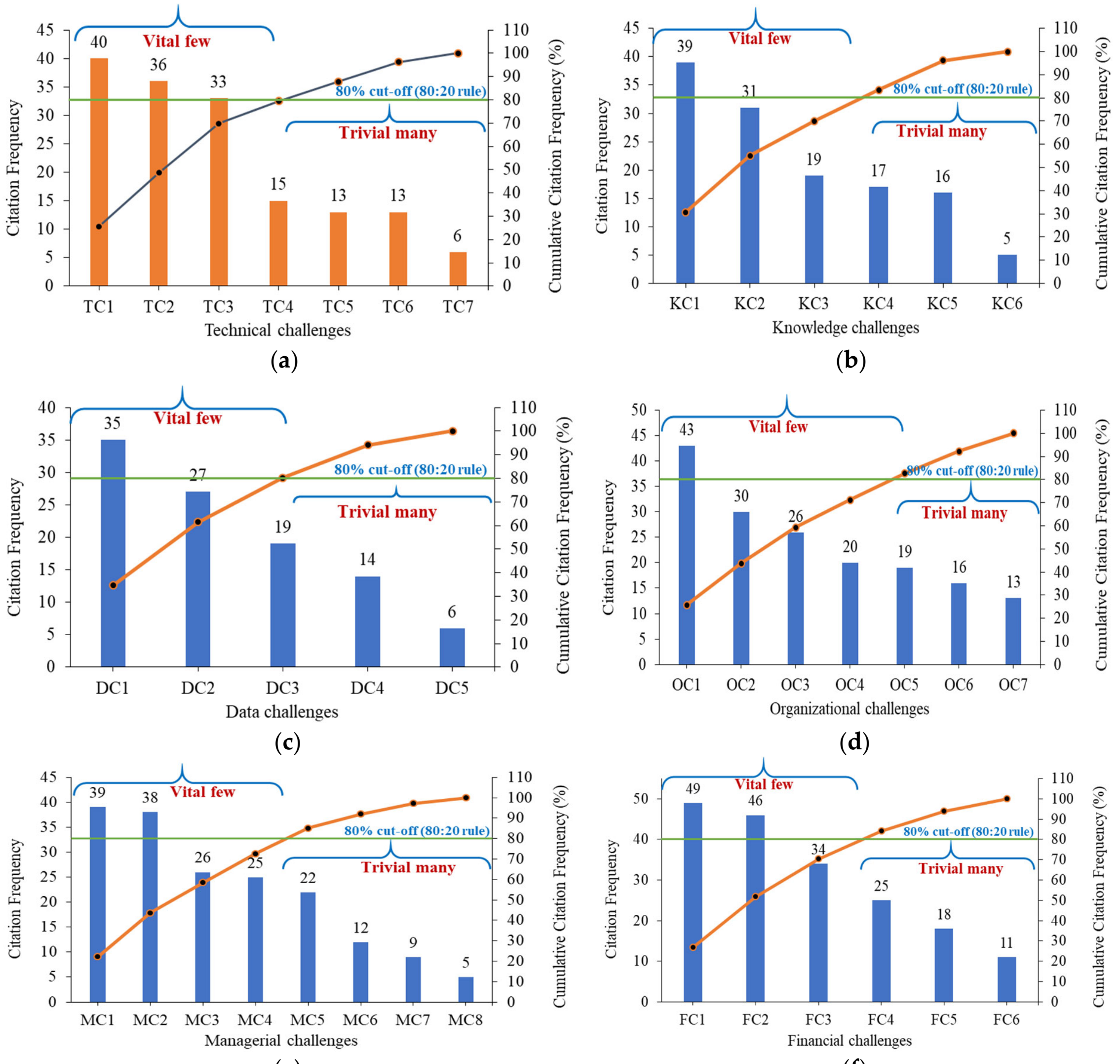
The top three taxonomies with the highest number of challenges are managerial, organisational, and technical challenges. Collectively, the top three most cited taxonomies of the challenges are financial, managerial, and organisational scores. Individually and on average, the mean scores indicate that the top three most profound taxonomies are the financial, organisational, and technical challenges.

3.2.2. Pareto Analysis of the Taxonomies of Challenges of BIM-AI Integration

The following section provides a detailed description of the key challenges identified in each taxonomy through the application of Pareto analysis. The analysis prioritises the most significant challenges by highlighting the "vital few" that have the greatest impact. These vital few challenges are targeted for mitigation strategies, serving as a foundation for focused efforts to address the most pressing issues within each taxonomy.

Technical Challenges

Figure 5a shows the technical challenges to BIM-AI integration in the construction industry. The most important challenges are listed as TC1 to TC3. The technical challenges are associated with the level of understanding, knowledge, and expertise required for successful BIM-AI-integrated applications in construction projects. The successful integration of AI with BIM requires tailored deployment of hardware and software resources [13,14].



(**a**) (**b**)

(**c**) (**d**)

(**e**) (**f**)

Figure 5. Pareto charts of the taxonomies of the challenges to BIM-AI integration. (**a**) Technical challenges; (**b**) knowledge-related challenges; (**c**) data-related challenges; (**d**) organisational challenges; (**e**) managerial challenge; (**f**) financial challenges.

The integration of BIM-AI needs requisite skills and experience. Currently, there is a vast shortage of AI engineers and specialists with design and construction experience in the industry (TC1) [26]. Although there are a few software solutions that provide bespoke AI applications coupled with BIM, organisations resist utilising them due to interoperability and IFC issues with the current BIM software solutions (TC2) [27]. The compatibility issues caused by the interoperability attributes disturb the early-stage integration of BIM-AI in construction projects (TC3) [28]. Not only do compatibility issues hamper the early stages of the project, but additional costs are also incurred when implementing other technologies in the design and construction stage. The additional workforce needed also reduce the utilisation and integration of BIM-AI within construction organisations (TC5) [28].

Additionally, due to the tight schedule of the project, the restrictions in terms of the capability of construction companies, and the complexities involved with BIM-AI integration, the overall adoption level is low. This reduces the technological acumen of the organisation (TC4) [7,29]. The cultural, managerial, knowledge, and organisational challenges within the companies further add fuel to the low-burning desire for learning and training with innovative BIM-AI prospects within construction companies [27]. The highlighted technical challenges, along with a traditional mindset, stifle the adoption of the BIM-AI processes in construction projects.

Knowledge-Related Challenges

Figure 5b shows the knowledge-related challenges of BIM-AI integration in the construction industry. The most important challenges are listed from KC1 to KC3. The knowledge-related challenges are linked to gaps and deficits in skills, awareness, and understanding of how to enable BIM-AI integration in the construction industry. The effective application and utilisation of BIM-AI-integrated attributes in a project require bespoke knowledge within the organisation. However, the knowledge distribution becomes difficult to implement on a wide scale [30]. Organisations and relevant stakeholders do not have the appropriate knowledge, experience, and capabilities to tailor tasks related to BIM-AI synergy (KC1) [26]. For instance, there is ill-informed and tenuous knowledge as to how to leverage BIM-AI to generate innovative, feasible, and best-working architecture and structural designs [31]. There is a severe challenge of finding AI experts with high knowledge and understanding in the construction industry. Thus, companies cannot provide related knowledge, training, and technical know-how of BIM-AI integration skills (KC2) [13].

The possibilities of BIM-AI integration are at a rudimentary scale. Construction organisations find such integration difficult and unfamiliar due to a lack of information, drivers, enablers, best practice guidelines, and proven studies (KC3) [26,27]. These challenges around knowledge call for open sharing platforms and providers that respective government or industry powerhouses may facilitate. Nevertheless, there is a huge shortage of such platforms and mitigations to deliver custom-based BIM-AI solutions in the construction industry [28]. These knowledge gaps and limitations in understanding the full potential of BIM-AI capabilities hinder the wide acceptance and adoption in the construction industry.

Data-Related Challenges

Figure 5c shows the data-related challenges of BIM-AI integration in the construction industry. The most important challenges are listed as DC1 to DC3. Due to the absence of concrete rules and regulations based on ethics and governance of AI usage by government and regulatory bodies, construction companies resist implementing BIM-AI integrated solutions and face data quality problems (DC1) [13]. The unfettered AI implementation could lead to issues with data and information security in the BIM model. This can compromise data security and lead to data theft and data loss concerns (DC5) [32]. Moreover, IP issues, cyber-crimes, data and information phishing, intrusion by hackers, and security become critical when dealing with sensitive projects, thus intensifying the requirements for proper legal regulations (DC2) [26]. Additionally, the software providers need to assure the construction companies of the licensing issues in the case of security attacks [1].

Due to the lack of AI-related regulatory standards for utilisation with BIM, different stakeholders are reluctant to hone AI capabilities within the project as the norms for data and information sharing are unidentified (DC3) [10]. Further, client ignorance due to perceived challenges in terms of extra time and cost for the project is overshadowed by stakeholders' opinions, resulting in a business-as-usual theory for most construction projects [28]. This conforms with the famous "If it is not broken, don't fix it" mindset of traditional construction organisations. These significant data-related challenges pose a threat to organisations that rely on BIM-AI synergy solutions and thus limit the adoption on a wide scale.

Organisational Challenges

Figure 5d shows the organisational challenges to BIM-AI integration in the construction industry. The most important challenges are listed as OC1 to OC4. Organisational challenges relate to structure, infrastructure, policy, management, governance, culture, and facilities provided by construction organisations. The lack of management awareness and traditional approaches to planning and administration relegates BIM-AI integration in most construction companies' strategic objectives (OC1) [33]. The lack of support from the top management to develop effective, conducive business models restricts the decision-making for BIM-AI implementation within the company (OC2) [26]. Further, the change management that requires the shift from business-as-usual to a more disruptive ideology of BIM-AI utilisation is hampered by a traditional mindset and culture within the organisation [15,16].

Moreover, there is a stark shortage of software providers specialised in delivering AI solutions within the BIM environment (tools and applications) (OC3) [7]. Additionally, using external software solutions brings in data fragmentation issues as the ethics, governance, and regulations are unknown while integrating different AI solutions within the BIM paradigms [34]. Further, the web of various stakeholders in a construction project makes it difficult to find parties utilising BIM-integrated AI in their respective tasks; thus, compatibility issues arise (OC4). These reported and cited organisational challenges limit the readiness and capabilities for smooth operation and allocation of resources in developing and adopting BIM-AI solutions.

Managerial Challenges

Figure 5e shows the managerial challenges related to BIM-AI integration in the construction industry. The most important challenges are listed as MC1 to MC4. Managerial challenges are ill-informed decisions, lack of business strategies, and weak coordination and communication within organisations that effectively slackens BIM-AI integration. A managerial barrier exists where limited practice guidelines for AI implementation in the different stages of a construction project are available (MC1) [16]. Due to the absence of clear rules and regulations based on ethics and governance of AI usage by government bodies, construction companies resist implementing integrated BIM-AI solutions [13].

Further, client ignorance due to perceived challenges in terms of extra time and cost for the project is overshadowed due to differing stakeholders' opinions, resulting in the business-as-usual theory for most of the construction projects (MC2) [28]. The availability or absence of bespoke legal systems, frameworks, and suitable environments affects the acceptance of BIM-AI solutions within the organisations. This further inhibits the rational and measurable outcomes (MC3) [12,28]. Finally, stakeholder management is another significant challenge that impedes the success of a construction project. This is because the issue of communication and collaboration between different stakeholders is inherited in the construction industry (MC4) [35,36]. These immature business models and processes present unprecedented challenges, and stifle the transition to BIM-AI and make it difficult.

Financial Challenges

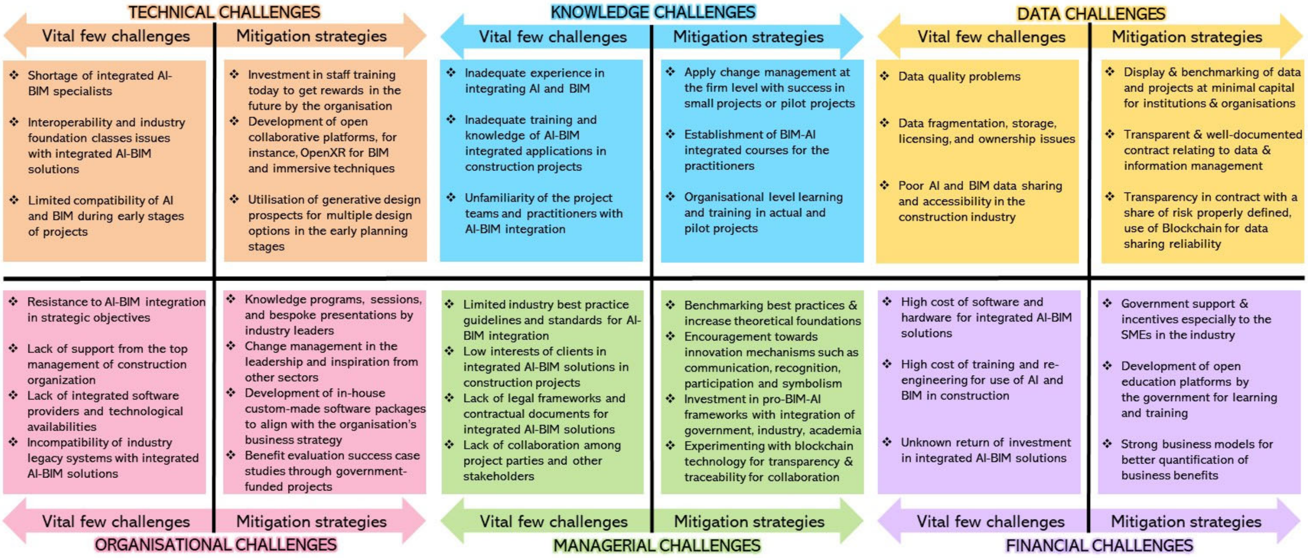
Figure 5f shows the financial challenges related to BIM-AI integration in the construction industry. The most important challenges are listed as FC1 to FC3. The monetary disincentives in terms of funding constraints, investment challenges, and capital allocation impedes the successful deployment of BIM-AI integration within construction projects and organisations [2,14]. The high upfront cost of software installation is a significant inhibitor for many construction companies (FC1) [27]. The integration of AI attributes requires bespoke coding and computational skills, which need a significant amount of finance for training the workforce within the design and construction companies (FC2) [7,13].

The return on investment in BIM-AI solutions is unknown, and organisations fear it will disturb their business values. With minimal use cases, success stories, and disruptive companies in the construction domain, the business market is unpredictable, and value is difficult to measure (FC3) [27]. Additionally, the high cost of owning and utilising BIM-AI integrated solutions is challenging for construction companies. This is because the integrative capabilities are not mature enough and need constant investment to be up to date with the rising advancement of the trends (FC4) [33]. These financial challenges render BIM-AI integration complex and unattractive to the key stakeholders of the construction industry.

3.3. Mitigation Strategy Map for BIM-AI Challenges in the Construction Industry

The Pareto analysis demarcated the top challenges in the various taxonomies which hinder the integration of BIM-AI in the construction industry. The reviewed studies implicitly and explicitly discussed strategies to address the various presented challenges. However, the documented strategies are scattered in the corpus of the literature, incubating a challenge for policymakers and industry practitioners to implement targeted interventions. The critical evaluation of the literature formed the basis to identify, compile, and allocate the strategies to the various challenges, resulting in more targeted intervention mechanisms presented in this study.

Figure 6 presents the mitigation strategy map, matching targeted interventions and strategies to the vital challenges in the various taxonomies identified in this study. The literature analysis revealed that most of the interventions are already implemented in practice, lending further credence to the feasibility and relevance of the strategy maps.



TECHNICAL CHALLENGES

Vital few challenges	Mitigation strategies
❖ Shortage of integrated AI-BIM specialists ❖ Interoperability and industry foundation classes issues with integrated AI-BIM solutions ❖ Limited compatibility of AI and BIM during early stages of projects	❖ Investment in staff training today to get rewards in the future by the organisation ❖ Development of open collaborative platforms, for instance, OpenXR for BIM and immersive techniques ❖ Utilisation of generative design prospects for multiple design options in the early planning stages

KNOWLEDGE CHALLENGES

Vital few challenges	Mitigation strategies
❖ Inadequate experience in integrating AI and BIM ❖ Inadequate training and knowledge of AI-BIM integrated applications in construction projects ❖ Unfamiliarity of the project teams and practitioners with AI-BIM integration	❖ Apply change management at the firm level with success in small projects or pilot projects ❖ Establishment of BIM-AI integrated courses for the practitioners ❖ Organisational level learning and training in actual and pilot projects

DATA CHALLENGES

Vital few challenges	Mitigation strategies
❖ Data quality problems ❖ Data fragmentation, storage, licensing, and ownership issues ❖ Poor AI and BIM data sharing and accessibility in the construction industry	❖ Display & benchmarking of data and projects at minimal capital for institutions & organisations ❖ Transparent & well-documented contract relating to data & information management ❖ Transparency in contract with a share of risk properly defined, use of Blockchain for data sharing reliability

Vital few challenges	Mitigation strategies
❖ Resistance to AI-BIM integration in strategic objectives ❖ Lack of support from the top management of construction organization ❖ Lack of integrated software providers and technological availabilities ❖ Incompatibility of industry legacy systems with integrated AI-BIM solutions	❖ Knowledge programs, sessions, and bespoke presentations by industry leaders ❖ Change management in the leadership and inspiration from other sectors ❖ Development of in-house custom-made software packages to align with the organisation's business strategy ❖ Benefit evaluation success case studies through government-funded projects

ORGANISATIONAL CHALLENGES

Vital few challenges	Mitigation strategies
❖ Limited industry best practice guidelines and standards for AI-BIM integration ❖ Low interests of clients in integrated AI-BIM solutions in construction projects ❖ Lack of legal frameworks and contractual documents for integrated AI-BIM solutions ❖ Lack of collaboration among project parties and other stakeholders	❖ Benchmarking best practices & increase theoretical foundations ❖ Encouragement towards innovation mechanisms such as communication, recognition, participation and symbolism ❖ Investment in pro-BIM-AI frameworks with integration of government, industry, academia ❖ Experimenting with blockchain technology for transparency & traceability for collaboration

MANAGERIAL CHALLENGES

Vital few challenges	Mitigation strategies
❖ High cost of software and hardware for integrated AI-BIM solutions ❖ High cost of training and re-engineering for use of AI and BIM in construction ❖ Unknown return of investment in integrated AI-BIM solutions	❖ Government support & incentives especially to the SMEs in the industry ❖ Development of open education platforms by the government for learning and training ❖ Strong business models for better quantification of business benefits

FINANCIAL CHALLENGES

Figure 6. Mitigation strategies for the top challenges to BIM-AI integration.

For instance, the challenge of integrating BIM and AI during early project stages (TC3) is largely due to differences in platforms and data formats between the two systems [14]. To overcome this, the implementation of generative design enables a range of design scenarios to be examined from the outset, thereby promoting greater alignment and compatibility as the project advances [37]. This approach not only enhances collaboration but also minimises the potential for integration problems emerging later in the project lifecycle.

Additionally, inadequate training and knowledge regarding BIM-AI integrated applications in the construction industry (KC2) represents a significant challenge to effective implementation [1]. A significant number of practitioners are presently lacking the necessary expertise to utilise these advanced technologies to their full potential. To address this issue, it is essential to establish specialised BIM-AI integrated courses that are specifically designed to equip practitioners with the requisite foundational knowledge and practical skills [14]. Such courses will enable construction teams to effectively apply BIM-AI solutions in their projects, thereby enhancing overall project performance and outcomes.

Further, data quality issues (DC1) pose a significant challenge to the dependability of BIM-AI systems. Inadequate data quality can result in incorrect outputs and reduced confidence in the integrated solutions [16]. The suggested solution includes the display and benchmarking of data and projects at a minimal cost for academic institutions and organisations. By promoting transparency and benchmarking, this strategy helps identify areas in need of improvement for data quality [1].

Similarly, resistance to incorporating BIM-AI into strategic objectives (OC1) often originates from a lack of comprehension or apprehension toward change among vital stakeholders [7]. This resistance can impede the implementation of BIM-AI solutions within an organisation. To mitigate this, educational programs, seminars, and tailored presentations delivered by industry experts can be implemented to educate and inform management and staff about the advantages and practical applications of BIM-AI [13]. By showcasing successful case studies and demonstrating concrete benefits, these initiatives can help align strategic objectives with technological advancements.

Moreover, the lack of comprehensive industry best practice guidelines and standards for the integration of BIM-AI (MC1) hampers the adoption of these technologies [12]. In the absence of clear standards, project teams may find it challenging to implement BIM-AI solutions efficiently. To address this issue, a mitigation strategy is proposed that involves benchmarking existing best practices and enhancing theoretical foundations, which can serve as a guide for organisations in the development and application of BIM-AI standards [7]. This approach advocates for the establishment of standardised frameworks that facilitate better collaboration and integration across projects.

Lastly, the significant challenge presented by the high cost of software and hardware for integrated BIM-AI solutions (FC1) is particularly problematic for small and medium-sized enterprises (SMEs) [12]. These expenses can be prohibitively limiting, hindering the ability of smaller organisations to embrace BIM-AI technologies. To overcome this challenge, a recommended strategy involves government backing and incentives, especially for SMEs in the industry. By providing financial assistance, such as subsidies or tax incentives, governments can alleviate the financial strain on these companies, enabling them to invest in the necessary software and hardware [38].

Addressing the various challenges in BIM-AI integration through targeted mitigation strategies not only enhances technical compatibility, knowledge, and organisational readiness, but also improves data quality and ensures financial feasibility, ultimately driving successful implementation across the construction industry through addressing these issues [39,40].

4. Discussion

The integration of BIM-AI in the construction industry presents a variety of unprecedented challenges, significantly impeding its widespread adoption. Analysis reveals that these challenges are deeply embedded in the industry's existing technical limitations, organisational structures, and financial constraints. Specifically, the findings highlight a fundamental deficit in comprehension regarding the potential benefits of BIM-AI synergy, which is exacerbated by a lack of practical, evidence-based studies demonstrating the value it can bring to project efficiency, cost reduction, and decision-making processes. Addressing these barriers necessitates a concerted effort from industry stakeholders to realign strategic objectives with the technological advancements of BIM-AI, as well as to implement targeted interventions aimed at overcoming these critical impediments.

The challenges identified in this study reveal interconnected technical, knowledge, data, organisational, managerial, and financial issues that collectively constitute a multifaceted barrier to BIM-AI integration. Rather than considering these challenges in isolation, our analysis suggests that addressing them holistically is crucial for the successful adoption of BIM-AI. For instance, technical challenges cannot be decoupled from knowledge and organisational challenges. The dearth of proficient BIM-AI specialists not only indicates a technical deficiency but also underscores the industry's challenge in attracting and retaining personnel capable of implementing advanced digital solutions. This lack of expertise directly contributes to organisational inertia and resistance to change.

Another significant aspect of this research is the emphasis on data governance and legal frameworks as critical factors influencing BIM-AI integration. While previous studies have acknowledged issues such as data fragmentation and ownership, this study clarifies how these challenges are intrinsically linked to organisational and managerial capacities. The absence of legal protocols for managing data exchange between BIM and AI systems renders firms susceptible to disputes and data security risks. This finding underscores an urgent need for policymakers to establish robust legal frameworks to facilitate data sharing and collaboration, a topic that has been insufficiently explored in the BIM-AI literature.

Financial challenges, while widely acknowledged, are examined in this study through a more comprehensive perspective. The findings demonstrate how financial constraints are directly correlated with knowledge gaps and organisational readiness. The industry's emphasis on short-term cost reduction, rather than long-term value creation, exacerbates the financial challenges associated with BIM-AI integration. The reluctance to invest in workforce training and upskilling, for instance, increases implementation costs and diminishes the potential for return on investment. This holistic view of financial challenges provides a more nuanced understanding of how these challenges reinforce one another and why they persist.

A significant characteristic of this study is the formulation of targeted mitigation strategies. Rather than simply listing challenges, we present a thorough structure that matches specific approaches with the most pressing concerns. This methodical approach yields actionable insights for industry professionals and decision-makers, underscoring the necessity for customised interventions to prevent these challenges. The mitigation strategies serve to guide the prioritisation of investments, training programmes, and legal reforms, thereby ensuring that resources are allocated towards the most pressing challenges.

Furthermore, this study shifts the perspective on BIM-AI integration from being solely a technological advancement to being part of a larger organisational transformation. Successful integration necessitates more than merely adopting new tools, and it requires changes in leadership, culture, and business models. This research challenges the conventional view of BIM-AI as a purely technical implementation, proposing that its success is contingent upon a broader transformation of organisational strategies and processes.

The findings of the study have theoretical, managerial, and policy implications. Theoretically, this study is a pioneering attempt to establish a comprehensive checklist of the challenges and constraints to BIM-AI integration in the construction industry. The identified challenges form the basis for future studies. The developed taxonomies of the challenges constitute the building blocks for theorising the inertia associated with the BIM-AI integration. Thus, the findings provide a more holistic understanding of why the widespread integration of BIM-AI is stifled in the construction industry.

The managerial implications of the findings are two-fold. First, the study provides construction organisations and project teams with a brief understanding of the benefits of BIM-AI integration through the lifecycle of construction projects. Second, it highlights the organisational, managerial, and technical changes required to leverage the vast opportunities associated with the BIM-AI integrations. The targeted intervention mechanisms constitute the starting points for construction organisations and firms to explore BIM-AI integration in the construction industry. The findings also provide policymakers and relevant stakeholders with the financial and data changes required to create an enabling environment for BIM-AI integration in the construction industry.

5. Conclusions

This study investigated the challenges to the integration of BIM-AI in the construction industry. The study relied on Scopus and the snowballing search strategy to identify sixty-four (64) studies addressing the challenges of BIM-AI integration in the construction industry. The included studies were examined using frequency analysis, mean citation ranking, and Pareto analysis. The frequency analysis revealed thirty-nine (39) challenges. The top five most-cited challenges and constraints to the BIM-AI integration are the high cost of software and hardware for integrated BIM-AI solutions, the high cost of training and re-engineering for the use of BIM-AI in construction, resistance to BIM-AI integration in strategic objectives, shortage of integrated BIM-AI specialists, and inadequate experience in integrating BIM-AI. Further, a cluster analysis derived six taxonomies of the challenges of the integration of BIM-AI in the construction industry. These taxonomies include technical ($n = 7$, $\sum = 156$, $\mu = 22.29$), knowledge ($n = 6$, $\sum = 127$, $\mu = 21.17$), data ($n = 5$, $\sum = 101$, $\mu = 20.20$), organisational ($n = 7$, $\sum = 167$, $\mu = 23.86$), managerial ($n = 8$, $\sum = 176$, $\mu = 22.00$), and financial ($n = 6$, $\sum = 183$, $\mu = 30.50$) challenges. A Pareto analysis revealed twenty (20) vital challenges and constraints to the BIM-AI integration in the construction industry. The study identified and matched targeted interventions to address the vital challenges, resulting in a novel mitigation strategy map for enabling BIM-AI integration in the construction industry.

This study developed taxonomies of the challenges, providing a more holistic understanding of the competing issues stifling BIM-AI integration. It offers construction organisations and stakeholders the knowledge of the relevant changes required and strategies to successfully integrate BIM-AI in the construction industry. The research presents a comprehensive framework for addressing the vital challenges to the integration of BIM and AI, along with corresponding mitigation strategies. This framework may serve as a reference for policymakers in developing guidance mechanisms, and regulatory measures to create an environment favourable to the adoption of BIM-AI technologies within the construction sector. However, one of the limitations of this study was that it exclusively utilised the Scopus database for identifying pertinent articles, which potentially may have diminished the scope of the literature review.

Nonetheless, future research can perform modelling of the causal relationships between identified challenges to comprehend their interdependencies and compound effects. Additionally, including industry stakeholders' insights via interviews or surveys could enhance the understanding of practical challenges and refine mitigation strategies. Last but not the least, longitudinal studies tracking the impact of BIM-AI integration over time would also offer valuable insights into long-term benefits and challenges, thereby guiding informed decision-making in the industry.

Author Contributions: Conceptualization, A.A.K.; methodology, A.A.K.; software, A.A.K.; validation, A.A.K.; formal analysis, A.A.K.; investigation, A.A.K.; resources, A.A.K.; data curation, A.A.K.; writing—original draft preparation, A.A.K.; writing—review and editing, A.A.K., A.O.B., M.A. and F.U.; visualization, A.A.K.; supervision, F.U.; project administration, F.U.; funding acquisition, F.U. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: All data are available from the first author and can be shared with interested readers upon reasonable requests.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. List of reviewed articles.

ID	Reference	ID	Reference	ID	Reference
1	Heidari et al., 2024 [1]	23	Khawaja and Mustapha 2021 [29]	45	Babatunde and Ekundayo 2019 [41]
2	Behzad et al., 2024 [31]	24	Babatunde et al., 2021 [36]	46	Marefat et al., 2019 [42]
3	Rangasamy and Yang, 2024 [2]	25	Arroteia et al., 2021 [43]	47	Liao et al., 2019 [44]
4	Abdulfattah et al., 2023 [8]	26	Wu et al., 2021 [35]	48	Zhou et al., 2019 [45]
5	Zhang et al., 2022 [14]	27	El Hajj et al., 2021 [46]	49	Gamil and Rahman 2019 [47]
6	Singh et al., 2022 [15]	28	Al-Yami and Sanni-Anibire 2021 [48]	50	Oesterreich and Teuteberg 2019 [49]
7	Pedral Sampaio et al., 2022 [16]	29	Khawaja and Mustapha 2021 [29]	51	Blay et al., 2019 [50]
8	Durdyev et al. 2022 [51]	30	Alemayehu et al., 2021 [52]	52	Chan et al., 2019 [53]
9	Hyarat et al., 2022 [54]	31	Ademci and Gundes 2021 [55]	53	Dao et al., 2019 [56]
10	Olanrewaju et al., 2022 [57]	32	Olanrewaju et al., 2020 [58]	54	Fitriani et al., 2019 [59]
11	Ma et al., 2022 [60]	33	Mostafa et al., 2020 [61]	55	Elagiry et al., 2019 [62]
12	Saka and Chan 2021 [63]	34	Saka and Chan 2020 [64]	56	Dao et al., 2019 [56]
13	Munir et al., 2021 [65]	35	Farooq et al., 2020 [66]	57	Olawumi et al., 2018 [67]
14	Lesniak et al., 2021 [68]	36	Al-Hammadi and Tian 2020 [69]	58	Hatem et al., 2018 [70]
15	Umar 2021 [71]	37	Van Roy and Firdaus 2020 [72]	59	Belayutham et al., 2018 [73]
16	Evans and Farrell 2021 [74]	38	Ma et al., 2020 [75]	60	Costin et al., 2018 [76]
17	Hire et al., 2021 [77]	39	Deng et al., 2020 [78]	61	Sreelakshmi et al., 2017 [79]
18	Olugboyega and Windapo 2021 [80]	40	Tan et al., 2019 [81]	62	Bosch-Sijtsema et al., 2017 [82]
19	Manzoor et al., 2021 [83]	41	Oraee et al., 2019 [84]	63	Li et al., 2017 [85]
20	Nguyen and Nguyen 2021 [86]	42	Li et al., 2019 [87]	64	Enshassi et al., 2016 [88]
21	Durdyev et al., 2021 [89]	43	Zhang et al., 2019 [90]	-	
22	Casasayas et al., 2021 [91]	44	Dixit et al., 2019 [92]		

References

1. Heidari, A.; Peyvastehgar, Y.; Amanzadegan, M. A Systematic Review of the BIM in Construction: From Smart Building Management to Interoperability of BIM & AI. *Archit. Sci. Rev.* **2024**, *67*, 237–254. [CrossRef]
2. Rangasamy, V.; Yang, J.-B. The Convergence of BIM, AI and IoT: Reshaping the Future of Prefabricated Construction. *J. Build. Eng.* **2024**, *84*, 108606. [CrossRef]
3. Sacks, R.; Eastman, C.; Lee, G.; Teicholz, P. *BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors*, 3rd ed.; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2018; ISBN 9780470185285.
4. Barlish, K.; Sullivan, K. How to Measure the Benefits of BIM—A Case Study Approach. *Autom. Constr.* **2012**, *24*, 149–159. [CrossRef]
5. Succar, B. Building Information Modelling Framework: A Research and Delivery Foundation for Industry Stakeholders. *Autom. Constr.* **2009**, *18*, 357–375. [CrossRef]
6. Azhar, S. Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. *Leadersh. Manag. Eng.* **2011**, *11*, 241–252. [CrossRef]
7. Sacks, R.; Girolami, M.; Brilakis, I. Building Information Modelling, Artificial Intelligence and Construction Tech. *Dev. Built Environ.* **2020**, *4*, 100011. [CrossRef]
8. Abdulfattah, B.S.; Abdelsalam, H.A.; Abdelsalam, M.; Bolpagni, M.; Thurairajah, N.; Perez, L.F.; Butt, T.E. Predicting Implications of Design Changes in BIM-Based Construction Projects through Machine Learning. *Autom. Constr.* **2023**, *155*, 105057. [CrossRef]
9. Zabin, A.; González, V.A.; Zou, Y.; Amor, R. Applications of Machine Learning to BIM: A Systematic Literature Review. *Adv. Eng. Inform.* **2022**, *51*, 101474. [CrossRef]
10. McAleenan, P. Moral Responsibility and Action in the Use of Artificial Intelligence in Construction. *Proc. Inst. Civ. Eng. Manag. Procure. Law* **2020**, *173*, 166–174. [CrossRef]
11. Makarius, E.E.; Mukherjee, D.; Fox, J.D.; Fox, A.K. Rising with the Machines: A Sociotechnical Framework for Bringing Artificial Intelligence into the Organization. *J. Bus. Res.* **2020**, *120*, 262–273. [CrossRef]
12. Pan, Y.; Zhang, L. Roles of Artificial Intelligence in Construction Engineering and Management: A Critical Review and Future Trends. *Autom. Constr.* **2021**, *122*, 103517. [CrossRef]
13. Abioye, S.O.; Oyedele, L.O.; Akanbi, L.; Ajayi, A.; Davila Delgado, J.M.; Bilal, M.; Akinade, O.O.; Ahmed, A. Artificial Intelligence in the Construction Industry: A Review of Present Status, Opportunities and Future Challenges. *J. Build. Eng.* **2021**, *44*, 103299. [CrossRef]

14. Zhang, F.; Chan, A.P.C.; Darko, A.; Chen, Z.; Li, D. Integrated Applications of Building Information Modeling and Artificial Intelligence Techniques in the AEC/FM Industry. *Autom. Constr.* **2022**, *139*, 104289. [CrossRef]
15. Singh, M.M.; Deb, C.; Geyer, P. Early-Stage Design Support Combining Machine Learning and Building Information Modelling. *Autom. Constr.* **2022**, *136*, 104147. [CrossRef]
16. Pedral Sampaio, R.; Aguiar Costa, A.; Flores-Colen, I. A Systematic Review of Artificial Intelligence Applied to Facility Management in the Building Information Modeling Context and Future Research Directions. *Buildings* **2022**, *12*, 1939. [CrossRef]
17. Higgins, J.P.T.; Thomas, J.; Chandler, J.; Cumpston, M.; Li, T.; Page, M.J.; Welch, V.A. *Cochrane Handbook for Systematic Reviews of Interventions*, 2nd ed.; The Cochrane Collaboration and John Wiley & Sons Ltd.: Hoboken, NJ, USA, 2019; ISBN 9781119536628.
18. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRIsMa Statement. *PLoS Med.* **2009**, *6*, e1000097. [CrossRef] [PubMed]
19. Khan, A.; Sepasgozar, S.; Liu, T.; Yu, R. Integration of Bim and Immersive Technologies for Aec: A Scientometric-swot Analysis and Critical Content Review. *Buildings* **2021**, *11*, 126. [CrossRef]
20. Levy, Y.; Ellis, T.J. A Systems Approach to Conduct an Effective Literature Review in Support of Information Systems Research. *Informing Sci. J.* **2006**, *9*, 181–212. [CrossRef]
21. Webster, J.; Watson, R.T. Analyzing the Past To Prepare for the Future: Writing a Literature Review. *MIS Q.* **2002**, *26*, xiii. [CrossRef]
22. Wohlin, C. Guidelines for Snowballing in Systematic Literature Studies and a Replication in Software Engineering. In Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering—EASE '14, London, UK, 13–14 May 2014; Association for Computing Machinery (ACM): London, UK, 2014; pp. 1–10.
23. Sajid, Z.W.; Aftab, U.; Ullah, F. Barriers to Adopting Circular Procurement in the Construction Industry: The Way Forward. *Sustain. Futur.* **2024**, *8*, 100244. [CrossRef]
24. Craft, R.C.; Leake, C. The Pareto Principle in Organizational Decision Making. *Manag. Decis.* **2002**, *40*, 729–733. [CrossRef]
25. Powell, T.; Sammut-Bonnici, T. Pareto Analysis. In *Wiley Encyclopedia of Management*; John Wiley & Sons: Hoboken, NJ, USA, 2014; pp. 1–2. ISBN 9781118785317.
26. Regona, M.; Yigitcanlar, T.; Xia, B.; Li, R.Y.M. Opportunities and Adoption Challenges of AI in the Construction Industry: A PRISMA Review. *J. Open Innov. Technol. Mark. Complex.* **2022**, *8*, 45. [CrossRef]
27. Rodrigues, F.; Alves, A.D.; Matos, R. Construction Management Supported by BIM and a Business Intelligence Tool. *Energies* **2022**, *15*, 3412. [CrossRef]
28. Darko, A.; Chan, A.P.C.; Adabre, M.A.; Edwards, D.J.; Hosseini, M.R.; Ameyaw, E.E. Artificial Intelligence in the AEC Industry: Scientometric Analysis and Visualization of Research Activities. *Autom. Constr.* **2020**, *112*, 103081. [CrossRef]
29. Khawaja, E.U.; Mustapha, A. Mitigating Disputes and Managing Legal Issues in the Era of Building Information Modelling. *J. Constr. Dev. Ctries.* **2021**, *26*, 111–130. [CrossRef]
30. Deng, M.; Menassa, C.C.; Kamat, V.R. From BIM to Digital Twins: A Systematic Review of the Evolution of Intelligent Building Representations in the AEC-FM Industry. *J. Inf. Technol. Constr.* **2021**, *26*, 58–83. [CrossRef]
31. Behzad, A.; Araz, N.; Sophia, D.; Abebe, D.; Madhav, P.N.; Yiliao, S. Measuring BIM Implementation: A Mathematical Modeling and Artificial Neural Network Approach. *J. Constr. Eng. Manag.* **2024**, *150*, 4024032. [CrossRef]
32. Yigitcanlar, T.; Desouza, K.C.; Butler, L.; Roozkhosh, F. Contributions and Risks of Artificial Intelligence (AI) in Building Smarter Cities: Insights from a Systematic Review of the Literature. *Energies* **2020**, *13*, 1473. [CrossRef]
33. Villena-Manzanares, F.; García-Segura, T.; Pellicer, E. Organizational Factors That Drive to Bim Effectiveness: Technological Learning, Collaborative Culture, and Senior Management Support. *Appl. Sci.* **2021**, *11*, 199. [CrossRef]
34. Omar, M.F.; Nursal, A.T.; Nawi, M.N.M.; Haron, A.T.; Goh, K.C. A Preliminary Requirement of Decision Support System for Building Information Modelling Software Selection. *Malaysian Constr. Res. J.* **2014**, *15*, 11–28.
35. Wu, P.; Jin, R.; Xu, Y.; Lin, F.; Dong, Y.; Pan, Z. The Analysis of Barriers to Bim Implementation for Industrialized Building Construction: A China Study. *J. Civ. Eng. Manag.* **2021**, *27*, 1–13. [CrossRef]
36. Babatunde, S.O.; Udeaja, C.; Adekunle, A.O. Barriers to BIM Implementation and Ways Forward to Improve Its Adoption in the Nigerian AEC Firms. *Int. J. Build. Pathol. Adapt.* **2021**, *39*, 48–71. [CrossRef]
37. Abrishami, S.; Goulding, J.; Rahimian, F. Generative BIM Workspace for AEC Conceptual Design Automation: Prototype Development. *Eng. Constr. Archit. Manag.* **2021**, *28*, 482–509. [CrossRef]
38. Debrah, C.; Chan, A.P.C.; Darko, A. Artificial Intelligence in Green Building. *Autom. Constr.* **2022**, *137*, 104192. [CrossRef]
39. Rane, N. Integrating Building Information Modelling (BIM) and Artificial Intelligence (AI) for Smart Construction Schedule, Cost, Quality, and Safety Management: Challenges and Opportunities. *SSRN Electron. J.* **2023**, *30*, 1–30. [CrossRef]
40. Pan, Y. Integrating BIM and AI for Smart Construction Management: Current Status and Future Directions. *Arch. Comput. Methods Eng.* **2022**, *30*, 1–30. [CrossRef]
41. Babatunde, S.O.; Ekundayo, D. Barriers to the Incorporation of BIM into Quantity Surveying Undergraduate Curriculum in the Nigerian Universities. *J. Eng. Des. Technol.* **2019**, *17*, 629–648. [CrossRef]
42. Marefat, A.; Toosi, H.; Mahmoudi Hasankhanlo, R. A BIM Approach for Construction Safety: Applications, Barriers and Solutions. *Eng. Constr. Archit. Manag.* **2019**, *26*, 1855–1877. [CrossRef]
43. Arrotéia, A.V.; Freitas, R.C.; Melhado, S.B. Barriers to BIM Adoption in Brazil. *Front. Built Environ.* **2021**, *7*, 520154. [CrossRef]

44. Liao, L.; Teo, E.A.L.; Chang, R. Reducing Critical Hindrances to Building Information Modeling Implementation: The Case of the Singapore Construction Industry. *Appl. Sci.* **2019**, *9*, 3833. [CrossRef]
45. Zhou, Y.; Yang, Y.; Yang, J.-B. Barriers to BIM Implementation Strategies in China. *Eng. Constr. Archit. Manag.* **2019**, *26*, 554–574. [CrossRef]
46. El Hajj, C.; Martínez Montes, G.; Jawad, D. An Overview of BIM Adoption Barriers in the Middle East and North Africa Developing Countries. *Eng. Constr. Archit. Manag.* **2023**, *30*, 889–913. [CrossRef]
47. Gamil, Y.; Rahman, I.A.R. Awareness and Challenges of Building Information Modelling (BIM) Implementation in the Yemen Construction Industry. *J. Eng. Des. Technol.* **2019**, *17*, 1077–1084. [CrossRef]
48. Al-Yami, A.; Sanni-Anibire, M.O. BIM in the Saudi Arabian Construction Industry: State of the Art, Benefit and Barriers. *Int. J. Build. Pathol. Adapt.* **2021**, *39*, 33–47. [CrossRef]
49. Oesterreich, T.D.; Teuteberg, F. Behind the Scenes: Understanding the Socio-Technical Barriers to BIM Adoption through the Theoretical Lens of Information Systems Research. *Technol. Forecast. Soc. Chang.* **2019**, *146*, 413–431. [CrossRef]
50. Blay, K.B.; Tuuli, M.M.; France-Mensah, J. Managing Change in BIM-Level 2 Projects: Benefits, Challenges, and Opportunities. *Built Environ. Proj. Asset Manag.* **2019**, *9*, 581–596. [CrossRef]
51. Durdyev, S.; Ashour, M.; Connelly, S.; Mahdiyar, A. Barriers to the Implementation of Building Information Modelling (BIM) for Facility Management. *J. Build. Eng.* **2022**, *46*, 103736. [CrossRef]
52. Alemayehu, S.; Nejat, A.; Ghebrab, T.; Ghosh, S. A Multivariate Regression Approach toward Prioritizing BIM Adoption Barriers in the Ethiopian Construction Industry. *Eng. Constr. Archit. Manag.* **2022**, *29*, 2635–2664. [CrossRef]
53. Chan, D.W.M.; Olawumi, T.O.; Ho, A.M.L. Perceived Benefits of and Barriers to Building Information Modelling (BIM) Implementation in Construction: The Case of Hong Kong. *J. Build. Eng.* **2019**, *25*, 100764. [CrossRef]
54. Hyarat, E.; Hyarat, T.; Al Kuisi, M. Barriers to the Implementation of Building Information Modeling among Jordanian AEC Companies. *Buildings* **2022**, *12*, 150. [CrossRef]
55. Ademci, E.; Gundes, S. Individual and Organisational Level Drivers and Barriers to Building Information Modelling. *J. Constr. Dev. Ctries.* **2021**, *26*, 89–109. [CrossRef]
56. Dao, T.-N.; Nguyen, Q.; Chen, P.-H. BIM Adoption in Construction Projects Funded with State-Managed Capital in Vietnam: Legal Issues and Proposed Solutions. In *CIGOS 2019, Innovation for Sustainable Infrastructure*; Springer: Singapore, 2019; pp. 1211–1216, ISBN 978-981-15-0801-1.
57. Olanrewaju, O.I.; Kineber, A.F.; Chileshe, N.; Edwards, D.J. Modelling the Relationship between Building Information Modelling (BIM) Implementation Barriers, Usage and Awareness on Building Project Lifecycle. *Build. Environ.* **2022**, *207*, 108556. [CrossRef]
58. Olanrewaju, O.I.; Chileshe, N.; Babarinde, S.A.; Sandanayake, M. Investigating the Barriers to Building Information Modeling (BIM) Implementation within the Nigerian Construction Industry. *Eng. Constr. Archit. Manag.* **2020**, *27*, 2931–2958. [CrossRef]
59. Fitriani, H.; Budiarto, A.; Ajayi, S.; Idris, Y. Implementing BIM in Architecture, Engineering and Construction Companies: Perceived Benefits and Barriers among Local Contractors in Palembang, Indonesia. *Int. J. Constr. Supply Chain Manag.* **2019**, *9*, 20–34. [CrossRef]
60. Ma, L.; Lovreglio, R.; Yi, W.; Yiu, T.W.; Shan, M. Barriers and Strategies for Building Information Modelling Implementation: A Comparative Study between New Zealand and China. *Int. J. Constr. Manag.* **2022**, *23*, 2067–2076. [CrossRef]
61. Mostafa, S.; Kim, K.P.; Tam, V.W.Y.; Rahnamayiezekavat, P. Exploring the Status, Benefits, Barriers and Opportunities of Using BIM for Advancing Prefabrication Practice. *Int. J. Constr. Manag.* **2020**, *20*, 146–156. [CrossRef]
62. Elagiry, M.; Marino, V.; Lasarte, N.; Elguezabal, P.; Messervey, T. BIM4Ren: Barriers to BIM Implementation in Renovation Processes in the Italian Market. *Buildings* **2019**, *9*, 200. [CrossRef]
63. Saka, A.B.; Chan, D.W.M. BIM Divide: An International Comparative Analysis of Perceived Barriers to Implementation of BIM in the Construction Industry. *J. Eng. Des. Technol.* **2023**, *21*, 1604–1632. [CrossRef]
64. Saka, A.B.; Chan, D.W.M. Profound Barriers to Building Information Modelling (BIM) Adoption in Construction Small and Medium-Sized Enterprises (SMEs): An Interpretive Structural Modelling Approach. *Constr. Innov.* **2020**, *20*, 261–284. [CrossRef]
65. Munir, M.; Kiviniemi, A.; Jones, S.; Finnegan, S. BIM Business Value for Asset Owners: Key Issues and Challenges. *Int. J. Build. Pathol. Adapt.* **2021**, *39*, 135–151. [CrossRef]
66. Farooq, U.; Ur Rehman, S.K.; Javed, M.F.; Jameel, M.; Aslam, F.; Alyousef, R. Investigating Bim Implementation Barriers and Issues in Pakistan Using Ism Approach. *Appl. Sci.* **2020**, *10*, 7250. [CrossRef]
67. Olawumi, T.O.; Chan, D.W.M.; Wong, J.K.W.; Chan, A.P.C. Barriers to the Integration of BIM and Sustainability Practices in Construction Projects: A Delphi Survey of International Experts. *J. Build. Eng.* **2018**, *20*, 60–71. [CrossRef]
68. Leśniak, A.; Górka, M.; Skrzypczak, I. Barriers to Bim Implementation in Architecture, Construction, and Engineering Projects—The Polish Study. *Energies* **2021**, *14*, 2090. [CrossRef]
69. Al-Hammadi, M.A.; Tian, W. Challenges and Barriers of Building Information Modeling Adoption in the Saudi Arabian Construction Industry. *Open Constr. Build. Technol. J.* **2020**, *14*, 98–110. [CrossRef]
70. Hatem, W.A.; Abd, A.M.; Abbas, N.N. Barriers of Adoption Building Information Modeling (BIM) in Construction Projects of Iraq. *Eng. J.* **2018**, *22*, 59–81. [CrossRef]
71. Umar, T. Challenges of BIM Implementation in GCC Construction Industry. *Eng. Constr. Archit. Manag.* **2022**, *29*, 1139–1168. [CrossRef]

72. Van Roy, A.F.; Firdaus, A. Building Information Modelling in Indonesia: Knowledge, Implementation and Barriers. *J. Constr. Dev. Ctries.* **2020**, *25*, 199–217. [CrossRef]
73. Belayutham, S.; Zabidin, N.S.; Ibrahim, C.K.I.C. Dynamic Representation of Barriers for Adopting Building Information Modelling in Malaysian Tertiary Education. *Constr. Econ. Build.* **2018**, *18*, 24–44. [CrossRef]
74. Evans, M.; Farrell, P. Barriers to Integrating Building Information Modelling (BIM) and Lean Construction Practices on Construction Mega-Projects: A Delphi Study. *Benchmarking* **2021**, *28*, 652–669. [CrossRef]
75. Ma, X.; Darko, A.; Chan, A.P.C.; Wang, R.; Zhang, B. An Empirical Analysis of Barriers to Building Information Modelling (BIM) Implementation in Construction Projects: Evidence from the Chinese Context. *Int. J. Constr. Manag.* **2022**, *22*, 3119–3127. [CrossRef]
76. Costin, A.; Adibfar, A.; Hu, H.; Chen, S.S. Building Information Modeling (BIM) for Transportation Infrastructure—Literature Review, Applications, Challenges, and Recommendations. *Autom. Constr.* **2018**, *94*, 257–281. [CrossRef]
77. Hire, S.; Sandbhor, S.; Ruikar, K.; Amarnath, C.B. BIM Usage Benefits and Challenges for Site Safety Application in Indian Construction Sector. *Asian J. Civ. Eng.* **2021**, *22*, 1249–1267. [CrossRef]
78. Deng, Y.; Li, J.; Wu, Q.; Pei, S.; Xu, N.; Ni, G. Using Network Theory to Explore Bim Application Barriers for BIM Sustainable Development in China. *Sustain.* **2020**, *12*, 3190. [CrossRef]
79. Sreelakshmi, S.; Kantilal, B.S.; Roshan, M.; Gopinath, S. A Study on the Barriers to the Implementation of Building Information Modeling. *Int. J. Civ. Eng. Technol.* **2017**, *8*, 42–50.
80. Olugboyega, O.; Windapo, A.O. Structural Equation Model of the Barriers to Preliminary and Sustained BIM Adoption in a Developing Country. *Constr. Innov.* **2022**, *22*, 849–869. [CrossRef]
81. Tan, T.; Chen, K.; Xue, F.; Lu, W.S. Barriers to Building Information Modeling (BIM) Implementation in China's Prefabricated Construction: An Interpretive Structural Modeling (ISM) Approach. *J. Clean. Prod.* **2019**, *219*, 949–959. [CrossRef]
82. Bosch-Sijtsema, P.; Isaksson, A.; Lennartsson, M.; Linderoth, H.C.J. Barriers and Facilitators for BIM Use among Swedish Medium-Sized Contractors—"We Wait until Someone Tells Us to Use It. " *Vis. Eng.* **2017**, *5*, 3. [CrossRef]
83. Manzoor, B.; Othman, I.; Gardezi, S.S.S.; Altan, H.; Abdalla, S.B. Bim-Based Research Framework for Sustainable Building Projects: A Strategy for Mitigating Bim Implementation Barriers. *Appl. Sci.* **2021**, *11*, 5397. [CrossRef]
84. Oraee, M.; Hosseini, M.R.; Edwards, D.J.; Li, H.; Papadonikolaki, E.; Cao, D. Collaboration Barriers in BIM-Based Construction Networks: A Conceptual Model. *Int. J. Proj. Manag.* **2019**, *37*, 839–854. [CrossRef]
85. Li, H.; Thomas Ng, S.T.; Skitmore, M.; Zhang, X.; Jin, Z. Barriers to Building Information Modelling in the Chinese Construction Industry. *Proc. Inst. Civ. Eng. Munic. Eng.* **2017**, *170*, 105–115. [CrossRef]
86. Nguyen, T.-Q.; Nguyen, D.-P. Barriers in Bim Adoption and the Legal Considerations in Vietnam. *Int. J. Sustain. Constr. Eng. Technol.* **2021**, *12*, 283–295. [CrossRef]
87. Li, P.; Zheng, S.; Si, H.; Xu, K. Critical Challenges for BIM Adoption in Small and Medium-Sized Enterprises: Evidence from China. *Adv. Civ. Eng.* **2019**, *2019*. [CrossRef]
88. Enshassi, A.; Ayyash, A.; Choudhry, R.M. BIM for Construction Safety Improvement in Gaza Strip: Awareness, Applications and Barriers. *Int. J. Constr. Manag.* **2016**, *16*, 249–265. [CrossRef]
89. Durdyev, S.; Mbachu, J.; Thurnell, D.; Zhao, L.; Reza Hosseini, M. BIM Adoption in the Cambodian Construction Industry: Key Drivers and Barriers. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 215. [CrossRef]
90. Zhang, L.; Chu, Z.; He, Q.; Zhai, P. Investigating the Constraints to Buidling Information Modeling (BIM) Applications for Sustainable Building Projects: A Case of China. *Sustainability* **2019**, *11*, 1896. [CrossRef]
91. Casasayas, O.; Hosseini, M.R.; Edwards, D.J.; Shuchi, S.; Chowdhury, M. Integrating BIM in Higher Education Programs: Barriers and Remedial Solutions in Australia. *J. Archit. Eng.* **2021**, *27*, 05020010. [CrossRef]
92. Dixit, M.K.; Venkatraj, V.; Ostadalimakhmalbaf, M.; Pariafsai, F.; Lavy, S. Integration of Facility Management and Building Information Modeling (BIM): A Review of Key Issues and Challenges. *Facilities* **2019**, *37*, 455–483. [CrossRef]