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Review

The Drivers, Barriers, and Enablers of Building Information Modeling (BIM) Innovation in Developing Countries: Insights from Systematic Literature Review and Comparative Analysis

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Abstract: Building information modeling (BIM) has received significant attention in the last two decades from the architecture, engineering, and construction (AEC) industry. Despite the popular trend of BIM in developing countries, the adoption of this technology is still low. This paper aims to investigate the drivers, barriers, and enablers of BIM adoption in developing countries with regard to global challenges. A systematic literature review and an in-depth comparative qualitative analysis were conducted to accomplish the objective. Relevant articles from three major databases covering 20 years (2002–2022) of journal article publications were analyzed. The comparative study identified drivers, barriers, and enablers influencing BIM innovation in six developing countries from three different continents. Additionally, a critical review and analysis explored the importance of BIM's innovation factors in developing countries. The stakeholders of AEC will benefit from insights offered by this study to prepare BIM implementation strategies effectively.

Keywords: BIM; building information modeling; developing countries; innovation; qualitative research; systematic literature review

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1. Introduction

Historically, the architecture, engineering, and construction (AEC) industry has lagged behind other sectors in innovation. Increasing demand to improve efficiency, reduce costs, raise safety, and business sustainability has stimulated this AEC sector to embrace advanced technology adoption [1–3]. The role of building information modeling (BIM) in improving the process of design, construction, and operation of buildings has triggered the increasing adoption demand from the industry [4–9].

The adoption of BIM has been vigorously promoted in many countries due to supportive government policies [10]. This top-down campaign for AEC innovation is triggered by early evidence of BIM benefits [11], such as cost savings and direct returns on investment [12]. For instance, one study reported that 75% of those adopting BIM had a positive investment return [13]. The same study revealed that BIM shortened project life cycles and increased savings on paperwork and material costs. Given this evidence, several governments of developed countries, including Britain, Finland, and Singapore, mandated BIM for public infrastructure projects.

While the adoption rate is high in developed countries, BIM adoption in developing countries is moving at a slower pace [14–16]. The phenomenon can be associated with the characteristics of AEC business actors in developing countries, e.g., inadequate levels of competence, low productivity, etc. [17,18]. This condition causes several issues, such as delays, rework, and miscommunication. Furthermore, many developing countries have no standard regulations obliging the implementation of BIM. Only large-scale projects are more familiar with the use of BIM in the construction design and engineering contexts [19].

On the other hand, the global agenda's mandate for developing countries to conduct economic decarbonization by 2050 has brought extra pressure on the AEC industry. The AEC and the built environment sectors account for 40% of global warming [20]. Developing countries require significant investments to procure new infrastructure. Governments, such as those of India and China, will need to build more than 100 million new housing estates over the next decade to keep up with growing demographics. The high carbon emission level in future construction projects needs to be addressed.

Acknowledging the global environmental agenda, prospective BIM adopters, especially those from developing countries, must be well informed on BIM's drivers, barriers, and enablers to improving their decision-making. In response, this study's research question is defined as follows: "What are the drivers, barriers, and enablers of BIM adoption in developing countries?".

2. Research Method

In order to answer the research question, exploratory empirical research is required. Nevertheless, exploratory research in AEC is not as advanced as in other mature research fields. Thus, qualitative exploratory studies are highly needed for developing the AEC body of knowledge in a more holistic manner [21].

Recently, most scholars have preferred mixed-method studies, which are highly valued because of certain advantages. However, in similar research within the AEC industry, qualitative research methods are considered more flexible than quantitative research methods [22]. This aspect of flexibility is acknowledged in qualitative research. The qualitative approach emphasizes a profound interpretation of words and contextual information rather than mere data quantification in a deductive manner [23].

This study has selected the qualitative approach as the most suitable approach for this study's objective. It applied a standard procedure from the preferred reporting items for systematic examination and meta-analysis (PRISMA) statement methodology [24]. This protocol is a screening process for relevant papers to the selection criteria. Subsequent to the article selection phase, the literature review and research question elaboration can be started.

To collect prospective articles, the researchers collected academic papers from three major electronic databases: Scopus, ScienceDirect, and ProQuest. These databases were selected for their shared reputation as the world's leading scientific research sources. The team used various search strings to identify relevant articles in line with this study's objective (see Table 1).

Table 1. Search strings in electronic databases.

Database	Search Strings
Scopus	(TITLE-ABS-KEY({Building information modelling} OR {Building information modeling} OR {BIM}) AND TITLE-ABS-KEY(innovat*) AND TITLE-ABS-KEY({developing country} OR {developing countries})) AND DOCTYPE(ar) AND (LIMIT-TO(LANGUAGE, "English"))
ScienceDirect	(TITLE-ABS-KEY({Building information modelling} OR {Building information modeling} OR {BIM}) AND TITLE-ABS-KEY({innovation} OR {innovative}) AND TITLE-ABS-KEY({developing country} OR {developing countries})) AND DOCTYPE(ar) AND (LIMIT-TO(LANGUAGE, "English"))
ProQuest	ti(Building information modeling) OR ti(Building Information modelling) OR ti(BIM) AND ab(innovat*) AND ab(developing countr*) [1]

[1] Excluded: Conferences/Proceedings, Developed Countries. Included: Scholarly Journals, full text, peer-reviewed, English, ABI/INFORM Collection, Global, Trade, and Industry.

This study included only articles published online between 1 January 2002 and 30 September 2022. This stage identified 12 articles from Scopus, 31 papers from ScienceDirect, and 36 papers from ProQuest. Overall, this work included 79 articles in the first screening phase. Even though many articles published in conference proceedings are in a good state, they were not further analyzed because many proceedings' analysis is not as thorough as journal articles [25]. Figure 1 illustrates the PRISMA framework executed in this study.

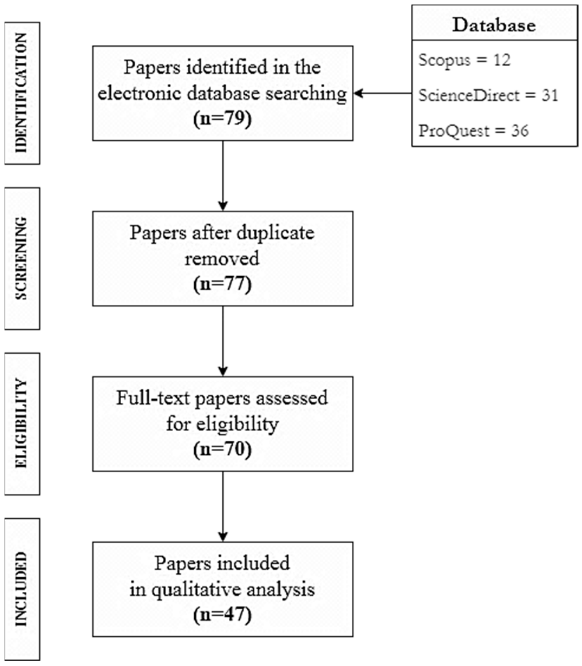

Figure 1. PRISMA framework.

The first step of the screening stage aims to eliminate duplicate articles. The results are 77 remaining articles. Next, the team excluded articles whose full text was inaccessible. Through this process, seven articles were excluded. Thus, only 70 papers were incorporated in the next eligibility stage. At this stage, the team further confirmed the eligibility of the articles to be included in the final study based on BIM innovation criteria. Eligible articles are those that review, survey, or discuss BIM innovations implicitly in the AEC environment, and research efforts explicitly dedicated to researching BIM drivers, barriers, and enablers. After removing 23 ineligible articles, the researchers retained 47 articles for the final qualitative analysis.

Figure 2 portrays the overview of the qualitative research framework executed in this study. This study adopts the e-qualitative research process based on Bryman and Bell [26] and Yin [27]. An in-depth comparative study was chosen to build a theory of BIM innovation factors in developing countries. To ensure a critical analysis, the researcher followed the guidelines to conduct a literature review. Mullins and Kiley [28] conclude that most reviewers derive their perceptions of the study from a literature review. Fellows and Liu [21] argue that literature should not just be discovered and reviewed but also has to be critically analyzed.

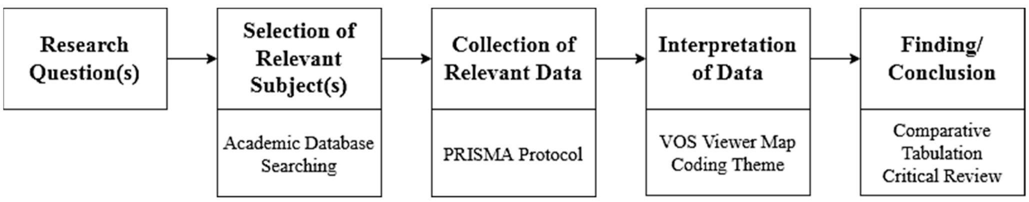

Figure 2. Qualitative research process.

Hence, literature should not be measured at 'face value'. Different academic sources should be reviewed from different perspectives. It must be ensured that the literature assessment uses a defined set of criteria. Existing research is not aggregated or synthesized but is judged on its level of acceptability [29–31].

The qualitative analysis also uses VOSviewer software to visualize the co-occurrence network map [32]. VOSviewer is a software to visualize the network of publications, journals, researchers, organizations, countries, keywords, or terms [33]. This application is mainly used for bibliometric studies. However, this study utilized the software to visualize and explore the co-occurrence network between BIM innovation keywords. It also analyzed several BIM research group locations in developing countries. The items identified in the mapped cluster were purposed as samples for qualitative analysis in the next step.

From this mapping process, researchers can select several countries to compare the adoption of BIM. Articles selected by the researchers were then examined thoroughly to develop conceptual definitions and discover the knowledge in line with this study's objective.

3. Analysis and Results

3.1. Previous Studies on BIM Innovation

The AEC industry's innovation pattern characteristics differ from other sectors [34]. Process and product innovations can be overlooked when only developed at an organizational (micro) level. Thus, there is a need to maximize value and benefits for all stakeholders involved in the process, including at higher levels such as countries (meso) or regions (macro).

An evolving technological improvement affected AEC innovations [35–37]. Technology has an essential role as a driver of innovation. Several studies were developed to investigate the adoption of Information and Communication Technology (ICT) in the AEC process. One of the ICT technologies representing AEC's innovation is BIM [38].

The adoption of BIM as a process innovation is influenced by various drivers, barriers, and enabling factors [39–42]. During the literature review, the research team explored previous studies, discussing BIM innovation between 2000–2010. When BIM was not as popular as today, research focused more on ICT innovation in the AEC industry [43,44]. After 2008, BIM innovation research began to evolve in the form of theoretical [45,46] and practical explanations [15,47–49].

Researchers have investigated BIM innovation drivers from 2011 to 2021 [50–53]. In general, the drivers of BIM innovation are the availability of trained personnel, a supportive environment, client interest, and awareness of industry stakeholders. These drivers are also supported by cooperation and commitment, perceived benefits of its implementation, government support, and collaborative procurement methods. Table 2 summarizes the drivers of BIM innovation identified from the literature study.

Table 2. The drivers of BIM innovation.

References	BIM Innovation Drivers
Kagioglou et al. (2000) [43]	• Environment/sustainability • Innovation Leaders • Strategic alliances and long-term relationships
Oladapo (2007) [44]	• Training • Innovation Leaders • Knowledge exchange • Integrated R&D • Contractor (Capability-push) • Coordination of participating groups
Kymmell (2008) [49]	• Desire to improve the firm's reputation • Strategic alliances and long-term relationships

Table 2. *Cont.*

References	BIM Innovation Drivers
Liu et al. (2010) [46]	• Client (Demand-pull) • Absorptive capacity
Becerik-Gerber et al. (2011) [50]	• Integrated R&D • Coordination of participating groups
Sinclair (2012) [51]	• Programs promoting collaboration
Eadie et al. (2013) [52]	• Training • Client (Demand-pull) • Absorptive Capacity • Competitive advantages • Increase performance and productivity • Improve efficiency • Regulations/Government
Badrinath et al. (2016) [53]	• Training

On the contrary, the researchers also investigated the barriers to BIM innovation [54–58]. Generally, they found that the barriers were lack of expertise, standardization, collaboration, demand, government policies, and project financing. In addition, BIM innovation faced the challenges of high investment costs, legal problems, and cultural resistance to the AEC industry. Table 3 presents an overview of the barriers to BIM innovation:

Table 3. The barriers to BIM innovation.

References	BIM Innovation Barriers
Oladapo (2007) [44]	• Economic conditions • Political conditions
Arayici et al. (2009) [45]	• Lack of technical capabilities • Inappropriate legislation • Lack of financial resources • Financial resistance
Rowlinson et al. (2009) [47]	• Technological resistance
Coates et al. (2010) [48]	• Lack of innovative investment procedure practices
Arayici et al. (2011) [15]	• Inappropriate culture and context
Olatunji (2011) [54]	• Inappropriate legislation
Giel and Issa (2013) [55]	• Risk of failure

Table 3. *Cont.*

References	BIM Innovation Barriers
Wang et al. (2015) [56]	• Lack of technical capabilities • Lack of technical competency of an innovation champion • Project delivery methods • Lack of recognition of the value of the innovation • Lack of demand • Lack of incentives
Ahmed et al. (2018) [57]	• Lack of technical capabilities • Lack of technical competency of an innovation champion • Project delivery methods
Tan et al. (2019) [58]	• Lack of technical capabilities • Lack of recognition of the value of the innovation

The BIM innovation enablers study began with ICT research. According to Kagioglou et al. [43], ICT is an enabler of a process protocol that covers the entire life cycle of an AEC project while integrating its participants under a common framework. Peansupap and Walker [59] studied ICT diffusion factors and implementation in AEC organizations. Several researchers then examined the enablers of BIM innovation, e.g., Kymmell [49], Cerosvek [60], Arayici, Egbu, and Coates [61]. Other studies related to these enablers were also discussed in the broader scope of the construction industry [38,62]. Table 4 presents an overview of the enablers of BIM innovation research.

Table 4. The enablers of BIM innovation.

References	BIM Innovation Enablers
Kagioglou et al. (2000) [43]	• Supportive work environment • Support from upper management/authorities
Peansupap and Walker (2005) [59]	• Reward schemes
Kymmell (2008) [49]	• Owner/client support • Collaboration with partners • Presence of the innovation champion
Ozorhon et al. (2010) [38]	• Government schemes • Awards, grants, funds • Education and training policy
Cerosvek (2011) [60]	• Owner/client support • Collaboration with partners • Presence of the innovation champion
Gambatese dan Hallowell (2011) [62]	• Support from upper management/authorities
Sinclair (2012) [51]	• Emphasis on R&D
Arayici, Egbu, and Coates (2012) [61]	• Knowledge Management Practices

3.2. Factors Influencing BIM Innovation in Developing Countries

BIM technology has been applied in the AEC sector for more than 40 years [63]. Umar (2021) found that over the past five years, the implementation of BIM in developing countries has been widely studied [64], such as by Li et al. (2017) in China [65], Arunkumar et al. (2018) in India [66], and Khodeir and Nessim (2018) in Egypt [67]. Primarily, the AEC industry in developing countries experiences both BIM opportunities and challenges regarding adoption, implementation, and innovation.

The emerging concerns of AEC in developing countries were also explored. For example, in Oman, Umar and Wamuziri [68] studied stakeholder collaboration on construction safety. Follow-up studies also examined increased energy consumption of developing countries in the last two decades that impacted global warming [69–71].

Research in developed countries, such as the UK and South Korea, has obtained empirical evidence that BIM innovations can improve construction waste management [72,73]. Regarding value management, a survey in the United States showed that 72% of AEC organizations believe BIM can significantly reduce project costs [74]. Therefore, forecasted savings are estimated at 10 to 20% of the AEC projects' value in developing countries [75]. Despite all the recognized benefits, the BIM adoption and implementation process are still unsatisfactory, one of which happened in Europe [76,77]. While Europe is considered more advanced than other continents, this study assumed that understanding BIM innovation processes in more developing regions or countries is essential.

Word co-occurrence data indicated certain relationships and were utilized as a foundation for semantic knowledge. For this purpose, this study used the meta-file "Research Information System" extension of 47 included articles and VOSviewer software. The title and abstract fields of the papers evaluated were assessed using a co-occurrence map based on text data. A full counting method analysis with a minimum threshold of five occurrences was chosen. Figure 3 portrays the terms associated with BIM innovation in developing countries.

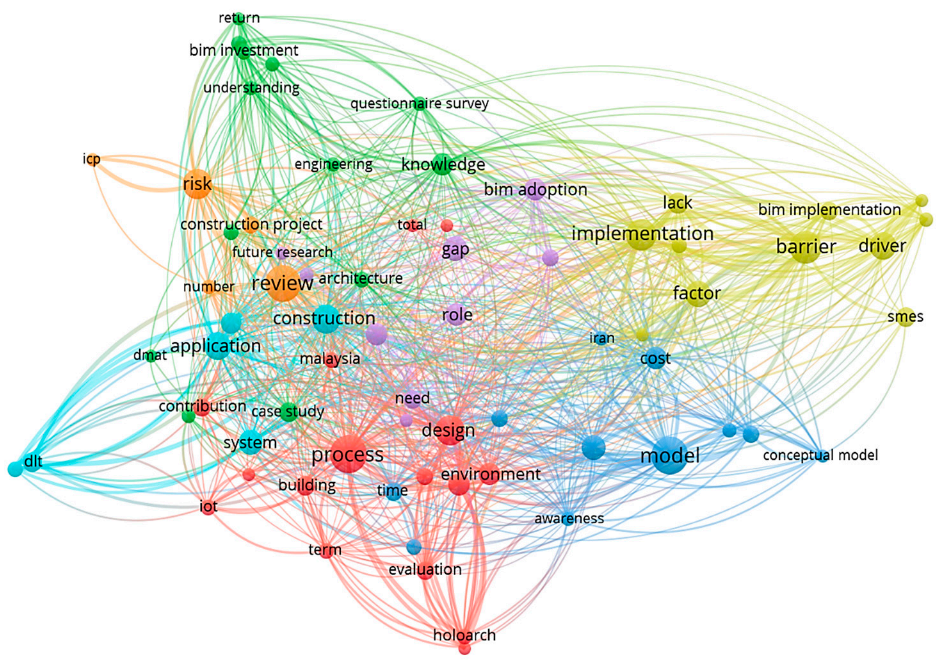

Figure 3. Co-occurrence map on BIM innovation in developing countries.

Through cluster analysis, we found four states with articles on BIM innovation, i.e., Malaysia (Southeast Asia) [78], China (Asia) [79], Iran (Middle-East) [80], and Nigeria (Africa) [39,40,81]. Additionally, we included two more countries based on a manual assessment of the literature, i.e., Saudi Arabia (Gulf Cooperation Council/GCC) [82] and

Croatia (Europe) [83]. In the following section, we will discuss the factors of BIM innovation using a comparative study of these nations.

3.2.1. Drivers of BIM Innovation in Developing Countries

The literature review explored various drivers of BIM innovation in developing countries. The government started BIM innovation initiatives in Malaysia through the Ministry of Public Works (PWD) and the Construction Industry Development Council (CIDB). Regulations were issued to improve the performance of AEC projects across the country [78]. The government collaborated with the research center (MyBIM) to facilitate training and consultation for AEC industry players through seminars and workshops.

BIM innovation in China is carried out by software developers, academics, and project owners. Clients and contractors are the main actors that drive BIM innovation [79]. With a centralized policy system, the Chinese government invested in construction projects of 20,000 square meters and green buildings at the provincial level. The State Ministry of Housing and Urban–Rural Construction (SMHURC) issued regulations for implementing BIM in these projects.

Iran in the Middle East has not implemented BIM massively [80]. However, practitioners and academics realized that BIM benefits economic growth and energy management. These two factors are used as drivers of BIM innovation in the region.

Olanrewaju et al. [39] explicitly classified the drivers of BIM innovation in Nigeria into four categories, i.e., "construction process", "digitalization process and economy", "sustainability and efficiency", and "visualization and productivity". The construction process involves planning, supervision, design, model recording, decision-making, productivity, and collaboration. The digitalization process and economy include estimation capabilities, cost control, environmental data, economic benefits, and project life cycle data. For sustainability and efficiency, the drivers are green building standards, increased efficiency, coordination, and customer service. Finally, visualization of the construction process, quality improvement, and sustainability improvement are related to visualization and productivity drivers.

In Saudi Arabia, the AEC firms emphasized the transformation of CAD into BIM [82]. Through this innovation process, industry players highlighted the value propositions in terms of expanding services to clients, gaining a competitive advantage in the market, integrating and collaborating from all disciplines, and adopting modern technology to improve the business process's effectiveness.

In addition to the literature review, Travaglini et al. [83] interviewed several participants working in the Croatian AEC industry. They categorized BIM innovation drivers by stakeholders. Internal stakeholders were classified into demand and supply sides, while external stakeholders were divided into the private and public sectors. Based on a comparative study of these countries, the drivers of BIM innovation in developing countries are summarized in Table 5.

Table 5. Drivers of BIM innovation in developing countries.

Malaysia (Southeast Asia) [78]	**China (Asia) [79]**	**Iran (Middle East) [80]**	**Nigeria (Africa) [39]**	**Saudi Arabia (GCC) [82]**	**Croatia (Europe) [83]**
Regulations/ Government [52] Knowledge exchange [44] Integrated R&D [44,50] Training [44,52,53]	Client (demand-pull) [46,52] Contractor (capability-push) [44] Regulations/ Government [52] Absorptive capacity [46,52] Environment/ sustainability [43]	Competitive Advantages [52] Environment/ sustainability [43]	Increase performance and productivity [52] Competitive Advantages [52] Environment/ sustainability [43] Programs promoting collaboration [51]	Increase performance and productivity [52] Improve efficiency [52] Desire to improve the firm's reputation [49] Competitive advantages [52] Client (demand-pull) [46,52] Innovation Leaders [43,44] Knowledge exchange [44]	Client (demand-pull) [46,52] Contractor (capability-push) [44] Coordination of participating groups [44,50] Strategic alliances and long-term relationships [43,49]

3.2.2. Barriers to BIM Innovation in Developing Countries

The second emphasis of the literature review is the BIM innovation barrier. According to Ibrahim et al. [78], obstacles that became barriers to BIM innovation in Malaysia were lack of expertise, lack of attention, internet connection, and resistance from AEC industry players. From a regulatory perspective, the Malaysian government has not obliged private projects to implement BIM. Consequently, BIM innovation from the private sector is lacking.

In China, the barriers that hinder BIM innovation mainly come from the high initial costs and effort or investment in project procurement [79]. It concerned not only software and hardware but also technical, managerial, and human resources aspects. AEC industry players considered the risk of a significant business return in implementing BIM.

Along with the lack of BIM implementation in Iran, the innovation barriers are high. Nemati et al. [80] conducted a survey and found several factors: AEC players are still not familiar with software and hardware, traditional construction methods are still dominant, there is a lack of attention to BIM, high costs for software acquisition, and inadequate incentives to improve BIM implementation.

For barriers to BIM innovation in Nigeria, Olanrewaju et al. [40] have also explicitly divided four categories, i.e., "technology and business", "training and human resources", "costs and standards", and "process and economy". Availability of software, inadequate contractual coordination, and data and intellectual property are barriers related to technology and business. The challenges faced by training and human resources categorization are a lack of training programs and skills, interoperability issues, and stakeholder reluctance. Costs and standards barrier included the cost of data and information exchange, changes in business culture, and the lack of specific standards. The process and economy that challenge BIM innovation include high implementation costs, lack of research and knowledge, inadequate government policies, and lack of demand for and acceptance of BIM.

The innovation barrier faced by the AEC industry in Saudi Arabia is the lack of interest from clients and stakeholders due to the low level of concern for the benefits of BIM [82]. The next barrier is the lack of experience from the BIM team and the lack of mentorship from the BIM champion. Apart from this, the lack of manpower is a barrier to innovation since it was divided into BIM and non-BIM projects.

The article from Travaglini et al. [83] did not address the barriers to BIM innovation in European countries. However, after the recent COVID-19 pandemic and unstable geopolitical conditions, it could be interpreted that unfavorable political and economic conditions will negatively impact BIM innovation. Based on the comparative study, the researchers summarized the barriers to BIM innovation in developing countries in Table 6.

Table 6. Barriers to BIM innovation in developing countries.

Malaysia (Southeast Asia) [78]	**China (Asia) [79]**	**Iran (Middle East) [80]**	**Nigeria (Africa) [40]**	**Saudi Arabia (GCC) [82]**	**Croatia (Europe) [83]**
Lack of technical capabilities [45,56–58] Technological resistance [47] Inappropriate legislation [45,54]	Risk of failure [55] Lack of innovative investment procedure practices [48]	Lack of technical capabilities [45,56–58] Inappropriate culture and context [15] Lack of recognition of the value of the innovation [56,58] Financial resistance [45] Lack of incentives [56] Lack of demand [56]	Lack of technical capabilities [45,56–58] Lack of financial resources [45] Lack of innovative investment procedure practices [48] Inappropriate legislation [45,54] Project delivery methods [56,57] Economic conditions [44]	Lack of recognition of the value of the innovation [56,58] Lack of technical competency of an innovation champion [56,57] Lack of technical capabilities [45,56–58]	Political conditions [44] Economic Conditions [44]

3.2.3. Enablers of BIM Innovation in Developing Countries

The enablers of BIM innovation in developing countries are studied through this literature review. In Malaysia, research and development institutions such as the "MyBIM

Satellite Center" collaborated with universities across the nation [78]. Malaysia also has a National BIM library and a government mandate for the transformation to Construction 4.0. All AEC industry players are encouraged to implement this technology, and all public projects worth RM100 million and above are required to implement BIM.

In line with the centralized nature of the state, many enablers of BIM innovation in China are driven by government institutions [79]. For example, the Shanghai Municipal People's Government issued the strategic objectives of BIM implementation. In addition, the China State Council issued prefabricated design codes, technical standards, and construction methods.

With the limited use of BIM in Iran, BIM innovation enablers are encouraged in the form of government initiatives as the largest user of the AEC industry [80]. Industry players have remarked that if the demand increased from the government side, it would automatically impact the construction community. The addition of BIM research is also encouraged, primarily to provide practical solutions in planning and management. The Iranian government designed free training and incentives for engineers to innovate BIM.

Oyewole and Dada [81] proposed special attention to professional practices in Nigeria as an enabler of BIM innovation. These professional practices consisted of Architecture functions (e.g., virtual modeling, project review, space management), Quantity Surveying (e.g., Bill of Quantities preparation, cost estimation, scheduling, budgeting), Engineering (e.g., digital fabrication, as-built modeling, clash detection), and other BIM-related practices (e.g., collaboration, interoperability, facility management, geotechnical surveys).

In the context of the AEC business firm in Saudi Arabia, the enabler for BIM innovation obtained through this literature review is top management's support for implementing new technology [82]. It was then expanded with support from the project owner or client. Internally, the company also pointed to the existence of a BIM champion who became the driving force of innovation within the AEC organization.

The participants interviewed by Travaglini et al. [83] also gave their opinions on the enablers of BIM innovation in developing European countries. Several factors include project owner/client support, a supportive working environment, collaboration with partners, and government schemes. Based on a comparative study of these countries, the researchers summarized the enablers of BIM innovation in developing countries in Table 7.

Table 7. Enablers of BIM innovation in developing countries.

Malaysia (Southeast Asia) [78]	**China (Asia) [79]**	**Iran (Middle East) [80]**	**Nigeria (Africa) [81]**	**Saudi Arabia (GCC) [82]**	**Croatia (Europe) [83]**
Supportive work environment [43] Education and training policy [38] Knowledge management practices [61]	Government schemes [38]	Emphasis on R&D [51] Support from upper management/ authorities [43,62] Education and training policy [38] Awards, grants, funds [38] Reward schemes [59]	Supportive work environment [43] Education and training policy [38] Knowledge management practices [61]	Support from upper management/ authorities [43,62] Owner/client support [49,60] Presence of an innovation champion [49,60]	Owner/client support [49,60] Supportive work environment [43] Collaboration with partners [49,60] Government schemes [38]

3.3. BIM Capability Sets in Developing Countries

The literature review results of 47 articles also elicited the potential uses of BIM in developing countries. This study frames the narration based on the BIM capability sets proposed by Succar [84], consisting of technology, process, and policy.

3.3.1. BIM Technology Capability Sets

Developing countries can benefit from BIM innovation to advance their building technologies. BIM innovation provides added value through visualizations and analyses in a project's life cycle's early stages. Previous technology developers even gave their specific term for BIM, i.e., "Visual Project Management" [83]. This terminology emphasized the importance of the BIM model for AEC practitioners, especially in terms of visualization during project management, design, and engineering. Developing countries could start BIM technology innovation by focusing on software training from proven developers like Autodesk. These skills are Revit [85] and Navisworks to improve coordination and clash detection [82].

In the construction phase, BIM technology provided practical benefits for developing countries. BIM applications could add value to quantity surveying (QS), additive manufacturing (AM), off-site manufacturing, on-site construction, lean construction, intelligent contracts with block-chain, health and safety, and construction waste recycling practices [42,86–91]. Other scholars recommended the use of monitoring and identification technologies (e.g., sensors, recording devices, RFID, QR Codes) that can improve construction progress [90,92,93]. Cloud computing applications could be developed to enable data sharing and gathering during construction [18]. This tool combined data engineering and management to impact more effective cost control.

Complementing BIM's innovations in the operation phase, these technological advances were particularly evident in facility management (FM) [87,94,95]. The added value of BIM was felt in managing the inventory of building assets and equipment so that they were maintained following specifications and contracts. The forms of innovation that could be improved include product data sheets, operational and maintenance schedules, warranties, data compliance, and equipment lists. AEC practitioners in developing countries could develop plugins or application program interfaces (API) to stimulate innovation and collaboration throughout the project lifecycle. API will enable seamless data transfer from the standard design software, construction platforms, and FM devices [94].

3.3.2. BIM Process Capability Sets

Sustainability concerns for developing countries resulted in product and process innovations such as Green Building and Smart Cities [96–98]. In the context of Green Building, BIM facilitates better material and equipment maintenance. Meanwhile, in Smart Cities, BIM innovation provided added value for IoT and Big Data management, network and transportation, and security issues.

Developing countries can also utilize BIM innovations in sustainability contexts, such as public health, entrepreneurship, heritage, housing, food sustainability, and energy sustainability. Several articles showed BIM research related to health facilities [99], SMEs [100], historic buildings [101], real estate [102], vertical farming [103], and oil and gas [104].

Based on the comparative study, BIM innovation in developing countries still faces enormous challenges. The government could play a role by inviting more participants from the private sector through the public–private-partnership (PPP) construction project scheme [105]. The success factors of this approach required several prerequisites, such as proper risk allocation and sharing, a robust private consortium body, political support, public support, and a transparent procurement process.

For developing countries, a practical solution to deal with the adversarial and fragmented characteristics of the AEC industry is to encourage the implementation of Integrated Project Delivery (IPD) [102,106]. This scheme is suitable for the traits of BIM, which prioritizes collaboration. However, it is necessary to adjust the legal contract to maintain the quality and compliance of BIM deliverables [107].

3.3.3. BIM Policy Capability Sets

The limitation of BIM innovation in developing countries is the lack of adequate implementation standards. For this reason, developing countries can adopt international standards that have already been established in developed countries. From the literature review, the maturity model by Bew and Richards (2008) [108] is very suitable for developing countries to measure BIM innovation. Another practical code that AEC industry players in developing countries could adopt is BS 1192:2007, which regulates the collaborative production of architectural, engineering, and construction information.

As an established institution, the International Organization for Standardization (ISO) has also issued BIM standards [109]. Developing countries could benefit from standards such as IFC (Industry Foundation Classes), IFD (International Framework Dictionary), IDM (Information Delivery Manual), iBIM (integrated BIM), CPIC (Construction Project Information Committee), AIM (Architectural Information Model), SIM (Structural Information Model), FIM (Facilities Information Model), BSIM (Building Services Information Model), and BrIM (Bridge Information Model). These standards could be used as the basis for building and infrastructure development.

Moreover, various global frameworks could be used by developing countries as policies to promote BIM innovation. These frameworks included ISO 37120, BREEAM, LEED for environmental development, CASBEE for urban development, STATUS (sustainability tools and targets for the urban thematic strategy project), SustainLane, and the United Nations' "habitat-indicators" [96,110].

3.4. Significance of BIM Innovation Factors in Developing Countries

In order to define the prioritization of BIM innovation, the factors in developing countries were then given scores and ranks [64]. All drivers, barriers, and enablers associated with BIM innovation from the literature review were coded to merge factors with similar characteristics. The BIM innovation factors are grouped into three main categories, i.e., technology, process, and policy. This qualitative synthesis can assist AEC stakeholders in prioritizing their BIM innovation strategy.

The weights for calculating scores of these BIM innovation factors use three criteria. The first criterion accounts for 50% of the final score and is adopted from the 2021–2022 journal's impact factor (IF). IFs have been used in 40% of universities in the United States and Canada for faculty review and promotion [111]. The second criterion gives 25% weight to the number of paper citations from which the factor was extracted. Citations from this paper are used to measure research quality and follow emerging topics [112]. The remaining 25% weight as the third criterion is given to the factors' significance in the qualitative study. This significance is measured by the number of factor repetitions in the comparative analysis.

The primary category that drives BIM innovation in developing countries is technology (Figure 4). The top three factors of this category are *absorptive capacity*, *competitive advantages*, and *increased performance and productivity*. The process category is the second-highest driver, with *training*, the *client (demand-pull)*, and *innovation leaders* as the major factors. Finally, the policy category is the last driver with the factors, i.e., *strategic alliances and long-term relationships*, *regulations/government*, and the *desire to improve the firm's reputation*. The scores and ranks of BIM innovation drivers are listed in Table 8.

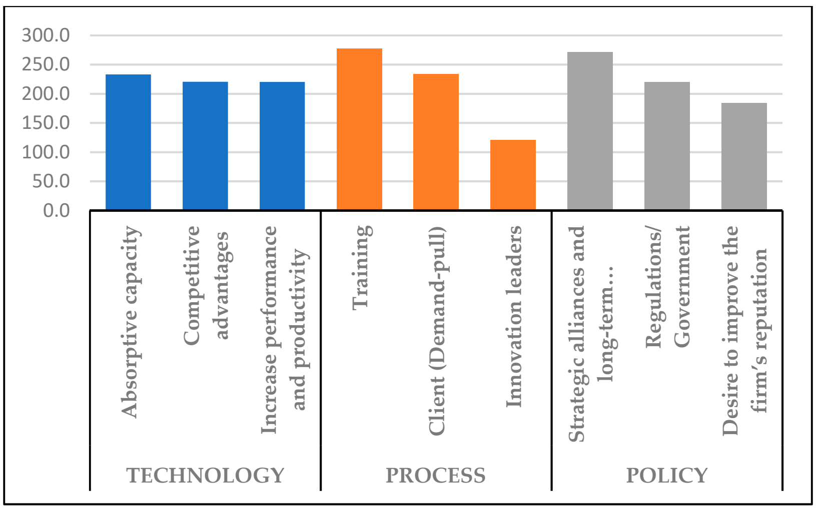

Figure 4. Top three BIM innovation drivers in developing countries.

Table 8. Scores and ranks of BIM innovation drivers in developing countries.

BIM Drivers	Categories	References	Sum of Impact Factor (SIF)	Sum of Citations (SIC)	Repetition in Comparative Study (Reps)	Ranking of Factor (50% × SIF + 25% × SIC + 25% × Reps)
Training	Process	[44,52,53]	18.6	1072	1	277.6
Strategic alliances and long-term relationships	Policy	[43,49]	3.5	1077	1	271.3
Client (Demand-pull)	Process	[46,52]	7.7	916	3	233.6
Absorptive capacity	Technology	[46,52]	7.7	916	1	233.1
Competitive advantages	Technology	[52]	7.7	863	3	220.4
Increase performance and productivity	Technology	[52]	7.7	863	2	220.1
Regulations/Government	Policy	[52]	7.7	863	2	220.1
Improve efficiency	Technology	[52]	7.7	863	1	219.9
Innovation leaders	Process	[43,44]	5.5	473	1	121.2
Integrated R&D	Technology	[44,50]	3.9	474	1	120.7
Coordination of participating groups	Process	[44,50]	3.9	474	1	120.7
Desire to improve the firm's reputation	Policy	[49]	0.0	734	1	183.8
Environment/Sustainability	Process	[43]	3.5	343	3	88.3
Contractor (Capability-push)	Process	[44]	1.9	130	2	34.0
Knowledge exchange	Process	[44]	1.9	130	2	34.0
Programs promoting collaboration	Policy	[51]	0.0	36	1	9.3

The most prevailing BIM barriers in developing countries are classified in the process category (Figure 5). *Inappropriate culture and context*, *lack of recognition of the value of the innovation*, and *risk of failure* are the top three factors of this category. The second-highest barrier is the policy category, with *inappropriate legislation*, *economic conditions*, and *political conditions* as the primary factors. Lastly, the technology category is a barrier with corresponding factors, i.e., *lack of technical capabilities*, *technological resistance*, and *lack of technical competency of an innovation champion*. The scores and ranks of barriers to BIM innovation are listed in Table 9.

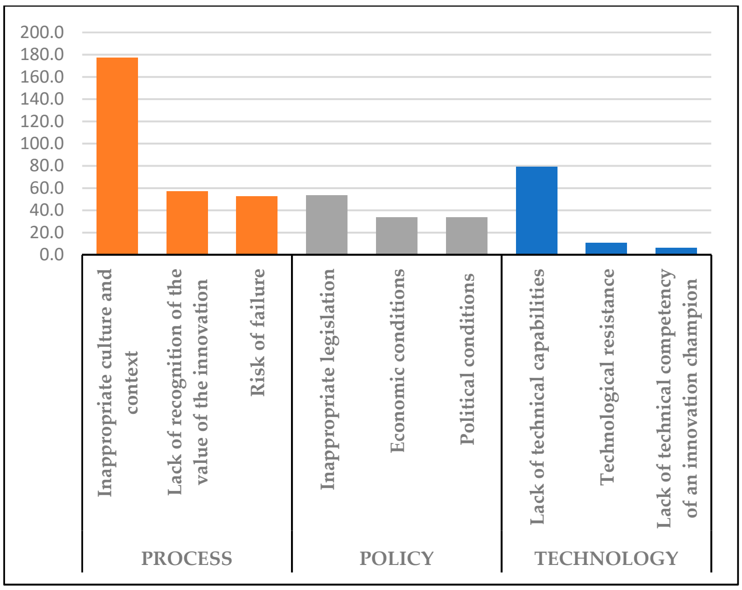

Figure 5. Top three BIM innovation barriers in developing countries.

Table 9. Scores and ranks of BIM innovation barriers in developing countries.

BIM Barriers	Categories	References	Sum of Impact Factor (SIF)	Sum of Citations (SIC)	Repetition in Comparative Study (Reps)	Ranking of Factor (50% × SIF + 25% × SIC + 25% × Reps)
Inappropriate culture and context	Process	[15]	7.7	693	1	177.4
Lack of technical capabilities	Technology	[45,56–58]	11.6	290	4	79.3
Lack of recognition of the value of the innovation	Process	[56,58]	9.3	208	2	57.1
Inappropriate legislation	Policy	[45,54]	4.2	204	2	53.6
Risk of failure	Process	[55]	4.6	201	1	52.8
Economic conditions	Policy	[44]	1.9	130	2	34.0
Political conditions	Policy	[44]	1.9	130	1	33.7
Lack of financial resources	Process	[45]	2.3	77	1	20.6
Financial resistance	Process	[45]	2.3	77	1	20.6
Technological resistance	Technology	[47]	0.4	42	1	11.0
Project delivery methods	Process	[56,57]	0.0	25	1	6.5
Lack of technical competency of an innovation champion	Technology	[56,57]	0.0	25	1	6.5
Lack of incentives	Policy	[56]	0.0	20	1	5.3
Lack of demand	Process	[56]	0.0	20	1	5.3
Lack of innovative investment procedure practices	Technology	[48]	1.9	12	2	4.4

The process category is also the most dominant enabling BIM innovation in developing countries (Figure 6). The main factors of this category are *owner/client support*, *collaboration with partners*, and *support from upper management/authorities*. Technology is the second category, with the *presence of the innovation champion*, *supportive work environment*, and *emphasis on R&D* as its main factors. After all, the policy category is the last enabler with *reward schemes*, *education and training policy*, and *government schemes*. The scores and ranks of BIM innovation enablers are listed in Table 10.

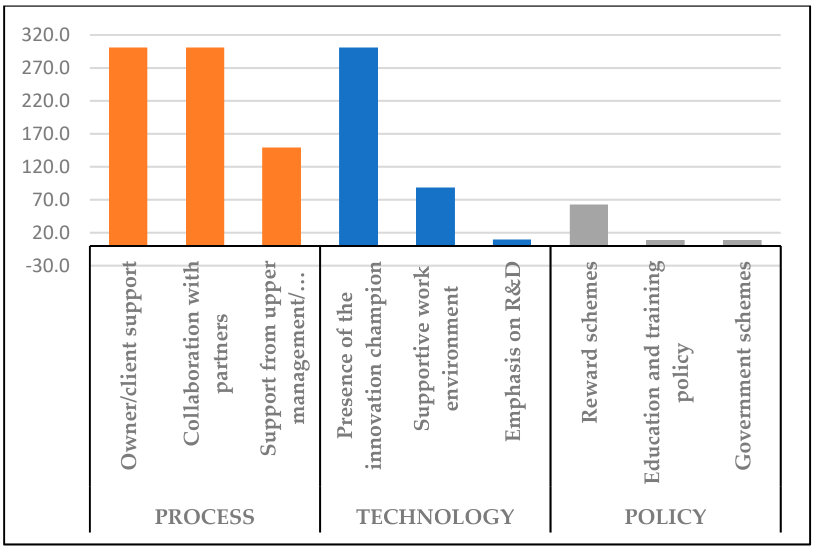

Figure 6. Top three BIM innovation enablers in developing countries.

Table 10. Scores and ranks of BIM innovation enablers in developing countries.

BIM Enablers	Categories	References	Sum of Impact Factor (SIF)	Sum of Citations (SIC)	Repetition in Comparative Study (Reps)	Ranking of Factor (50% × SIF + 25% × SIC + 25% × Reps)
Owner/client support	Process	[49,60]	5.6	1191	2	301.1
Collaboration with partners	Process	[49,60]	5.6	1191	1	300.8
Presence of the innovation champion	Technology	[49,60]	5.6	1191	1	300.8
Support from upper management/ authorities	Process	[43,62]	7.3	580	2	149.2
Supportive work environment	Technology	[43]	3.5	343	3	88.3
Reward schemes	Policy	[59]	1.9	245	1	62.5
Knowledge management practices	Process	[61]	1.9	182	2	47.0
Emphasis on R&D	Technology	[51]	0.0	36	1	9.3
Education and training policy	Policy	[38]	0.0	33	3	9.0
Government schemes	Policy	[38]	0.0	33	2	8.8
Awards, grants, funds	Policy	[38]	0.0	33	1	8.5

4. Discussion

Based on the perspective of construction innovation, there has been a fundamental paradigm shift from manual drawing-based processes to more digitalized and automated modeling processes. This revolution has been a breakthrough in the AEC sector, often considered lacking in innovation. BIM drivers, barriers, and enablers could significantly impact the AEC industry at the region (macro), country (meso), and organization (micro) levels. Public and private practitioners need to be aware of these innovation factors. As portrayed in Table 11, this study provides holistic insights into BIM's drivers, barriers, and enablers in developing countries. Understanding these dimensions and their most significant importance will benefit the AEC stakeholders during BIM implementation.

Table 11. BIM drivers, barriers, and enablers in developing countries.

Capability Sets Category	BIM Drivers	BIM Barriers	BIM Enablers
Technology	1. Absorptive capacity 2. Competitive advantages 3. Increase performance and productivity 4. Improve efficiency 5. Integrated R&D	1. Lack of technical capabilities 2. Technological resistance 3. Lack of technical competency of an innovation champion 4. Lack of innovative investment procedure practices	1. Presence of the innovation champion 2. Supportive work environment 3. Emphasis on R&D
Process	1. Training 2. Client (Demand-pull) 3. Innovation leaders 4. Coordination of participating groups 5. Environment/Sustainability 6. Contractor (Capability-push) 7. Knowledge exchange	1. Inappropriate culture and context 2. Lack of recognition of the value of the innovation 3. Risk of failure 4. Lack of financial resources 5. Financial resistance 6. Project delivery methods 7. Lack of demand	1. Owner/client support 2. Collaboration with partners 3. Support from upper management/authorities 4. Knowledge management practices
Policy	1. Strategic alliances and long-term relationships 2. Regulations/Government 3. Desire to improve the firm's reputation 4. Programs promoting collaboration	1. Inappropriate legislation 2. Economic conditions 3. Political conditions 4. Lack of incentives	1. Reward schemes 2. Education and training policy 3. Government schemes 4. Awards, grants, funds

One of the main challenges of the AEC industry is the diversity and uniqueness of each project and the stakeholders. The uniqueness of AEC projects impacts the variety of service providers and demands. Highlighting the broader potential of BIM in developing countries, Figure 7 demonstrates that future innovation requires more collaborations among four different stakeholders, namely, (1) the government (e.g., building industry authority, building consent authority, site-safe and city councils); (2) communities (e.g., building association, certified builders association); (3) the AEC industry itself (e.g., contractors, architects, designers, suppliers); and even (4) non-AEC sectors that still have interconnections with BIM (e.g., IT, energy, transportation).

Figure 7. BIM innovation participants.

By involving relevant BIM stakeholders, the opportunities and challenges of implementing BIM can be better accommodated. In order to encourage more innovations in BIM, this study proposes the following recommendations:

1. The government can formulate the most effective and efficient integrated project delivery (IPD) schemes and policies related to BIM. For example, these entities could include ECI (Early Contractor Involvement), EPC (Engineering Procurement Construction), and PPP (public–private-partnership).
2. Academic institutions can improve their curriculum and align it with new BIM roles required by the AEC industries, e.g., BIM coordinator, the system integrator, and the institutional environment for BIM personnel development.
3. Additionally, the communities can prepare their digital transformation process in line with BIM implementation features. For example, these operations could include the implementation of VDC (virtual design construction), expert systems for building code checking, and BIM organizational culture most suitable for the innovation process.
4. Subsequently, the industry can analyze the scope of its extant operations and strategic management for suitable BIM implementation by addressing the rule of thumb for decision-making, production management processes, supply chain management, and a cross-section of IT functionalities with business.

Beyond individual initiatives, myriad stakeholders can collaborate at the project and enterprise levels, such as developing 3D parametric model catalogs benefitting many stakeholders and using BIM for intelligent modeling. Furthermore, an innovation agenda for BIM in developing countries could be proposed for researching performance-driven design and lean construction. Although these two concepts were adopted simultaneously with BIM, they have different complementary impacts on the AEC industry.

Nevertheless, some stakeholders in developing countries are still reluctant to implement BIM due to uncertain potential benefits, a lack of clear implementation procedures, and the significant investments required. Because construction projects are unique and the project's organization is non-permanent, it is not easy to agree on a common standard for managing projects from a standardization perspective.

This paper provides a scientific foundation for selecting recognized BIM software, tools, and standards, such as Revit for modeling and visualization, Navisworks for the model reviewer, IFC for data formatting, cloud computing for connection and networking, and LEED for environmental and sustainability. The recognized standards, software, and hardware could direct BIM adoption in developing countries to promote innovative materials, intelligent constructions, capable buildings, inventive infrastructures, smart cities, and well-ordered regions. Beyond this, project compliance with environmental certification and adjusting specifications to climatic conditions should guide the BIM innovation related to sustainability.

5. Conclusions

Within the scope of AEC innovation studies, this paper aims to understand the drivers, barriers, and enablers of BIM adoption in developing countries. In order to achieve the objective, a systematic literature review was conducted. Article data from three academic databases—i.e., Scopus, ScienceDirect, and ProQuest—were extracted from 2002 to 2022 related to BIM innovations in developing countries. BIM innovation factors in developing countries were grouped into three categories: (a) drivers, (b) barriers, and (c) enablers. Comparative in-depth analysis was then carried out on the cases of six developing countries representing their respective continents: Malaysia, China, Iran, Nigeria, Saudi Arabia, and Croatia. A critical analysis complemented this literature review to discuss the capability sets of BIM and their importance in developing countries. Technology as a driver supported by a process as an enabler (e.g., project owner/client support, collaboration with partners, and support from upper management/authorities) is an excellent combination that embodies BIM innovation.

For most developing countries, BIM innovation has been developed in a top-down fashion driven by higher levels of authority, such as the government. This condition happened because the government commonly owns large AEC projects. Awareness related to the benefits and needs of BIM innovation is disseminated through a collaborative process between public institutions, research centers, and universities. The innovation faced challenges related to a lack of technical capabilities, human resources, infrastructure, and initial investment costs. Stakeholders in developing countries need more private-sector involvement to innovate BIM. This objective could be achieved through PPP schemes that accommodate risk allocation and sharing. Then, one practical solution to innovate in the AEC sector could also be achieved through an integrated project procurement scheme (e.g., IPD). It concluded that factors such as competitive advantage, market expectations, business relations, policies, collaboration, and government create a BIM innovation-supportive environment within developing countries.

This study explores how the innovation discourse in the AEC sector is acknowledged and practiced. The article makes a theoretical contribution by applying a critical literature review and an in-depth comparative qualitative analysis of BIM adoption in representative developing countries from three continents. This paper contributes to the body of knowledge about the drivers, barriers, and enablers of BIM innovation in developing countries, a study normally conducted in the context of developed countries.

This research makes a practical contribution by presenting AEC stakeholders with valuable insights on what to consider in implementing BIM. Policymakers in developing countries can benefit from this study to manage and extract economic values from BIM innovation. This paper also shows that the interpretation of BIM technologies, processes, and policies can support each AEC institution to value its resources and use them to achieve global targets in their respective contexts. Thus, it can lead to strategic decisions on the AEC environment and human development. This BIM innovation research can influence how AEC stakeholders act, solve recent problems, and prepare for future challenges.

This study focused on analyzing BIM innovation in six developing countries as the research sample and appeared as a limitation. The BIM innovation process also occurs in other nations. Further research may also be needed to investigate BIM innovation factors in other developing states within the different regional characteristics. Finally, the AEC industry in various nations and levels (sector–business–project) has its own features. Thus, the significance or ranking of the innovation factors identified in this paper may vary from context to context and require further investigation. Overall, the AEC industry has a vital role in economic development by producing sustainable buildings and infrastructures. BIM is one of the reform enablers that will help the AEC industry achieve this target and contribute to both global and local sustainable development goals.

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