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Towards Resilient Energy Systems: The Role of BIM and GIS Integration in Southern Africa

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1 ABSTRACT

Driven by emerging technologies, the integration of Building Information Modelling (BIM) and Geographic Information Systems (GIS) is an expanding field supporting the digital transformation of energy infrastructure. However, a significant gap exists in digital transformation research in Southern Africa compared to developed countries, exacerbated by governance challenges in developing regions. This paper reviews the state-of-the-art in BIM and GIS integration research to enhance the resilience and adaptability of green infrastructure planning. Using bibliometric analysis, the study examines publications related to green infrastructure, BIM-GIS integration, and climate change. The findings highlight emerging research areas, including sensor data, microgrids, green infrastructure, digital twins, digital transformation, and cybersecurity. Despite these advances, developing countries face critical challenges, such as the need for support systems, affordable digital twin technologies tailored to local contexts, and capacity building for decision-makers and experts. Key lessons reveal that BIM-GIS integration solutions must accommodate diverse equipment types and operating conditions. The findings provide valuable insights for policymakers, urban planners, and stakeholders to create resilient, equitable, and sustainable urban environments that address the unique challenges of Southern African cities.

Keywords: Building Information Modelling, Geographic Information Systems, digital transformation, green infrastructure, literature review

2 INTRODUCTION

Driven by emerging technologies, the integration of Building Information Modelling (BIM) and Geographic Information Systems (GIS) is an expanding field supporting the digital transformation of energy infrastructure. Globally, the adoption of digital technologies to assist climate change strategies has become the cornerstone of effective green infrastructure planning (Wang et al., 2013; Rafiee et al., 2014; Bansal, 2010). Over time, developing countries have grappled with underlying inefficiencies related to technology adoption, a topic extensively studied (Yau et al., 2014; Irizarry & Karan, 2012). BIM is a digital representation of a facility's physical and functional characters. It is based on technology incorporating information in three dimensions. In contrast, GIS is developed to manage and analyze spatial data, which is based on geomatics technologies. The integration system of BIM and GIS enables the effective management of information in various stages of a project's life cycle, namely planning, design, construction, operation, and maintenance (Amirebrahimi et al., 2015; Hijazi et al., 2011). BIM-GIS integration has been hailed as a solution, leveraging technology to address shortcomings in green infrastructure planning. Aligning national priorities and project objectives is paramount for meeting the Sustainable development gaoal mandates. With unified BIM and GIS technologies, it can occur seamlessly, reducing waste and enhancing designs. Scholars have outlined that the adoption and utilisation of BIM-GIS applications hold promise in alleviating collaboration challenges within the green energy sector while streamlining processes and improving efficiency in the planning lifecycle.

Global development organisations can streamline workflows, enhance communication, and unlock efficiencies throughout the project lifecycle by leveraging digital technologies such as Building Information Modelling (BIM), Geographic Information Systems (GIS), and cloud-based collaboration platforms. However, the journey towards digital transitioning in the green energy sector of developing countries is not without its challenges (De Laat et al., 2011; Virmani et al., 1997). Limited digital infrastructure, skill gaps, and institutional barriers often hinder the widespread adoption of digital technologies and workflows (Horrocks, 2008; Xiao et al., 2007). Moreover, cultural factors, stakeholder resistance, and data privacy and security concerns further complicate the landscape. Despite these challenges, the imperative for digital transformation remains clear. The benefits extend beyond mere efficiency gains to encompass broader socioeconomic impacts, including job creation, economic growth, and improved quality of life for communities. By embracing digital workflows and fostering collaboration between public and private stakeholders, organisations in the built environment of developing countries can unlock new avenues for innovation, resilience, and inclusive development (Stanton-Chapman et al., 2011; Liu et al., 2014). This chapter seeks to explore the role of organisational digital workflows in driving digital transitioning within the built environment of developing countries. Through case studies, best practices, and insights from industry leaders and experts, we aim to elucidate the opportunities, challenges, and strategies for harnessing the power of digital technologies to catalyze sustainable development and build more resilient and equitable societies.

Nevertheless, the literature suggests that achieving widespread BIM-GIS adoption and usage requires a paradigm shift and establishing common standards and operational protocols, among other considerations (Eadie et al., 2015; Ahuja et al., 2020). Ensuring the active engagement of key stakeholders during the planing, design and development phases is crucial. Scholars have advocated for proactive involvement particularly significant during the early stages of implementation (Becker et al., 2009; Boguslawski et al., 2011). This proactive action can greatly enhance the flow of information across the design, operations and maintenance phases (Olowa et al., 2022). However, in many African countries, several obstacles hinder the widespread adoption of BIM-GIS integration in green infrastructure projects. Scholars have noted a lack of involvement by government agencies and resistance from project owners; Inadequate participation by planning professionals, failure of architects to share complete models with engineers, and the reluctance to share project data (Stadler, 2007; Gröger, 2012; Valentini, 2014). Similay, the lack of education and training can make it difficult for built environment professionals to implement BIM effectively (Taylor & Bernstein, 2009; Peters, 2010).

Tan et al., (2019) mentioned that one of the most serious challenges to BIM-GIS implementation in green infrastructure projects is the adaptation to new technology and processes. Stakeholders, especially those in a developing market, have to deal with the difficulty in effectively reengineering the existing process, which significantly constrains BIM-GIS implementation. Stakeholders have to spend extra time and effort ensuring the digital objects in a BIM model have the required level of development. Thus, the extra workload will result in negative attitudes toward BIM implementation. The implementation of BIM unavoidably changes project delivery and potentially an organisation's structure. Stakeholders in the construction industry are known to be resistant to change. They are used to traditional paper-based methods and unwilling to adopt new technologies (Kolbe, 2009; Wang, 2012). Persuading these reluctant parties to use BIM can be extremely difficult. External motivation has been identified as an important factor affecting new technology implementation (Yau et al., 2014). However, stakeholders in the South African industry generally do not have enough motivation to intergrate BIM and GIS, and the incentive mechanism for BIM implementation in South Africa has not been well established. Such insufficient external impetus will inhibit positive attitudes towards BIM. The limited study of BIM-GIS integration, conducted within the context of South Africa could lead to a low level of adaptability and hinder actual implementation. To address this gap, this study reviews the state-of-the-art BIM and GIS integration research to enhance the resilience and adaptability of green infrastructure planning

3 METHODOLOGY

The continuing lag in technology adoption within the green energy practice is emerging as a growing concern amongst developing countries. This digital divide among professionals poses a considerable obstacle to fostering resilient infrastructure and inclusive growth. The review of the literature was undertaken using PRISMA protocols and bibliometric analysis. Literature from Scopus database was collected for the bibliometric analysis. All studies relating to the research were eligible for review with no specification on publication years. The database search in WoS was conducted and classified using the following keywords. The database search and the subsequent analysis were both carried out on a global scale.

- "Green infrastructure" and "Building information modeling"
- "Green infrastructure" and "Geographic information system"

- "Green infrastructure" and "climate change"

The inclusion criteria were all articles published in the field of quality of service in public transport (table 1).

Inclusion criteria	**Exclusion criteria**
All articles with topics in green infrastructure in climate change research	Studies outside green infrastructure scope
All articles with topics relating to BIM-GIS integration in climate change research	Unpublished thesis and dissertations; Non-peer-reviewed papers
All articles with topics relating to BIM-GIS integration in green infrastructure planning	Newspapers, conference papers
Language: English	Non-English language
Countries: All	

Table 1: Inclusion and exclusion criteria for the data collection extracted from the database.

The search in the literature was directed by screening titles and abstracts for each article to confirm eligibility. The protocol for the inclusion and exclusion process is presented in Fig. 1 as guided by the PRISMA protocols. The approach was adopted to eliminate bias when conducting a literature review. Therefore enhancing the validity of the study's findings of the study.

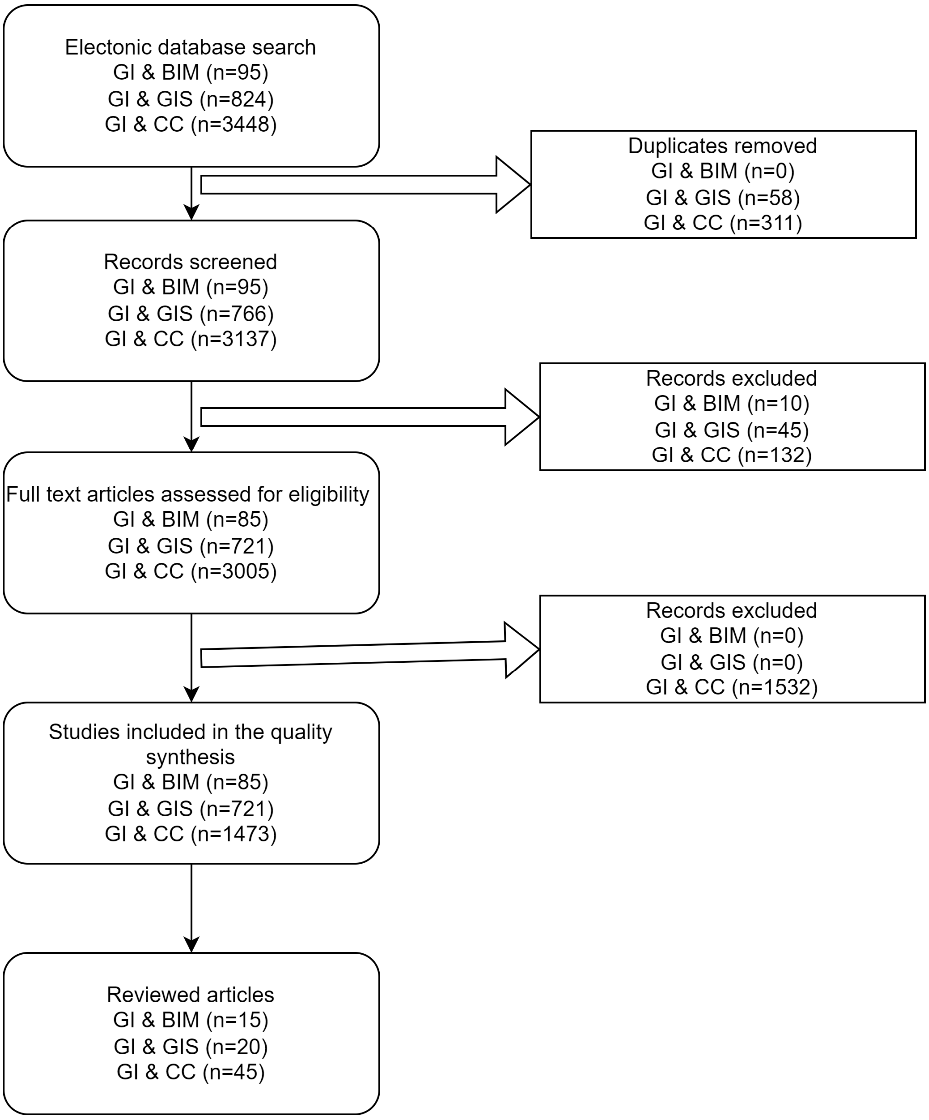

Figure 1: Summary of search procedure

4 FINDINGS AND DISCUSSION

Figure 2 presents the development of research on BIM-GIS integration within green infrastructure planning as part of efforts to address climate change challenges between 1996 and 2025. Up to 2008, research was limited, inconsistent, and highly fluctuating. An increase in research is noted from 2012 to 2020 and remained constant in 2025. Findings corroborate the trend observed in the existing literature on digital maturity and a lack of detailed analyses of barriers encountered in achieving successful BIM-GIS integration (Musonda et al., 2025). The sudden increase in research from 2020 could be because research on the subject had become a "recent vintage". This illustrates that while research on the subject is not new, it is simply now being valued and given more consideration than before.

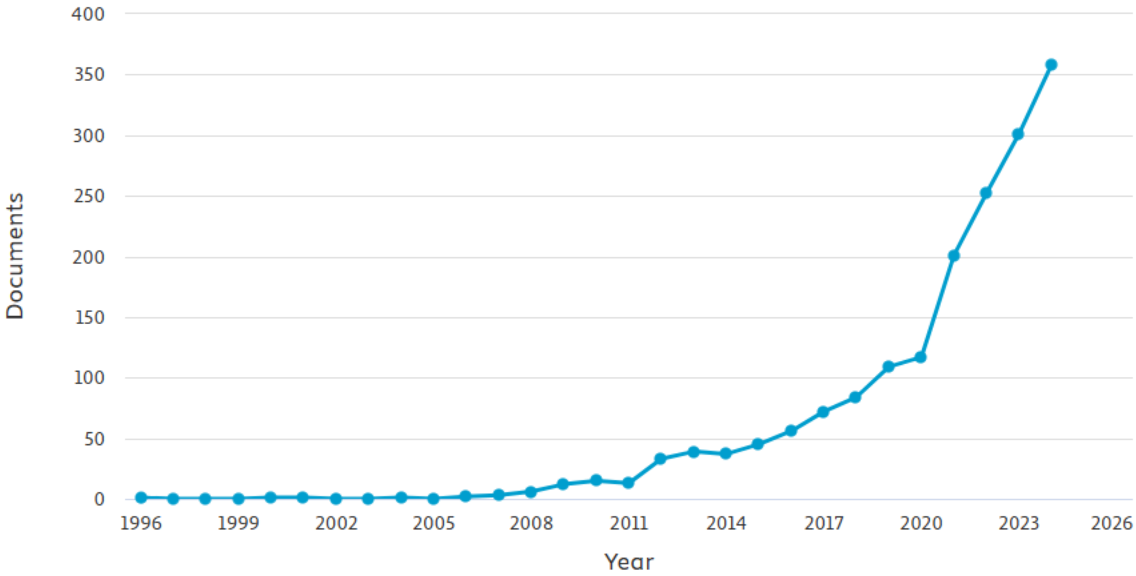

Figure 2: Research publication trend between 1996 to 2025

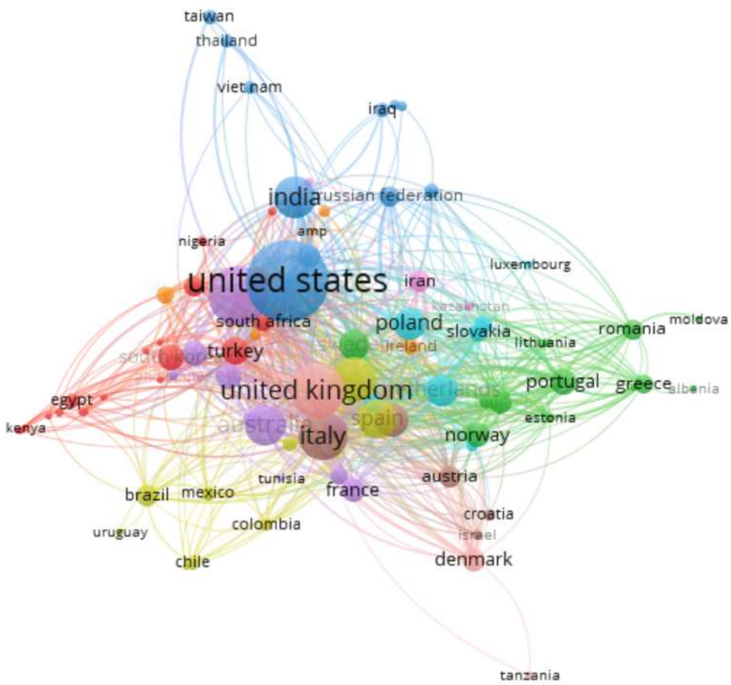

Figure 3: Institutional collaboration

4.1 Co-occurrence network analysis of institutions

Co-authorship between institutions publishing research on BIM-GIS integration within green infrastructure planning is shown in Figure 2. 73 countries met the threshold with a minimum of 5 documents. The United

States (232 documents, 268 total ink strength), the United Kingdom (509 documents, 250 total ink strength), China (265 documents, 201 total ink strength), and Germany (158 documents, 193 total ink strength), were the dominant countries. In Africa, South Africa (30 documents, 44 total ink strength), Egypt (18 documents, 17 total ink strength), and Kenya (4 documents, 8 total ink strength) are producing research on the subject. The low publications in Africa could be because of low BIM-GIS adoption. The relatively low research performance is also reflected in research on digital maturity in Africa.

4.2 Emerging Research

Figure 3 reveals the existing, current and emerging research trends in GIS-BIM integration research in green infrastructure from 2019 to 2021. The timelines are divided into 4 clusters (yellow, navy blue, green, and turquois blue). The navy blue cluster indicates the trend topics in research GIS-BIM integration research in green infrastructure from 2019 to 2019.5. A turquois blue cluster presents trend topics from 2019.5 to 2020. In addition, 2020 to 2020.5 is presented by a green cluster, while 2020.5 to 2021 is presented by a yellow cluster.

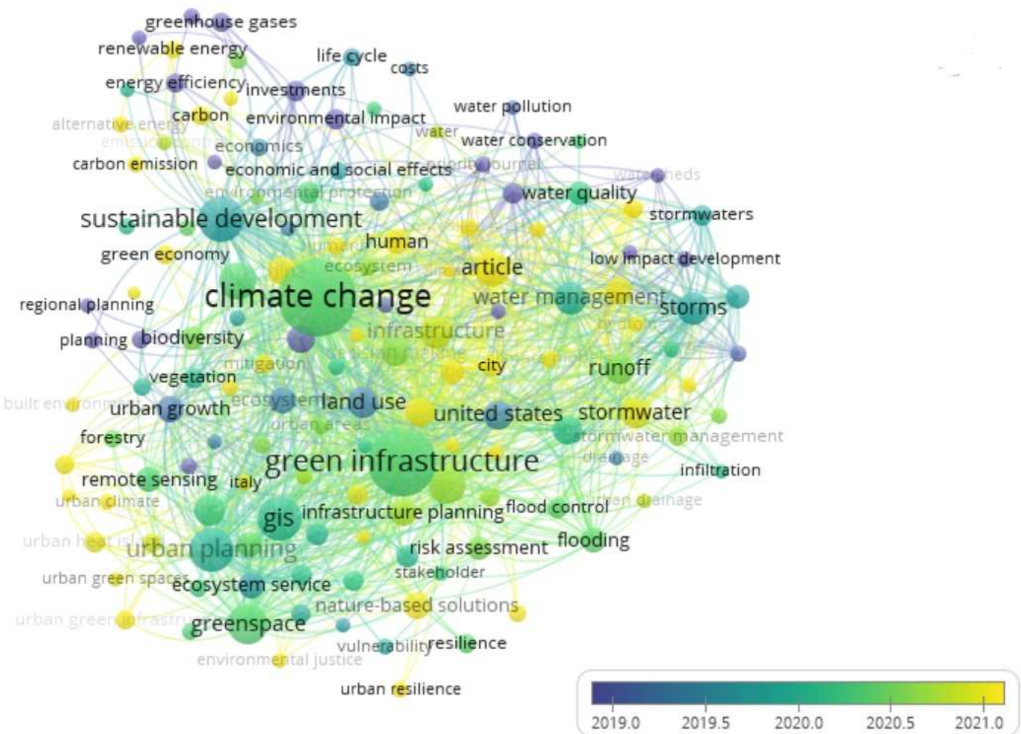

Figure 4: Emerging research areas

The significance of information and technology management is on the rise, especially with the advent of smart cities. The integration of BIM and GIS at data level normally involves the introduction of new standards, revision of old standards, or the conversion/translation of data format. The introduction of a new standard or model has the potential to fundamentally transform and revolutionize the integration problem by eliminating barriers between different domains (Wang et al., 2013; Rafiee et al., 2014; Bansal, 2010). However, emerging standards and models typically address integration from a specific perspective such as typology of green infrastructure, rather than providing a comprehensive, all encompassing solution. No single standard can fully cover all aspects of a region due to the inherent complexity and diversity of urban environments.

One of the primary reasons for this limitation is that developing a new standard or model is a resource-intensive process, requiring significant time, expertise, and financial investment. Additionally, information loss whether intentional or unintentional remains an unavoidable challenge, particularly in large-scale, ambitious models that attempt to encompass all elements of a region. As standards and models evolve, gaps may emerge due to discrepancies in data compatibility, institutional constraints, or the sheer difficulty of integrating diverse datasets. A review of existing frameworks suggests that targeted, domain-specific projects tend to achieve greater success (Yau et al., 2014; Irizarry & Karan, 2012). These focused initiatives demonstrate higher efficiency in minimizing information loss, maintaining flexibility, and optimizing labor costs. By concentrating on well-defined objectives rather than attempting to create an all-inclusive model, such projects are more adaptable to evolving technological and contextual requirements. Ultimately, while new standards and models play a crucial role in addressing integration challenges, their effectiveness depends on strategic implementation, incremental development, and careful consideration of domain-specific needs. Striking a balance between comprehensiveness and practicality is key to ensuring sustainable and scalable solutions for integration in complex environments.

A critical pathway to digitalising the energy sector is through the adoption of GIS and BIM at process level. BIM and GIS have different contents and data structures, and BIM normally has much more information than GIS. In order to develop a seamless integration system, a reference ontology as part of semantic web technologies can be used to store and represent the differences. The ultimate goal of semantic web is to "allow data to be shared effectively by wider communities, and to be processed automatically by tools as well as manually. Similar to the ongoing work on "Climate change" and "green infrastructure" are the most central and dominant topics, indicating a strong research focus on sustainability and resilience strategies. This reveals implementing GIS-BIM integration necessitates a systematic, incremental development process in collaboration with users, occurring both on-site and off-site.

In the past decade, BIM-GIS technology has made significant progress, leading to its widespread acceptance. The rapid growth can be attributed to the manifold benefits across the project lifecycle, encompassing planning, design, operation, and maintenance (Ramaji et al., 2020). The Internet of Things (IoT) integration has been instrumental in modernizing green infrastructure planning, facilitating data integration, and real-time data exchange (Zhang et al., 2022). By incorporating artificial intelligence (AI) and machine learning algorithms, processes can be optimised, leading to the implementation of more effective information-based management strategies (Arisekola & Madson, 2023).

The last cluster of integration methods is at application level. At this level, both source data and object data are not changed, and no service or ontology is developed. The integration methods at application level solve the problem from one particular angle, and normally cannot be adopted by other methods. Furthermore, the integration of emerging technologies not only enhances operational efficiency but also facilitates predictive maintenance and performance optimisation. IoT sensors continuously monitor various aspects of building performance, such as energy consumption or production, and equipment health. This real-time data is then fed into models, enabling stakeholders to simulate different scenarios, predict potential issues, and proactively address them before they escalate. Moreover, the convergence of with IoT, and AI offers opportunities for enhanced collaboration and decision-making throughout the building lifecycle (Žigiene et al., 2019; Nabizadeh & Hossein, 2021). By centralizing project information and streamlining stakeholder communication, project teams can work more cohesively, reducing errors and delays. Additionally, AI-driven analytics enable data-driven insights, empowering stakeholders to make informed design, construction, and operation decisions.

The presence of "GIS," "remote sensing," and "infrastructure planning" suggests the growing use of spatial data and technology in sustainable urban development. By continuously updating BIM models with real-time data from IoT sensors, facility managers can monitor green energy facility performance, identify inefficiencies, and implement corrective actions to improve operational effectiveness and occupant comfort. Combining BIM with GIS has yielded substantial achievements in automation, error diagnosis, energy optimisation, facility management, and sustainable development (Biswas et al., 2024). Additionally, The interlinkage with "risk assessment" and "flood control" shows the application of geospatial technologies in climate adaptation. The synergistic benefits of implementation include increased productivity, efficiency, and the integration of cost and schedule management for construction projects (Nawari, 2019; Zhang et al., 2023). Moreover, BIM-GIS integration finds applications in green energy evaluation, clash detection, optimisation, and enhancing communication and productivity (Liu et al., 2016; Abdal Noor & Yi, 2018).

Santos et al. (2017) underscore the role of BIM-GIS based project management tools in enhancing project learning outcomes, bridging the gap between theory and real-world challenges. espite these advancements, the energy sector faces challenges in establishing common understandings of BIM-GIS concepts and consistent methodologies. As seen with the interlinkage between "risk assessment" and "flood control" shows the application of geospatial technologies in climate adaptation. Hooper (2015) suggests that while technology facilitates collaboration through proprietary BIM-GIS tools, there's still a need to enhance industry-wide stewardship of digital information throughout green infrastructure project phases. Overall, the benefits of BIM-GIS integration are vast, but there remains a gap in knowledge dissemination and standardised methodologies.

5 LESSONS LEARNT AND IMPLICATIONS FOR PLANNING

The finding from the review has several implications with regard to the new knowledge generation for academic purposes and policy formulation and implementation in the local, provincial, and national spheres. The rise of "GIS" and "BIM" implies that spatial technologies are becoming fundamental tools for climate adaptation and urban planning. The transition to BIM-GIS integration adoption has the potential to improve real-time information management on green infrastructure projects. BIM-GIS integration uses data collected from sensors, simulations, and other sources to digitally represent the physical system. A close reflection on emerging research trends reveals in developed countries, digital maturity with regard to BIM-GIS integration is at an advanced level. Additionally, the diverse range of topics, from economic effects to environmental justice, highlights the interdisciplinary nature of climate adaptation research.

While in the global South, few countries have made strides to utilize BIM and GIS in green infrastructure projects. In Africa, knowledge gaps exist due to few local case studies are available that have successfully implemented GIS-BIM integration in green infrastructure projects. Additionally, Musonda et al., 2025 have outlined that most planners have not participated in at least one project where GIS-BIM integration was adopted in Southern Africa. This reveals low awareness and adoption of emerging technologies. Addressing these barriers is essential for facilitating the successful implementation of GIS-BIM integration and promoting their widespread adoption in the energy sector.

The focus on "urban resilience" and "nature-based solutions" suggests that cities increasingly incorporate green infrastructure to enhance climate adaptability. These efforts require governments and relevant stakeholders in developing countries to play a crucial role in supporting and investing in GIS-BIM integration initiatives. By providing funding, infrastructure, and regulatory frameworks conducive to green implementation, policymakers can help drive the built environment's digital transitioning and unlock this technology's potential benefits for economic growth and development.

6 CONCLUSION

The integration of BIM and GIS is essential for advancing digital workflows in urban planning, infrastructure management, and smart city development. This paper reviews the state-of-the-art in BIM and GIS integration research to enhance the resilience and adaptability of green infrastructure planning. Three levels of BIM-GIS integration methods were revealed in this study, namely at data, process, application level. As a compromise, semi-automatic methods have shown potential in balancing integration efficiency with cost-effectiveness. Additionally, application-focused methods provide effective solutions but often lack generalizability. However, achieving seamless interoperability requires overcoming technical, semantic, and institutional barriers. While new standards and ontologies offer long-term solutions, practical integration today relies on adaptable, application-driven, and semi-automated methods. The key to successful integration lies in fostering openness and collaboration across disciplines, ensuring that stakeholders from both domains work together to develop shared frameworks and best practices. Moving forward, initiatives that promote cross-domain cooperation, supported by advancements in ICT and smart city technologies, will be crucial in realizing the full potential of BIM-GIS integration.

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