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BIM green infrastructure – Exploring sustainable materials and technologies: A systematic literature review

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ABSTRACT

This paper presents a systematic literature review on the topic of Building Information Modelling (BIM) in the context of green infrastructure and its sustainable materials and technologies. The objective of this review is to explore the current state of knowledge regarding the application of BIM in promoting sustainable practices within the domain of green infrastructure, with a specific focus on sustainable materials and technologies. The systematic literature review follows a predefined methodology, including the identification of relevant studies, data extraction, and content analysis. Multiple academic databases were searched using appropriate keywords and criteria. The inclusion and exclusion criteria encompassed publications in peer-reviewed journals, conference proceedings, and relevant industry reports. The review reveals that BIM enables the modelling and simulation of sustainable materials to assess their environmental performance and impact. It also supports the integration of energy-efficient technologies, and smart infrastructure solutions within green infrastructure projects. However, several challenges and limitations were identified in the literature including issues related to interoperability, data standardization, and the need for improved integration between BIM and sustainability assessment tools. Limited adoption and awareness of BIM in the context of green infrastructure, along with the lack of specific guidelines and protocols, were also recognized as barriers to widespread implementation. Based on the research gaps identified in the literature, future research should focus on developing standardized frameworks and guidelines for integrating BIM with sustainable materials and technologies in green infrastructure projects. More studies are needed to assess the long-term environmental and economic benefits of BIM-enabled green infrastructure.

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1.0 INTRODUCTION

In recent years, the construction industry has increasingly confronted the need to adopt sustainable practices due to growing environmental concerns and the imperative to reduce carbon footprints. Building Information Modelling (BIM) has emerged as a transformative technology that facilitates comprehensive management and integration of information throughout the lifecycle of construction projects (Sacks et al., 2018). BIM's capabilities extend beyond traditional design and construction tasks to support the implementation of green infrastructure and the use of sustainable materials, thereby contributing to more sustainable urban development (Chong et al., 2017).

The integration of BIM and green infrastructure has emerged as a pivotal approach in advancing sustainable practices within the construction industry (Zhang & Ying, 2023; Lozano et al., 2023; Maqsoom et al., 2021). The pursuit of environmentally conscious solutions and the drive towards sustainable development have prompted researchers and practitioners alike to explore the synergies between BIM technologies and green infrastructure principles (Al-Tekreeti et al., 2022). The built environment plays a crucial role in addressing global environmental challenges, and green infrastructure has gained prominence as an innovative strategy to enhance urban sustainability (Bonenberg & Wei, 2015). Green infrastructure involves the planning and management of natural and semi-natural systems in urban areas to enhance ecological health, improve resource efficiency, and provide resilience against environmental challenges (Norton et al., 2015). Sustainable materials are essential in this approach as they minimize environmental impact and enhance the durability and performance of built environments (Asif et al., 2007). BIM, with its advanced data integration and modelling features, is well-positioned to support these sustainable practices by providing detailed insights and facilitating informed decision-making (Lu et al., 2017).

By harnessing the potential of BIM, the integration of sustainable materials and technologies within green infrastructure projects can be streamlined (Bapat et al., 2021), fostering a holistic approach to design, construction, operation, and maintenance. However, challenges such as the lack of standardized protocols and data interoperability remain as significant barriers (Liu et al., 2018; Iacovidou & Purnell, 2016). Integrating IoT with BIM can improve real-time monitoring and energy efficiency (Bapat et al., 2021), yet there is still a need to refine BIM applications with on-site data and address energy consumption and sustainability assessment limitations (Al-Tekreeti et al., 2022; Lozano et al., 2023). As interest in sustainable development grows, effective use of BIM for information management and lifecycle assessment is essential for advancing green infrastructure and construction practices (Onososen & Musonda, 2022).

Therefore, this research paper presents a comprehensive systematic literature review that delves into the convergence of BIM, green infrastructure, sustainable materials, and advanced technologies. The objective of this systematic literature review is to critically analyze existing research at the intersection of BIM, green infrastructure, sustainable materials, and technologies. The review aims to identify trends, challenges, opportunities, and gaps in the current body of knowledge and address the research question "How is Building Information Modelling (BIM) driving the integration of green infrastructure and sustainable materials and technologies?". By synthesizing insights from diverse studies, this paper seeks to contribute to a deeper understanding of the multidimensional relationships between BIM-enabled green infrastructure and sustainable practices. The insights derived from this review can guide practitioners, researchers, and policymakers in making informed decisions that promote the effective integration of BIM, green infrastructure, sustainable materials, and technologies, ultimately contributing to a more sustainable and resilient built environment.

2.0 METHODOLOGY

This research paper employs a systematic literature review (SLR) methodology to comprehensively examine the relationship between Building Information Modelling (BIM), green infrastructure, and sustainable materials and technologies. The approach for the systematic literature review is based on the guidelines provided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al. 2010; Page et al. 2021). The PRISMA flow diagram is shown in Fig 1.

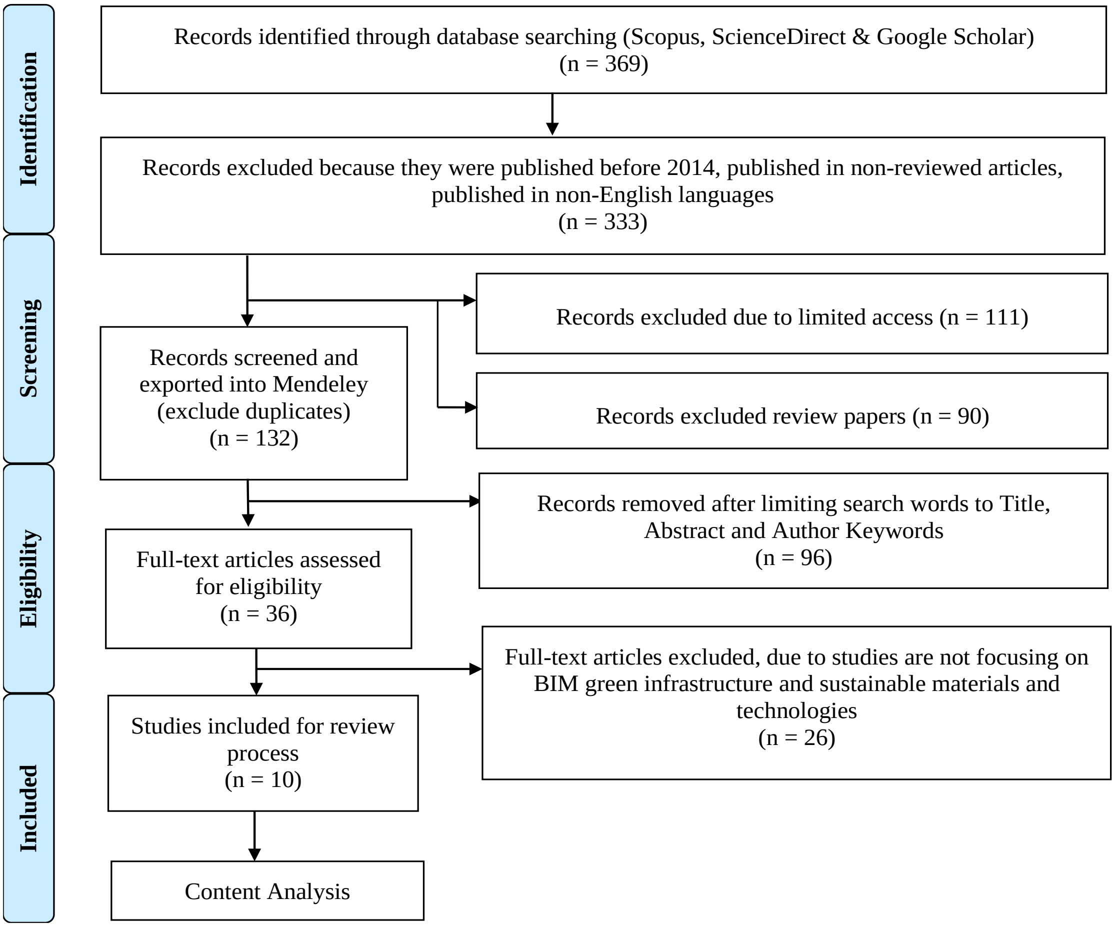

Fig. 1. PRISMA flow diagram

A comprehensive search strategy is designed to identify relevant literature from various academic databases. In this research paper, three main databases (Scopus, ScienceDirect and Google Scholar) were used to find related articles. Keywords related to BIM, green infrastructure, sustainable materials, and technologies were combined using Boolean operators to ensure a thorough search (Atkinson & Cipriani, 2018). This paper, the search strategy incorporated the keywords ("Building Information Modelling" OR "BIM") AND ("green infrastructure" OR “sustainable infrastructure”) AND ("sustainable materials" OR “green materials”) AND ("technologies" OR “innovations”).

Inclusion and exclusion criteria were defined to maintain the relevance and quality of selected studies. The inclusion criteria included peer-reviewed articles, articles written in English, published in between 2014 to 2023, open-access articles, and studies focused exclusively on Building Information Modelling (BIM), green infrastructure, and sustainable materials and technologies. The exclusion criteria encompassed non-peer-reviewed articles, articles using non-English language, articles published before 2014, limited-access articles, and studies that are not aligned with the research question or objectives.

Subsequently, in a two-phase screening process, all identified articles underwent title and abstract screening followed by full-text screening. Relevant data from selected studies were extracted capturing key information, including authors, publication year, research focus, methodologies, findings, and implications related to the integration of BIM, green infrastructure, sustainable materials and technologies. The full texts of potentially pertinent articles were collected and subsequently assessed to ascertain their final inclusion in the review.

3.0 RESULTS AND DISCUSSION

The systematic literature review (SLR) on the integration of Building Information Modelling (BIM), green infrastructure, sustainable materials and technologies has revealed several key themes and insights. Table 1 presents the main findings. The synthesis of diverse studies has provided a comprehensive understanding of the current landscape, challenges, and opportunities in this multidisciplinary domain.

Table 1. Key findings on the integration of BIM, green infrastructure, and sustainable materials and technologies

Author (Year)	Key findings	Future research direction
Bonenberg & Wei (2015)	BIM integration enhances analog-energy buildings by optimizing air flow analysis and sunlight utilization. It minimizes waste, elevates construction quality, and creates multidimensional digital models that support scientific collaboration among designers, architects, utility engineers, developers, and end users.	The examples demonstrate that the use of BIM (Building Information Modelling) is an effective tool for the integration of natural and technical systems in architectural design.
Iacovidou & Purnell (2016)	Utilizing 'smart' technologies like Radio Frequency Identification (RFID) and Building Information Modelling (BIM) to tag and archive construction component properties for potential reuse is promising for sustainable infrastructure. The integration of RFID and BIM helps reduce materials and waste while preserving the functionality of secondary construction components. Each construction component gets a unique RFID tag linked to a BIM database, facilitating information retrieval and organization throughout all project phases within a 3D information model.	To explore the potential and limitations of the technologies. Although they are currently in their early stages, if they become widely adopted, they could bring about a significant transformation in the construction industry, unlocking value and promoting sustainability with numerous benefits for the environment, economy, and society.
Liu et al. (2018)	This study introduces a framework for combining sustainability rating systems with BIM through a sustainability metric plug-in. This approach enables the exploration of 'what-if' scenarios to enhance sustainability in design decisions and evaluate sustainability during the infrastructure project's design phase. The framework is employed to improve designs, achieve sustainability objectives, and demonstrate compliance with regulations.	This paper suggests focusing more on supporting technical requirements to make it easier to combine BIM and sustainability rating systems. It highlights how adopting BIM can impact the sustainability of infrastructure projects. This framework aims to simplify sustainable design and promote more integrated infrastructure development.

Bapat et al. (2021)	This study adds valuable insights to the field by showing how BIM can be used for sustainable development. It also suggests using alternative building materials and sustainable designs to reduce energy consumption in metro rail stations and other buildings, promoting a sustainable future.	This research can be extended by combining IoT with BIM to create an automated control and monitoring system for energy-efficient infrastructure. This involves using sensor data in the BIM model to make real-time decisions for heating, cooling, and lighting based on standard needs. This versatile model can also be applied to other types of buildings, such as shopping malls, multiplexes, and commercial establishments.
Maqsoom et al. (2021)	This study creates a BIM-based system to assess Rainwater Harvesting (RwH). It finds that the study area has RwH potential to meet demands. This approach offers a foundation for addressing water scarcity in future residential and factory buildings. Using BIM, houses were designed using local knowledge, and the study estimated rooftop area and rainwater storage capacity empirically.	The method can assess Rainwater Harvesting (RwH) potential and household supply and demand in cities worldwide, whether in developing or developed countries. BIM serves as the foundation for understanding rainwater potential and its usefulness throughout the year. This approach can be used worldwide to tackle water scarcity and urban management problems. Other nations can also adopt this approach to leverage the overall advantages of BIM-based RwH.
Onososen & Musonda (2022)	This study adopts 'interpretive structural modelling' to create a ranked structure showing how barriers to integrating BIM into building sustainability assessment are connected. It also uses 'Matrice d'Impacts croises-multipication applique a classement analysis (MICMAC)' to group these barriers in the model. The study found that although there's increasing interest in global sustainability, the focus on sustainable development in the construction industry is gradually growing, mainly due to the demand for sustainable infrastructure. The study emphasizes the importance of using BIM for efficient information management in life cycle assessments and preventing data loss.	Understanding these barriers and their relationships is valuable for discussing challenges in BIM-based life cycle assessments, developing policies, and making design decisions to advance the process. Additionally, it contributes to the ongoing conversation about BIM's role in infrastructure sustainability. These findings are essential for policymakers, stakeholders, and expanding knowledge in this area.
Al-Tekreeti et al. (2022)	This study identified three standard sustainable development indicators: waste reduction, energy consumption, and carbon emissions, which are crucial factors. It created a framework to monitor project stakeholders' commitment to these indicators during the project design phase. The framework was validated by experts and used to develop a Sustainable Development Commitment Tracking Tool (SDCTT-D), which was tested in a real infrastructure project. The results confirmed the tool's usability. The second indicator involves the level of commitment to BIM computer modelling, with 75% commitment representing strong BIM integration and analysis. However, using BIM to model carbon emissions is not widespread, so it received a lower ranking. Similarly, using BIM to reduce energy consumption is not a common practice among designers since it is mainly used for building modelling and space optimization.	The SDCTT-D is a useful tool for monitoring project participants' dedication to sustainable development decisions during the design phase. It helps project teams align their commitment with chosen sustainable development decisions. This tool serves as a foundation for future performance indicators that connect participants' commitment to the desired sustainable development outcomes. The SD tracking tool developed in this study offers a fresh approach to aligning project participants' dedication with decisions made by organizational leaders. Its practical application is to assist project participants in tracking information and measurements used to achieve project goals and, ultimately, the organization's objectives. It also helps identify areas where project participants may need to improve their commitment to sustainable development decisions during the design phase.

Lin et al. (2022)	This article explains the connection between railways and landscapes and the idea of scenic railways in French literature. It then examines the current geographic distribution of these scenic railways in France using GIS tools. By using various techniques like georeferencing, mapping, data analysis, calculation, and categorization, the scenic railways are organized and made available online. After conducting statistical analysis, the article uncovers how these scenic railways are distributed compared to the standard-gauge railway system in France. The article suggests that future research should focus on evaluating the landscapes along scenic railways and how they can be combined with other spatial technologies for more in-depth geographic analysis.	In future research, it is recommended to incorporate additional spatial technologies, such as using TLS (Terrestrial Laser Scanning) to capture railway landscapes and track changes in heritage sites. We also intend to implement BIM (Building Information Modelling) to create models of heritage sites that can be used for future tourism activities and heritage analysis.
Zhang & Ying (2023)	The study's experimental results confirm that the low-carbon building evaluation standard cloud model, which integrates an all-electronic computer interlocking system for urban rail transit, along with comprehensive weighting, effectively calculates the low-carbon index and overall risk level for operational safety. The model optimization is successful. In practice, the combination of GIS and BIM technology enhances construction management by making it more detailed and digital. This approach holds great potential for growth in the urban rail transit and underground construction sector.	This paper creates a construction-focused microservice that integrates management and business aspects. It uses 3D visualization supported by GIS to organize project production and technical management. This approach enhances the quality and safety of engineering construction. In a real-world case study in Ningbo, the system met the information management needs of an urban rail transit project. The system's design was found to be reasonable and effective in improving the efficiency of rail transit project management.
Lozano et al. (2023)	This study created a new method that combines MIVES and BIM approaches to automatically assess the sustainability of bridges. They tested this method on a real viaduct to measure its sustainability and identify which factors had the most impact on its sustainability. Importantly, this method is not restricted to bridges; it can easily be applied to assess the sustainability of other types of infrastructure.	The findings are specific to this case study. All indicator measurements were theoretical, the BIM was not calibrated with on-site data from construction and maintenance phases, and time (4D) and cost (5D) dimensions were not considered. These limitations may affect the accuracy of sustainability assessments for other structures using this method, and future studies will address these issues.

3.1 BIM Applications in Green Infrastructure

The review revealed a growing emphasis on utilizing BIM for the design, planning, and management of green infrastructure projects. Studies highlighted BIM's ability to enhance visualization, simulation, and coordination in the development of sustainable urban landscapes. According to Bonenberg and Wei (2015), BIM facilitates the "visualization" of digital building models using multifaceted digital design solutions, enabling "simulation and analysis" within collaborative scientific platforms for designers, architects, utility engineers, developers, and even end users. Moreover, this contributes to the ongoing discourse on BIM within the context of life cycle sustainability assessment for infrastructure. The discoveries hold significance for policy development, stakeholders, and the expansion of understanding in this field (Onososen & Musonda, 2022).

The integration of BIM with Geographic Information Systems (GIS) was also found to facilitate data-driven decision-making for optimizing green spaces. For example, when examining the existing layout of scenic railways in France, GIS tools were used, by employing techniques such as georeferencing, mapping, data integration, calculations, and categorization (Lin et al., 2022). Lin et al. (2022) further suggested that future research could incorporate additional spatial technologies for these railways, such as to use Terrestrial Laser Scanning (TLS) to document railway landscapes and monitor heritage alterations.

Additionally, BIM can be introduced to create models of heritage sites, supporting future tourism endeavors and heritage analysis. Practical experience demonstrates that the combination of GIS and BIM technologies can enhance precision and digitalization in construction management, with vast potential for growth in the urban rail transit and urban underground space construction sectors (Zhang & Ying, 2023).

3.2 Sustainable Materials Selection

An array of research underscored the significance of sustainable materials selection in construction. BIM's role in facilitating the assessment of material life cycle impacts, embodied energy, and carbon emissions was recognized. Studies by Bapat et al. (2021) showcased significant knowledge in the field by highlighting the application of BIM as a tool for sustainable development. They recommended a few alternate building materials and sustainable designs that reduce energy consumption in metro-rail-station and other building structures leading to a more sustainable future. Meanwhile, Liu et al. (2018) established a conceptual framework for integrating sustainability rating systems by incorporating BIM with a sustainability metric plug-in. This innovative approach enables the exploration of 'what-if' scenarios, providing better support for integrating sustainability considerations into design decisions and evaluating sustainability during the infrastructure project's design phase. The framework helps to fine-tune designs, ensure the achievement of sustainable objectives, and demonstrate compliance with regulatory standards.

Furthermore, the research by Lozano et al. (2023) has introduced an innovative approach that combines the MIVES and BIM methodologies to achieve automated sustainability assessments of bridges. The technique was validated through its application on an actual viaduct, where sustainability was assessed, and a sensitivity analysis was conducted to identify the most impactful sustainability indicators. Importantly, this method is not restricted to bridges; it can be easily adapted for other types of infrastructure. The results highlight how integrating the BIM methodology streamlines sustainability assessments and simplifies the process of evaluating different scenarios.

3.3 Technological Innovations and Tools

The literature indicated a growing trend toward integrating advanced technologies with BIM to promote sustainable construction practices. Exploiting BIM's capabilities in monitoring construction progress, reducing waste, and ensuring precision in sustainable materials installation could be a disruptive innovation in the construction sector. For example, the integration of Radio Frequency Identification (RFID) with BIM offers significant potential for constructing sustainable infrastructure by reducing materials and waste and preserving the functionality of secondary construction components. Each construction component is equipped with a distinctive RFID tag linked to a BIM database, allowing for efficient retrieval and organization of information across all phases of a project, integrated into a 3D information model (Iacovidou & Purnell, 2016).

In addition, research by Maqsoom et al. (2021) assessed a Rainwater Harvesting (RwH) using BIM, demonstrating the potential to meet future water needs. The study introduced a foundational approach to RwH, addressing concerns about future water scarcity in residential and industrial buildings. By using BIM, local insights informed the design of houses, enabling subsequent estimation of rooftop areas and empirical determination of rainwater storage potential. Other than that, Al-Tekreeti et al. (2022) developed a framework which underwent validation by an expert panel and employed it to construct a Sustainable Development Commitment Tracking Tool (SDCTT-D). This tool was also applied in an infrastructure project case study, in which the second indicator is the usage level of BIM computer modelling to a 75% degree of commitment represented by BIM integration and analysis to reduce carbon emissions.

3.4 Challenges and Future Directions

Despite the promises of BIM-driven green infrastructure and sustainable materials and technologies, challenges were identified. The lack of standardized protocols for sustainable material assessment using BIM and the need for interdisciplinary collaboration emerged as significant concerns. Liu et al. (2018) suggest that there should be a stronger focus on supporting technical prerequisites to enable the seamless integration of BIM with sustainability rating systems. Their study highlights the potential of BIM adoption to positively impact the sustainable performance of infrastructure projects. Therefore, the developed framework has the potential to simplify the sustainable design process and promote a more unified approach to delivering infrastructure projects.

Additionally, data interoperability and model accuracy were noted as barriers to the seamless integration of BIM with advanced technologies. For example, as highlighted by Iacovidou & Purnell (2016), further research is essential to explore the potential advantages and limitations associated with the adoption of integrated RFID and BIM technologies. Although this technology is still in its early stages, widespread adoption could significantly revolutionize the construction industry, unlocking value and fostering circularity. Such a transformation could yield numerous benefits for the environment, economy, and society as a whole. The effectiveness of BIM as a valuable tool for seamlessly integrating both natural and technical systems is shown where a multi-dimensional digital model facilitated efficient coordination across multiple disciplines in alignment with green design principles (Bonenberg & Wei, 2015).

When it comes to leveraging BIM for carbon emissions reduction, its useto reduce energy consumption is not yet common among designers, who primarily employ it for building modelling and optimizing spatial arrangements (Al-Tekreeti et al., 2022). The lack of fine-tuned with on-site data gathered during construction and maintenance phases, as well as the omission of the 4D (time) and 5D (cost) dimensions, could negatively impact the precision of sustainability assessments for other structures (Lozano et al., 2023). However, a study by Onososen and Musonda (2022) found that despite increasing global attention to sustainability, interest in sustainable development within the construction industry is gradually growing. This trend is driven by the necessity to deliver sustainable infrastructure for clients. The study emphasizes the importance of adopting BIM for efficient information management in Life Cycle Assessment (LCA) and preventing information loss.

Moreover, combining Internet of Things (IoT) capabilities with BIM features paves the way for an automated control and monitoring system, promoting energy-efficient infrastructure development. This integration involves incorporating sensor data into the BIM model to enable real-time automated decisions for managing the heating-cooling system and lighting fixtures, adhering to standard requirements. Given its versatility, this model can be applied to various building facilities, including shopping malls, multiplexes, and other commercial establishments (Bapat et al., 2021). Additionally, as discussed by Zhang and Ying (2023), utilizing 3D visualization supported by GIS for technical management enhances both the quality and safety of engineering construction. The real-world application of the project demonstrates that this system effectively fulfills the information management needs of urban rail transit projects. The system's design is deemed reasonable and contributes to a significant improvement in the efficiency of rail transit project management.

4.0 CONCLUSION

This systematic literature review has undertaken a comprehensive exploration of the dynamic intersections among Building Information Modelling (BIM), green infrastructure, sustainable materials, and technologies. Through a meticulous analysis of existing research, this study has shed light on the interrelation, challenges, and transformative potentials arising from the convergence of these multidisciplinary domains. The findings of this review indicate the pivotal role that BIM plays in shaping the future of green infrastructure and sustainable materials in the construction industry. BIM's ability to integrate spatial data, assess environmental impacts, and facilitate collaborative decision-making has emerged as a pillar for advancing ecologically conscious urban development.

The synthesis of research also emphasizes the promising potential of sustainable material selection processes within BIM frameworks, enabling designers and practitioners to make informed choices that align with environmental objectives. Technological innovations, including the integration of BIM with advanced systems such as Internet of Things (IoT) and Geographic Information Systems (GIS), have demonstrated their capacity to create responsive and adaptive urban environments. By enabling real-time monitoring, data-driven decision-making, and dynamic modelling, these technologies contribute to the realization of resilient and sustainable infrastructure.

Nonetheless, this review also highlights existing challenges that require attention. The lack of standardized protocols for sustainable material assessment using BIM, as well as issues related to data interoperability and model accuracy, need to be addressed for the seamless integration of these domains. In conclusion, the composition of this systematic literature review marks the importance of interdisciplinary collaboration between architects, engineers, urban planners, and technologists to fully harness the potential of BIM-driven green infrastructure and sustainable materials. The findings serve as a catalyst for further research, innovation, and practice in creating ecologically conscious urban environments that promote human well-being while safeguarding the natural world. As the global imperative for sustainable urbanization escalates, the insights accumulated from this study provide a robust foundation for researchers, practitioners, and policymakers to collaboratively shape the future of urban development, one that seamlessly integrates technology, green infrastructure, and sustainable materials towards resilient and vibrant cities.

This systematic literature review offers substantial benefits to practitioners in the construction industry including architects, engineers, quantity surveyors, urban planners, technologists, as well as policymakers and researchers. It provides comprehensive analysis of how BIM innovation integrates with green infrastructure and sustainable materials and technologies. It highlights BIM's role in informed decision-making, integrates advanced technologies like IoT and GIS, and accentuates the need for interdisciplinary collaboration. By addressing existing challenges and identifying areas for further research and policy development, the study offers valuable insights that can enhance sustainable urban development practices and foster innovation across various sectors.

5.0 CONTRIBUTION OF AUTHORS

The authors contributed equally to the body of the work and writing of the manuscript.

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7.0 CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

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