

Systematic Review

BIM for Sustainable Urban Construction: A Systematic Review of Capability Assessment and Implementation with Implications for China

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Abstract

Driven by China's green and low-carbon development strategy, sustainable urban construction has become a crucial issue in the construction industry. In recent years, building information modeling (BIM) has been widely applied in the construction industry due to its advantages in information management, project coordination, and construction optimization. Although numerous studies have explored the application of BIM in sustainable construction, existing research findings are scattered across different research topics and project stages. Therefore, it is still necessary to develop a clearer understanding of the BIM functions that can support sustainable urban construction and their practical applications, especially in the context of China's construction industry. To address this issue, this study provides a systematic literature review of BIM functions related to sustainable urban construction. Using the PRISMA framework, this study identified and analyzed relevant research to examine the main BIM functions reported in the literature, their application methods, and their contributions to sustainable urban construction. The review identified twelve main BIM functions, including 3D modeling and visualization, data management, multi-party collaboration, cost control, schedule optimization, environmental management, and construction safety management. Based on published research, this study further explores the potential relationships between different BIM functions and proposes several conceptual frameworks to clarify how to integrate these functions in sustainable urban construction. The research results indicate that BIM can support sustainable urban development through information integration, lifecycle coordination, data-driven decision-making, and optimized project management. These findings also provide a reference for the future implementation of BIM and the promotion of sustainable urban development in China, especially in the context of digital transformation and green development in the construction industry.



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1. Introduction

Sustainable environment development is considered to be the future direction of urban development. Sustainable environmental development aims to maintain ecological integrity while meeting economic and social needs. Compared to conventional urban development models, sustainable environmental development tends to protect the long-term resource efficiency of cities, minimize degradation, and promote the regeneration

of natural systems. Through the development of sustainable environments, it can effectively help people to protect and optimize soil health, water conservation, biodiversity, and climate adaptation. Sustainable environment development can ensure the balanced distribution of land, water, air, living comfort, biodiversity, and other environmental resources. It can secure the health, comfort, and resources for the future of human beings. For residents, their living experience can be significantly improved in terms of safety and durability, health and comfort, transportation convenience, resource conservation, and environmental friendliness.

Despite government encouragement for the development of sustainable urban environments, technological barriers severely hinder the further development of urban areas in China. The insufficient efficiency and effectiveness of conventional construction technologies in urban construction are a crucial challenge to the development of urban areas with sustainable environments in China [1,2]. According to the study by Wang et al. [3], technology-related barriers ranked in the top three challenges that hinder the development and promotion of urban constructions in China. To accomplish the sustainable specifications of urban areas with sustainable environments in China, multiple high-tech approaches are necessary to be adopted in the urban construction process in China, including but not limited to prefabrication, sustainable energy utilization methods, green roof technology, and waste mitigation approaches [3].

BIM is deemed the effective method to promote sustainable environment development in cities [4,5]. Building information modeling (BIM) is a business process that enables all stakeholders to create and use building data for design, construction, and operation [6]. BIM is also a database that can provide shared knowledge resources about facility information, providing a solid foundation for decision-making throughout the project's life cycle [6]. During the urban construction process, BIM can effectively assist the stakeholders in accomplishing project quality enhancement, lifecycle information retrieval and management, efficient cooperation improvement, and schedule management optimization. Through BIM utilization in the urban construction process, stakeholders can effectively overcome technical barriers based on its modeling and visualization capability, schedule and project management capability, environmental simulation capability, collaboration capability, and knowledge management capability [5–7]. Based on the survey of Huang et al. [5], it can be deduced that 86.34% of the respondents endorse that BIM can be utilized as a collaborative platform to improve the collaborative quality between stakeholders from different organizations. Furthermore, approximately 89% of the respondents believe that BIM could dynamically simulate the construction process and thus improve the efficiency and accuracy of material conservation during the construction process [5].

Although BIM has been widely discussed in the field of sustainable urban construction, the existing studies focus on different aspects of BIM applications and are often presented separately. As BIM technology continues to develop, new functions and application methods are constantly being introduced. However, there is still a lack of a clear overview of what BIM capabilities have been applied to support sustainable urban construction and how these capabilities have been implemented in practice. This situation makes it difficult for researchers and practitioners to obtain a complete understanding of the current development of BIM in this area. Therefore, a systematic review is needed to summarize the existing knowledge and provide a clearer picture of BIM capabilities and their applications in sustainable urban construction. The findings may also offer useful references for the future development of BIM in China.

To address this gap, this study conducts a systematic review of BIM capabilities related to sustainable urban construction. The review examines existing studies on BIM applications, implementation practices, and sustainability-related outcomes to better understand

the role of BIM in supporting sustainable urban development. Based on the review findings, the study also discusses their possible implications for BIM implementation and sustainable urban construction in China. To achieve this aim, the following research objectives have been developed:

1. To identify the BIM capabilities that contribute to sustainable urban construction.
2. To analyze how BIM capabilities have been implemented to support sustainability objectives in urban construction projects.
3. To summarize the implementation strategies, challenges, and future development trends of BIM-enabled sustainable urban construction and discuss their implications for BIM adoption in China.

This study reviews and summarizes the BIM capabilities currently reported in the literature on sustainable urban construction. It also examines how these capabilities have been applied in different construction activities and sustainability-related scenarios. The findings provide a useful reference for understanding the current development of BIM in sustainable urban construction and may support future BIM implementation and sustainable urban development efforts in China.

2. Methodology

This study adopts a systematic literature review (SLR). A systematic literature review is a review method that comprehensively retrieves, screens, evaluates, and synthesizes literature related to specific research objectives to draw reliable conclusions and opinions. Compared with conventional literature review methods, SLR can reduce bias through clear search criteria, clear inclusion and exclusion criteria, and independent data screening processes. In addition, SLR can cover relevant research as comprehensively as possible and provide more objective and reliable review results than conventional reviews. Furthermore, SLR can also clearly reveal the deficiencies in the current knowledge system, thereby identifying research gaps and future research directions.

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is adopted as the review procedure in this study. PRISMA aims to define standardized procedures of literature search, screening, and review to help authors obtain reliable search results and conclusions. The literature search and review procedures for this study are as follows:

1. Determine the database used in the SLR process.
2. Identify the keywords, inclusion criteria, and exclusion criteria of the article screen.
3. Create search strings based on the keywords, inclusion criteria, and exclusion criteria. Conducting the first round of literature search through developed search strings.
4. Remove duplicate articles.
5. Review the titles and abstracts of the remaining articles and filter out those that do not meet the criteria.
6. Review the full text of the remaining articles and filter out those that do not meet the criteria.

The document search for this study was conducted in May 2026, and the documents included in the search are those published in May 2026 or earlier. The databases used for document retrieval in this study are Web of Science, Engineering Village, and Scopus. Due to limited resources, title/abstract screening and full-text eligibility assessment are primarily conducted by the first author (Y.C.). To improve consistency and reduce selection bias, the review process is conducted strictly according to the inclusion and exclusion criteria and involves multiple rounds of review and screening. If, during the paper screening process, the first author is unable to confirm whether one document met the inclusion

criteria, this document will be submitted to the second author (H.S.) for secondary review. All screening decisions were processed according to the predefined criteria, and uncertain cases were discussed between the authors before a final decision was reached. Nevertheless, independent dual screening and inter-rater reliability assessment were not performed, which should be considered when interpreting the findings of this review.

The process of article screening and review is presented below.

Phase 1: Formulation Stage. This initial stage involves defining the databases, search keywords, and criteria for including or excluding articles. To ensure the quality of retrieved literature, Web of Science, Engineering Village, and Scopus are selected as the primary database. The search strategy incorporated the keywords: “Building Information Modeling”, “BIM”, “urban construction”, “green construction”, “green building”, “low-carbon building”, “smart construction”, “sustainable construction”, “environment”, “ecology”, “carbon footprint”, “life cycle assessment”, “circular economy”, “China”, and “Chinese”. Regarding document types, the articles, conference papers, and reviews were considered; other formats were excluded. Specific inclusion and exclusion criteria are detailed in Table 1. Regarding document types, journal articles, conference papers, and review papers were considered, while other document types were excluded. Grey literature (e.g., theses, technical documents, and unpublished materials) was not included in this review. The search period was defined from 2013 to May 2026 because research on BIM applications for sustainable urban construction became increasingly visible in the international literature after 2013, while May 2026 represented the most recent period accessible at the time of the database search, which was the date when the database search was conducted. Specific inclusion and exclusion criteria are detailed in Table 1.

Table 1. Inclusion and exclusion criteria.

Primary Criteria		Secondary Criteria	
Inclusionary	Exclusionary	Inclusionary	Exclusionary
Journal articles, reviews, and conference papers that can be searched in the Scopus	Duplicated papers	Empirical, case-study, review, modeling work, methodological framework research, or theoretical derivation that includes at least one BIM capability applied in an urban construction or building project, with a measurable or qualitatively described environmental, ecological, or sustainability outcome.	No technologies classified as BIM (building information modeling) were discussed in this study.
			The core objectives and discussions of this study do not involve themes such as environment, ecology, sustainable development, green construction, or urban development, nor is there any discussion of the connection between BIM applications and these themes.
Written in English	Written in non-English		The amount of information provided in the literature is insufficient to determine whether it meets the above inclusion criteria.
			Multiple papers have been published based on the same set of data or the same research results.

Phase 2: Screening Stage. The retrieved documents underwent screening based on the criteria in Table 1. The initial database search using these parameters yielded 907 docu-

ments, with the exact search strings and results presented in Table 2. The first screening step removes duplicates and other problematic articles. After retrieval, records from different databases were merged into a single dataset. Duplicate records were identified and removed through comparison of titles, authors, publication years, and DOI information. When inconsistencies were found across databases, manual verification was conducted to determine whether the records referred to the same publication before exclusion. This step excludes 305 documents, leaving 602 for title/abstract review. In the second step, title and abstract screening further excludes 458 documents primarily based on the inclusive and exclusive criteria. After the title/abstract screening was completed, 144 articles remained. In the third step, the authors filtered out 7 articles that could not be retrieved. In the fourth step, the authors conducted an eligibility assessment on the remaining documents and excluded 55 documents according to the criteria shown in Figure 1. Consequently, 82 articles proceed to full-text review. After the full-text screening process, the included studies were reviewed in detail. Information relevant to BIM capabilities, implementation practices, and sustainability contributions was extracted and organized. The findings reported in the selected studies were then compared and summarized to identify common observations and key research trends. Figure 1 illustrates the complete article screening process flowchart for this study.

Table 2. Search strings and documents search results.

Search Engine	Search String	Document Types	Results
Scopus	("Building Information Modeling" OR "Building Information Modelling" OR "BIM") AND ("urban construction" OR "green construction" OR "green building" OR "low-carbon building" OR "smart construction" OR "sustainable construction" OR "environment" OR "ecology" OR "carbon footprint" OR "life cycle assessment" OR "circular economy") AND ("China" OR "Chinese")	Article OR Proceeding Papers OR Review Articles	338
Web of Science		Article OR Conference Papers OR Conference Review OR Review	341
Engineering Village		Journal Article OR Conference Article OR Conference Proceeding	228
Sum of the papers = 907			

Phase 3: Review Stage. The final 82 articles underwent systematic analysis to identify the specific capabilities of BIM that can be utilized in urban construction to improve or protect the environment. To enhance transparency and consistency in the quality assessment process, a simplified quality assessment framework adapted from Mixed Methods Assessment Tool (MMAT) Version 2018 principles was applied. Three aspects were evaluated for each included study: data source reliability, methodological rigor, and evidence strength (as shown in Table 3). The specific scoring criteria for each dimension in the simplified quality assessment framework, adapted from the MMAT principles, are shown in Table 4. Each aspect was assigned a rating of high (3 points), medium (2 points), or low (1 point) according to predefined criteria (as shown in Table 4). The scores from the three dimensions were then summed to obtain an overall quality score ranging from 3 to 9. Studies with total scores of 8–9 were classified as high quality, those scoring 5–7 were classified as medium quality, and those scoring 3–4 were classified as low quality.

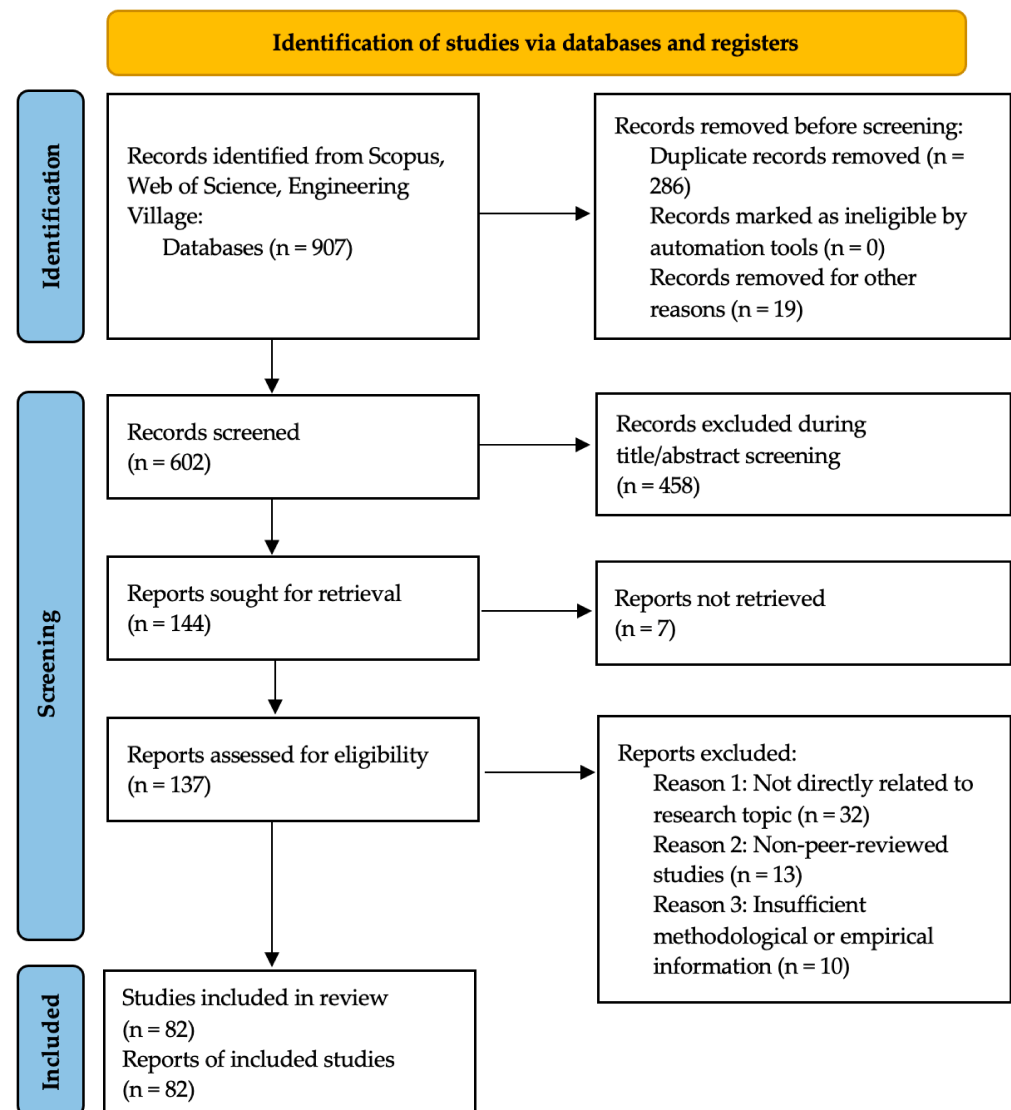


Figure 1. The complete article screening process flowchart for this study (PRISMA 2020 (Supplementary Materials)).

Table 3. A simplified quality assessment framework adapted from the Mixed Methods Assessment Tool (MMAT) principles.

Assessment Dimension	Evaluation Criteria	Rating Standard
Data source reliability	Whether the study used reliable and clearly described data sources	High/Medium/Low
Methodological rigor	Whether the research methods and analytical procedures were clearly explained and systematically applied	High/Medium/Low
Evidence strength	Whether the conclusions were supported by sufficient empirical evidence or multiple cases	High/Medium/Low

This approach provided a transparent basis for comparing studies while accommodating the diversity of research designs included in the review. Because the included literature consisted of diverse study types, including but not limited to case studies, simulation studies, review articles, and conceptual studies, the assessment framework focused on evaluating general indicators of research quality rather than study-design-specific criteria. The three dimensions were intentionally selected because they can be applied across

different research designs. For example, data source reliability assesses the transparency and credibility of information sources regardless of study type; methodological rigor evaluates the clarity and systematic application of research procedures; and evidence strength examines the extent to which conclusions are supported by empirical evidence, cases, or well-developed analytical arguments. This approach was adopted to ensure consistency of assessment while accommodating methodological diversity among the included studies.

Table 4. The specific scoring criteria for each dimension in the simplified quality assessment framework adapted from the Mixed Methods Assessment Tool (MMAT) principles.

Dimension	High (3 Points)	Medium (2 Points)	Low (1 Points)
Data Source Reliability	Peer-reviewed empirical studies with transparent data sources	Partially described data sources	Unclear or weak data sources
Methodological Rigor	Clear research design and analytical procedures	Moderate methodological detail	Limited methodological transparency
Evidence Strength	Strong empirical support and validated findings	Moderate support	Weak or largely speculative findings

Based on the above criteria, this study conducted a quality assessment analysis of the included articles using the simplified quality assessment framework adapted from the Mixed Methods Assessment Tool (MMAT) principles. Specific assessment information is shown in Table A1 (refer to Appendix A). The analysis results indicate that the overall quality of the selected studies is relatively high. Approximately 83% (68/82) of the documents received a “high” quality rating, indicating that most studies employed reliable data sources, rigorous methodologies, and reliable empirical evidence. Many studies utilized case studies, simulations, quantitative analyses, systematic literature reviews, or integrated BIM-based frameworks, which effectively ensured the validity and reliability of the research results. Furthermore, approximately 17% (14/82) of the documents received a moderate quality rating. It is mainly due to the situations that these studies relied on conceptual discussions or limited case validation. However, the findings of these studies still provide an indispensable contribution to this research, offering necessary knowledge and data support for researchers exploring the applications of BIM in construction management, sustainability, visualization, scheduling, and information management.

3. Results

3.1. Descriptive Analysis

Analysis of publication trends shows that research on BIM for sustainable urban construction has developed unevenly over time (Figure 2). Between 2013 and 2015, only four studies were published, with an average of 1.33 papers per year. The studies published during this period mainly explored the basic applications of BIM in construction projects and their potential relevance to sustainability.

The number of publications began to increase after 2016. In 2019, 14 papers were published, accounting for 17.07% of the reviewed studies. This increase coincided with the growing attention given to digital construction, information management, and sustainability issues within the construction sector. The highest number of publications was recorded in 2022, when 19 studies were published, representing 23.17% of the final sample. Compared with the earlier studies, the research topics during this period became more diverse and included environmental assessment, lifecycle management, resource optimization, and the integration of BIM with other digital technologies.

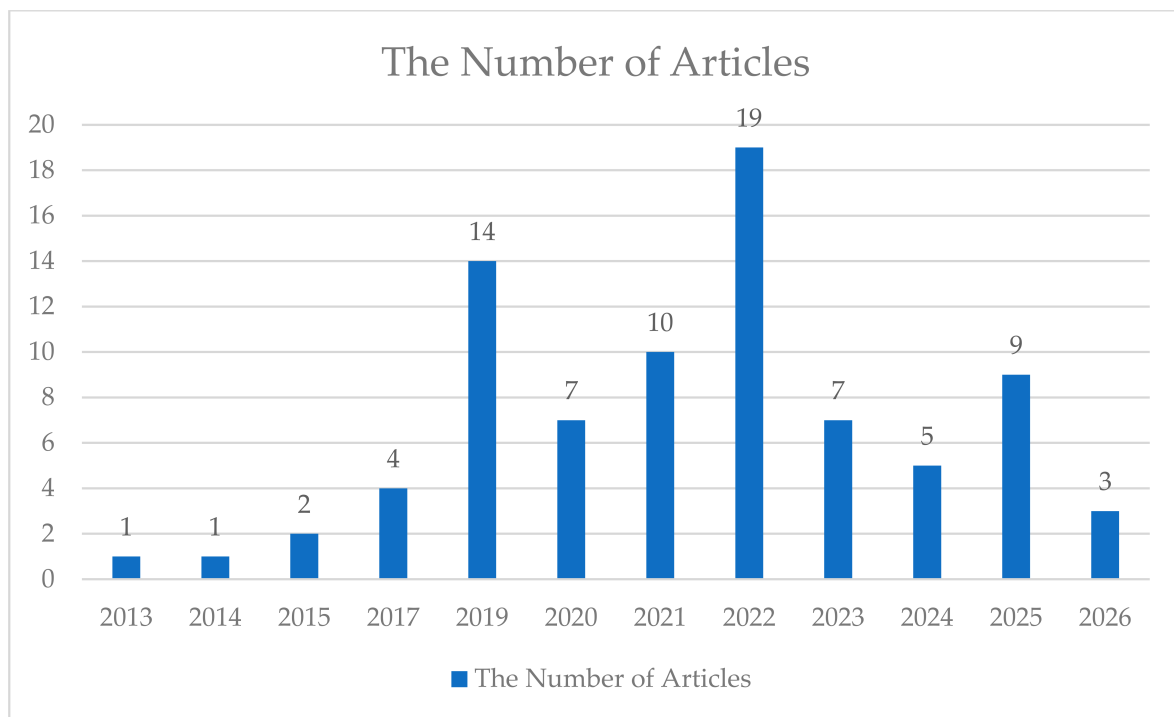


Figure 2. The number of articles published per year.

The number of publications decreased slightly from 2023 to 2025, but the annual output remained higher than that observed before 2019, averaging about seven papers per year. This indicates that BIM for sustainable urban construction has continued to attract research attention in recent years. Since the literature search was conducted in May 2026, publications released after the search date were not included. Consequently, only three studies published in 2026 were captured in this review.

In terms of the countries of publication, 82 documents originated from 28 countries or regions (as presented in Figure 3). An analysis of the national distribution of these 82 papers (based on the first correspondence address) reveals significant regional imbalances. China leads with 26 papers (31.71%), reflecting its emphasis on BIM implementation in sustainable urban construction and environmental protection. This phenomenon is directly related to the support policy drive of China (the 14th Five-Year Plan clearly requires the promotion of BIM development and application). Traditionally developed countries such as the United States (7 papers), Australia (6 papers), the United Kingdom (6 papers), and Canada (5 papers) also contribute numerous academic papers, demonstrating their emphasis on advanced construction technologies, urban development, and environmental protection. Singapore (4 papers), Pakistan (3 papers), Malaysia (3 papers), South Korea and India (2 papers each) represent emerging research power in Asia. As a traditional industrial powerhouse, Germany (2 papers) has also made contributions in this field. In summary, BIM research is highly concentrated in countries with strong development of building technology and supportive policies. And many developing countries (such as Egypt and Vietnam) are also beginning to participate sporadically.

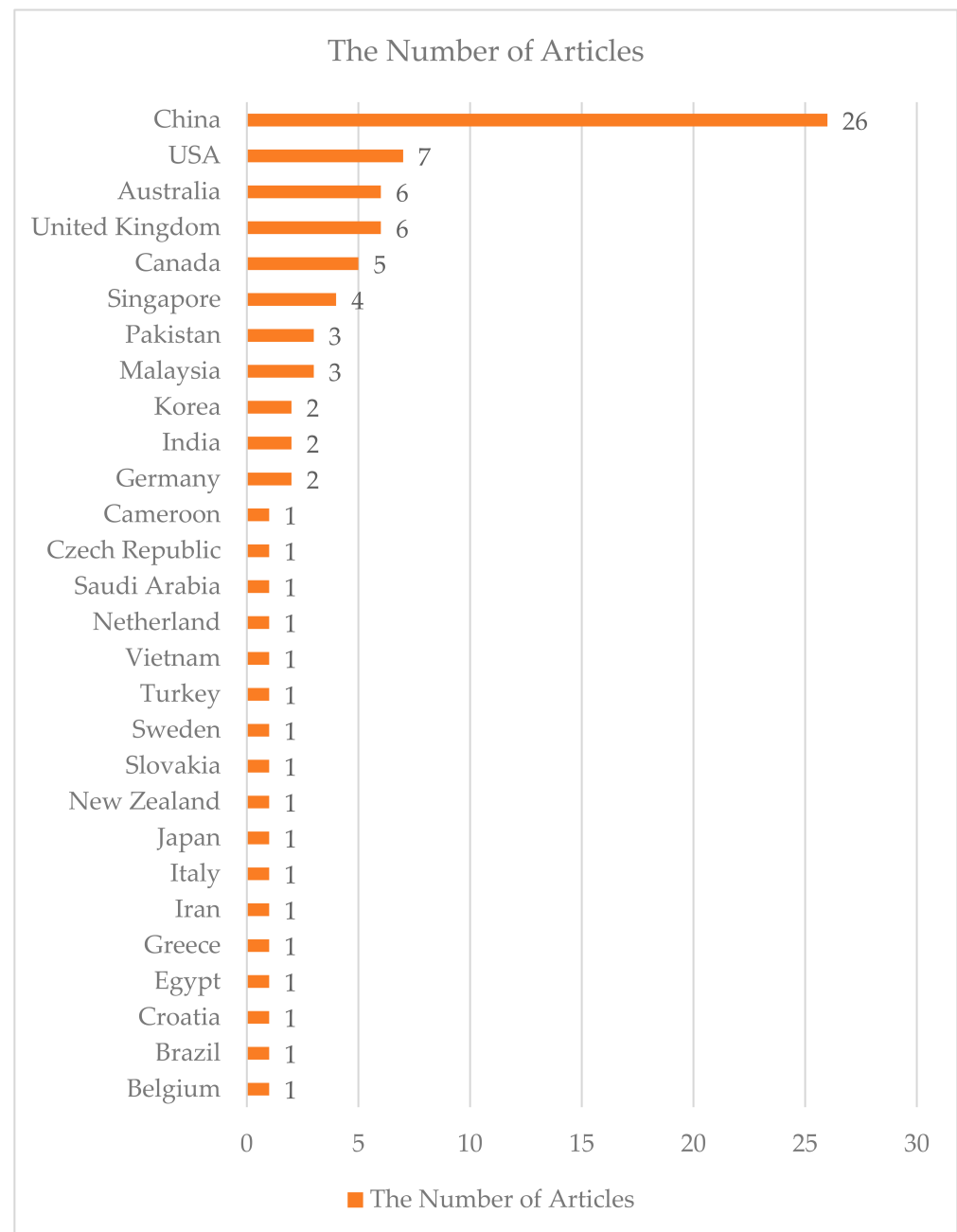


Figure 3. The number of articles published in different countries or regions.

3.2. Results Analysis

The analysis of the selected studies identified 12 BIM capabilities that have been applied in sustainable urban construction. To facilitate presentation and discussion, these capabilities are examined separately in Sections 3.2.1–3.2.12. However, they should not be regarded as completely independent functions. In many of the reviewed studies, the reported benefits of BIM were achieved through the combined use of multiple capabilities, including information management, visualization, project coordination, environmental simulation, and resource optimization.

The reviewed literature also indicates noticeable differences in the maturity and practical application of these capabilities. Functions such as 3D modeling, schedule management, and cost management have been widely adopted and are supported by relatively established implementation procedures. By comparison, some emerging applications, including environmental impact simulation, carbon assessment, and intelligent decision support, are

still under active development and often rely on additional technologies, external databases, or specialized analytical tools.

Therefore, the 12 capabilities identified in this review are better understood as interconnected components rather than isolated technical functions. The following sections present the detailed findings for each capability, while their similarities, differences, maturity levels, and potential relationships are further discussed in Section 4.

3.2.1. 3D Modeling and Visualization

BIM is a digital representation that includes physical and functional information of assets and a shared knowledge resource that can support stakeholders in formulating reliable decisions throughout the lifecycle. As an effective multi-functional information technology, BIM can provide significant contributions to the entire urban construction process.

Multiple studies acknowledge that the BIM capabilities could provide significant contributions to urban construction. Multiple studies have emphasized the significance of 3D modeling and visualization [8–15]. Compared to the conventional 2D planar presentation of CAD drawings, BIM can present the 3D model to the stakeholders, which can enhance the understanding of the stakeholders of the urban construction scheme [10]. Moreover, with the integration of third-party sensors, BIM can be utilized to present the real-time layout and conditions of the construction site and surrounding environment [12]. The real-time demonstration can effectively facilitate the stakeholders to better arrange the construction activities and plan the logistic routes, which can effectively prevent urban construction from polluting and damaging the land environment and resources.

In addition, 4D BIM can achieve the integration of a 3D building diorama with the construction schedule [11]. The fourth dimension of BIM (4D BIM) technology integrates the time dimension into existing BIM modules, effectively mitigating ambiguity and uncertainty in complex construction projects [16]. This viewpoint was supported by Rehman et al. [17], who believed that the application of 4D BIM in the construction field improves the accuracy and efficiency of planning, reduces construction delays, and enhances coordination and communication among all stakeholders. Through this integration, 4D BIM can demonstrate to stakeholders the situation of modeled buildings with 3D visualization presentations at different time nodes/schedule nodes [11].

To achieve real-time four-dimensional visualization of construction projects and solve the problems of information delay and data inconsistency to better protect the environment, Park et al. [13] propose a visualization method that integrates web and database support. Park et al. [13] build a central database framework that can perform automatic updates of BIM object visualization and integrate it into the BIM implementation process, thus ensuring that BIM can visualize the constructions in real time and in 4D. Jeong et al. [9] develop the BIM-based thermal energy performance visualization (TEPV) approach by integrating object-oriented physical modeling (OOPM) and BIM. This BIM-based visualization approach connects BIM with external databases, including thermal performance simulation information through application programming interfaces (APIs), thereby visualizing the thermal performance of building components in a color-coded manner [9]. Based on the above modeling functions and information integration, stakeholders can effectively manage urban construction activities to reduce the negative impact on the land environment and ensure the sustainability of the land environment and living comfort.

In order to realize the visualization of construction risks, Zou et al. [15] integrate the risk breakdown structure (RBS) with 4D BIM in its risk management framework, thereby mapping the risk data of urban construction projects into the BIM model. By interlinking BIM with the risk control module and mapping the construction model with risk information, this BIM-based risk management prototype tool can achieve the three-dimensional

visualization of automatic identification of construction risks [15]. To realize the advantages of 4D BIM through immersive 3D visualization and sequential modeling, Afzal and Shafiq [18] used VR-integrated 4D BIM to conduct realistic and real-time simulations of the construction site environment to conduct the safety training for workers. Through conducting immersive simulations of hazardous factors and corresponding countermeasures on the construction sites, communication barriers between workers from different cultural backgrounds are avoided [18]. To avoid safety issues and property damage caused by sudden supply chain disruptions, Zeng et al. [19] propose a 4D BIM-based safety management tool that can simulate and display the construction site and non-construction logistics areas in three dimensions. This 4D BIM-based safety management tool can provide early warning signals with location information, enabling construction managers to intuitively identify risk areas and proactively adjust schedules and promptly identify supply chain disruptions [19].

In addition, BIM's 4D visualization can effectively solve the structural health monitoring (SHM) problem of buildings with complex structures. The SHM visualization warning framework based on the Web-BIM module proposed by Hou et al. [8] can effectively locate and display the source of danger in three-dimensional modeling. By establishing an information upload channel between sensors and BIM models, the construction site can be visualized and updated in real time in BIM. Through the Web-BIM risk management platform that integrates the Web UI interface, link database and background controls, BIM can achieve the 4D visualization of the potential risk factors and structural health status of buildings [8]. Moreover, the three-dimensional visualization function of BIM also includes the visualization of structural internal stress. Wang and Huang [14] use the Dynamo visualization programming module in Revit to establish linkages between the BIM model and the Midas Civil finite element model. On this basis, the BIM-based visualization tool can visualize the internal force condition of the stress measurement point in a color-coded mode according to the data of the stress measurement points and the building models [14]. Through the above functions, stakeholders can take precautions and take safety measures in advance to avoid environmental pollution and casualties among urban residents.

Through the systematic review and analysis in this study, it can be identified that 4D BIM can improve the efficiency of schedule visualization, construction coordination, and short-term planning. Moreover, the shifts in research focus over time reveal the development direction of BIM's 3D modeling and visualization capabilities. Early studies primarily concentrated on visualization and database integration to enhance schedule transparency (e.g., Park et al., [13]), while recent research increasingly incorporates predictive and adaptive capabilities, such as supply chain disruption warnings (e.g., Zeng et al. [19]) and AI-assisted schedule optimization (e.g., Rehman et al. [17]; Awe et al. [16]). This trend indicates that 4D BIM is gradually shifting from a passive visualization tool to an intelligent decision support system.

Although most reviewed studies reported positive outcomes, the reported benefits appear to vary across different project contexts. Stronger evidence is generally observed in large-scale and information-intensive projects, where BIM can be more effectively integrated with scheduling, coordination, and management systems. By contrast, evidence from projects with lower levels of digitalization remains relatively limited.

Nevertheless, current research primarily demonstrates the effectiveness of 4D BIM in high-technology-level and information-intensive projects. However, given the high technical requirements of 3D BIM, its applicability in projects with low levels of digitization or in enterprises with limited technical capabilities still requires further validation. Furthermore, while most research reports indicate that BIM's modeling and visualization capabilities can improve coordination and planning efficiency, its long-term impact on project performance,

cost reduction, and organizational decision-making still requires further empirical research by future researchers for evaluation.

3.2.2. Data Storage and Management

Multiple studies [20–24] have shown that the variable ‘data storage and management’ has a significant contribution to urban construction to improve the sustainable performance of the environment. The data storage and management function in BIM is an effective approach to solving information fragmentation issues. During the urban construction phase, information about the construction projects can be classified and stored in a BIM database for data management by stakeholders. Although information sharing and collaboration are also discussed in the drawing design/construction design delivery capability, the studies reviewed in this section mainly focus on data integration, interoperability, and information management throughout the project lifecycle rather than the delivery of design outputs. In addition, BIM supports the multidisciplinary information integration on specific project models, thus facilitating building performance optimization by stakeholders [20,21,23,24].

Moreover, BIM can be implemented as a collaboration platform that can support stakeholders from various organizations to collaborate and communicate with each other. Based on widely adopted industry foundation classes (IFC) data standards and the assistance of model view definitions (MVD), data exchange and information sharing can be achieved between modules without omission and inaccurate transcription [22]. To optimize material information management during the construction phase, Průša et al. [25] create models from existing libraries provided by building material manufacturers and suppliers, including but not limited to the mechanical properties, physical properties, and costs of individual construction components and materials, and use them for energy modeling. Considering the incompatibility of format standards between information from different sources, Abanda et al. [26] proposed a BIM ontology for information management (BIM-OIM) and deeply developed this information management framework using the ontology methodology (YAMO). This module further optimizes the usability and ease of use of BIM process data, effectively reducing the difficulty of data management during construction [26]. Conventional information management methods suffer from a lack of real-time feedback and insufficient dynamic adaptability. To solve these challenges, Wang et al. [27] integrate 3D visualization, intelligent analysis, and real-time sensor data with BIM applications to develop a multifunctional building information management framework based on BIM, thereby achieving triple optimization in design efficiency, feedback accuracy, and user satisfaction.

The documents reviewed in this study suggest that BIM-based data management can improve interdisciplinary communication, information sharing, and project coordination by integrating project information within a common digital environment. Compared with some emerging BIM applications, such as environmental simulation and sustainability assessment, data storage and management functions appear to be relatively mature and have been adopted in a wider range of project settings. However, their contribution to sustainability is often indirect, as they mainly provide the information foundation required for other BIM-enabled environmental applications. Furthermore, the reported benefits are not entirely consistent across all studies. While several studies emphasize the effectiveness of BIM in reducing information fragmentation and supporting collaborative decision-making, others highlight persistent challenges associated with data interoperability, software compatibility, and information exchange across different platforms.

An issue identified multiple times in the literature is the incompatibility of data formats among BIM software systems. Although the IFC standard has been widely promoted as a mechanism for information exchange, differences in IFC export, interpretation, and

implementation among software platforms may still result in information loss, attribute inconsistencies, or classification errors. In addition, software updates and version changes can create further barriers to long-term data accessibility and model reuse. These findings suggest that the effectiveness of BIM-based information management is influenced not only by the functionality of BIM platforms themselves but also by the maturity of data standards, interoperability mechanisms, and organizational information management practices. Therefore, despite the considerable progress achieved in BIM-enabled data management, interoperability remains one of the most frequently reported challenges and continues to affect the wider application of BIM in sustainable urban construction.

3.2.3. Drawing Design/Construction Design Delivery

Many studies [28–31] have revealed that the variable ‘Drawing design/construction design delivery’ can significantly help improve urban construction quality and efficiency. For urban construction projects that adopt BIM in their design phase, the models and other data generated during the design phase can be seamlessly delivered to the construction organization, which can improve the efficiency and data accuracy in the project delivery process [29]. BIM-based integrated project delivery (IPD) is deemed an effective way to eliminate boundary barriers in document delivery and improve project efficiency. The definition of IPD is “A project delivery approach that integrates people, systems, business structures, and practices into a process that collaboratively leverages the talents and insights of all participants to optimize project outcomes, increase owner value, reduce waste, and maximize efficiency in all phases of design, fabrication, and construction [31].” BIM-based IPD effectively avoids information/document/data delivery issues caused by docking problems and the lack of communication between organizations by integrating various participants. Drawing design/construction design delivery functions based on BIM can achieve accurate delivery of urban construction information, avoid secondary re-work/construction errors/delays/waste, and effectively achieve resource conservation and ecological protection to protect the environment and the ecological diversity of urban areas.

Although BIM-based information delivery has made significant contributions to improving document transfer between design organizations and construction contractors, there are still some issues that should be addressed in the BIM-based information delivery between design organizations and construction contractors. Mayer et al. [30] reveal in their survey that although disciplines such as architecture, structural engineering, and some MEP disciplines implemented BIM at the beginning of the project, disciplines such as fire protection and electrical engineering rarely adopted BIM or only used CAD for design. In addition, the incompatibility of BIM software or the inconsistent formats used by designers and builders also seriously hinder the delivery of BIM-based files. In order to solve the problem of format incompatibility, the Delivery Standard for Building Information Modeling [28] stipulates the following:

- I. BIM models should provide the original file format, convert and provide one or several common file formats (such as IFC, NWD, DWF);
- II. Analysis models should provide the original file format and analysis reports in common file formats (such as DOC and PDF).
- III. Visualization results should provide common media file formats (such as AVI, WMV, FLV, etc.).
- IV. Two-dimensional views should provide the original file format, convert it, and provide one common file format (such as PDF and DWF).
- V. Explanatory documents should provide common file formats (such as PDF).
- VI. For all delivered documents, a unified document directory structure should be standardized and divided into levels (such as by document category, profession, etc.).

VII. A file list directory should be provided according to the document category, and basic information such as the purpose of each specific file should be indicated.

Above all, the implementation of BIM in project delivery has moved beyond traditional two-dimensional drawing production, gradually expanding to information sharing throughout the entire project lifecycle. Some studies focus on the integration of BIM with the IPD (Integrated Project Development) model, arguing that early multi-party participation and data platform sharing can improve the efficiency of information transmission between design and construction, reducing project fragmentation (represented by Piroozfar et al. [31]). Other studies combine 5D BIM with cost management methods for early-stage cost forecasting and risk control, thereby improving the reliability of design-phase decisions (represented by Elghaish et al. [29]). However, current research shows differences in team responsibilities, information standards, and collaborative processes, indicating that a unified implementation model for BIM design delivery has not yet been established. Furthermore, some research remains at the theoretical and technical level, lacking exploration of the application effects of BIM-based project delivery in real-world engineering environments.

3.2.4. Cost Estimation and Optimization

Many studies [12,32–35] have pointed out that the BIM capability ‘cost estimation and optimization’ can be applied to urban construction and bring benefits. In urban construction projects, many contractors find it difficult to take environmental protection measures to protect the environment due to cost constraints. The cost estimation and optimization function based on BIM can help stakeholders effectively achieve urban construction cost control, and then carry out environmental protection measures in the urban construction process in a cost-effective manner, thereby further achieving a dynamic balance between economic benefits and ecological environmental benefits.

BIM can provide significant contributions to cost estimation and optimization in urban construction projects. The conventional cost estimation requires tremendous workloads to perform calculations and statistical tasks, which places heavy burdens on the quantity surveyors. In BIM-based design and construction, the building components, equipment, and utilized materials are included in a multi-dimensional building model so that BIM can automatically perform the quantity takeoff and cost estimation tasks with more efficiency and accuracy [32]. The common data exchange standard (e.g., IFC) effectively facilitates the mutual information transmission between modules with the information related to cost estimation [32]. The BIM-based compound element quantity takeoff improvement (BCEQTI) method is proposed by Khosakitchalert et al. [34] to mitigate the negative impact of inappropriate BIM approaches on the quantity takeoff. By integrating BIM clash detection with quantity takeoff activities, BIM can eliminate the number of elements with double counting and supplement the quantity of missed elements, enabling precise counting of compound element quantities [34].

By integrating BIM 4D with cost management functions, BIM can assist stakeholders in analyzing the cost at different nodes to avoid overspending [12]. In addition, BIM-adopted quantity take-off can assist the stakeholders in developing cost budgets [35]. Given the dynamic link between the model and the costing information, the BIM can facilitate stakeholders renewing the cost and bill of quantities in accordance with the alteration made [35].

In the aspect of cost optimization, BIM has the obvious effect of reducing the rework rate to avoid unnecessary expenditure and reduce urban construction costs. According to the survey by Hwang et al. [33], the rework rate of BIM-implemented construction projects is significantly lower than that of construction projects that adopted conventional construction methods. By utilizing BIM throughout the urban construction process, devel-

oping the rework tracking system and working framework applicable to BIM-implemented buildings, and formulating the strategy for BIM-based work guidelines, BIM can effectively reduce rework rates and the negative impact of rework on construction projects [33]. The case study of Das et al. [36] also supports this opinion. The study by Das et al. [36] was conducted in two phases. In the first phase, Das et al. [36] use the questionnaire survey method, selecting experienced BIM experts (BIM managers, architects, etc.) and identifying key factors affecting project time and cost. Based on this, Das et al. [36] invite these participants to a second phase of interviews, asking them to estimate the percentage change in these key factors after implementing BIM, drawing on their own project experience. Triangulation is performed using project plans, budget reports, and on-site observations to ensure the research results are largely consistent with reality. Studies have shown that 5D BIM-based design error identification, budget allocation, dynamic workforce updates, and construction schedule optimization have successfully reduced coordination requests (RFIs) by 80%, rework costs by 40–50%, and design errors by 50–60% [36]. This effectively reduced the rework rate and overall cost of the construction project.

The reviewed studies generally agree that BIM-based cost estimation and optimization can improve quantity takeoff accuracy, enhance information integration, and support more efficient cost management throughout the project lifecycle. Nevertheless, differences can be observed in the ways these benefits are achieved and evaluated across the literature. Early studies primarily focused on improving the accuracy and reliability of quantity takeoff and cost estimation through automated data extraction and model-based calculations (e.g., Khosakitchalert et al. [34]). More recent studies have increasingly explored the integration of BIM with project performance management, machine learning techniques, dynamic budgeting, and lifecycle cost control (e.g., Banihashemi et al. [32]; Nguyen et al. [12]; Das et al. [36]). This shift suggests that BIM-based cost management is gradually evolving from a measurement-oriented tool toward a broader decision-support function.

Compared with environmental simulation and carbon assessment applications, BIM-based cost estimation and optimization have been more widely implemented in practice because cost information is directly linked to project profitability and decision-making. However, most existing studies focus on technical improvements in quantity take-off and budgeting, while the organizational and managerial implications of BIM-enabled cost management remain relatively underexplored.

In addition to these, the reported effectiveness of BIM-based cost management is not entirely consistent across different project contexts. Current studies report substantial reductions in rework costs, estimation errors, and coordination-related expenditures, particularly in large-scale projects with high levels of digitalization and organizational support. In contrast, evidence regarding small and medium-sized projects remains relatively limited. The implementation of BIM-based cost management often depends on the availability of accurate models, standardized data structures, and skilled personnel, all of which may be more difficult to achieve in projects with limited technical resources. Consequently, although the potential benefits of BIM-enabled cost optimization are widely recognized, the extent to which these benefits can be transferred across different organizational and project environments remains uncertain.

Another observation is that cost optimization rarely relies on cost management functions alone. Many of the reported benefits are closely associated with other BIM capabilities, including clash detection, schedule management, information sharing, and project coordination. For example, reductions in rework costs are often achieved through the combined effects of design coordination and clash detection rather than through cost estimation functions themselves. This suggests that the effectiveness of BIM-based cost optimization

may depend on the successful integration of multiple BIM capabilities rather than on any single function in isolation.

Overall, existing research demonstrates considerable potential for BIM-based cost estimation and optimization. However, much of the available evidence remains concentrated in technology-intensive projects and focuses primarily on technical feasibility. Further empirical studies are needed to examine how these capabilities perform in different organizational settings and to better understand the managerial, institutional, and contextual factors that influence their practical effectiveness.

3.2.5. Project Schedule Management

‘Project schedule management’ is highlighted by multiple studies as a necessary BIM capability in urban construction [12,37–39]. Conventional progress management has the disadvantages of cumbersome engineering quantity calculation tasks and the lack of three-dimensional displays, which leads to low progress control efficiency. While both this capability and 4D BIM involve construction scheduling, their analytical focus differs. The 4D BIM capability primarily emphasizes the visualization and simulation of construction sequences. In contrast, the studies reviewed in this section focus more on schedule control, progress monitoring, coordination, and management decision-making during project execution. By integrating BIM-4D with project schedule management, BIM can build an information-rich, intuitive, and dynamic project progress control system [12]. The progress management platform based on 4D-BIM can provide construction personnel with 4D real model management, buffer critical chain monitoring, and progress warning modules [12]. In the BIM-implemented schedule management, BIM can record and display details of individual construction activities (including their planned start and finish dates, and actual start and finish dates).

To visualize the project progress, BIM can also match and visualize the specific colors of building components at different states (including those under construction, those overdue, those having been completed, and those not yet started) in the building information model to inform the stakeholders of the project progress [12]. Based on the recorded planned/actual completion time of the construction activities and the project schedule, BIM can be used to perform schedule comparison analysis to determine the interval period between the expected and actual schedule and to conduct project schedule alerts [12,38].

In the BIM-based project management process, project schedule development is no longer a series of repetitive and isolated tasks [39]. 4D BIM can achieve accurate material quantity estimation, determine the required time for each delivery to be included in the overall structure, locate the exact location of the required materials, and integrate these three types of data to establish connections between them [39]. Nguyen et al. [12] also point out that BIM can use the component library in the database to enhance modeling efficiency, simulate the construction process to improve the accuracy of on-site construction, and use the quality management platform to identify components that need to be revised. Based on the BIM project management platform, project managers can mark existing problems in the model and provide feedback to other participants to identify and solve problems in a timely manner; tracking verification and statistical analysis play a vital role in effective control [37].

In construction projects involving multiple parties, the lack of effective coordination or cooperation among the multiple construction teams often leads to delays in the planned progress. BIM, as a multi-functional tool that combines multi-party coordination and schedule management, can effectively address this issue. During the pandemic, to avoid construction delays caused by widespread infection, Perera et al. [40] developed a BIM-based construction framework that integrates social distancing regulations into the

construction schedule. This BIM-schedule management framework is based on the visual programming platform. It can help different construction teams coordinate their schedules, thereby helping control the spread of viruses [40]. Case studies show that this BIM-based scheduling framework can effectively optimize scheduling efficiency and reduce overall project delays [40].

The reviewed studies generally support the application of BIM in project schedule management and report improvements in schedule visualization, construction coordination, progress monitoring, and communication among project participants. However, the focus of existing research has gradually evolved over time. Earlier studies primarily emphasized BIM's ability to visualize construction schedules and improve the communication of project plans, thereby enhancing transparency and facilitating coordination among stakeholders. More recent studies increasingly examine how BIM can support dynamic decision-making, real-time progress tracking, logistics coordination, and adaptive schedule management in complex construction environments [38–40].

Differences can also be observed in the maturity of various schedule management applications. BIM-based schedule visualization, progress comparison, and construction sequencing have been widely adopted and represent relatively mature applications of 4D BIM. In contrast, more advanced applications involving artificial intelligence, automated progress recognition, real-time monitoring, and predictive schedule optimization remain at an earlier stage of development. Although these approaches have demonstrated promising results in pilot studies and technology-oriented projects, evidence regarding their effectiveness across a broader range of construction environments remains limited.

Moreover, the project schedule management rarely functions as an independent BIM capability. Most reviewed studies indicate that schedule management is closely connected with other BIM functions, including 3D modeling, data management, construction logistics planning, component tracking, quality management, and project coordination. Consequently, the effectiveness of BIM-based schedule management often depends on the quality of project information, the degree of data integration, and the ability to coordinate information flows across different project participants. These interdependencies may partly explain why the outcomes reported in different studies are not always consistent.

In summary, the reviewed evidence suggests that BIM has become an important tool for supporting construction schedule management. However, the role of BIM is gradually shifting from schedule visualization toward broader construction process coordination and decision support. While many studies report positive outcomes, further empirical research is still needed to evaluate the applicability of advanced schedule management approaches in projects with different levels of digitalization, organizational capacity, and technological maturity.

3.2.6. Natural Daylighting, Wind, and Thermal Environment Simulation

Simulation is also a significant BIM capability to improve the quality of the sustainable environment. According to the review of multiple studies [41–47], 'natural daylighting, wind, and thermal environment simulation' is identified as an essential BIM capability that can be implemented in the urban construction process to influence green performance. With the integration of the local environment and multi-dimensional building model, BIM can be used to effectively complete the indoor natural daylighting simulation, natural ventilation simulation, and thermal environmental simulation [45,46]. From the perspective of outdoor wind environmental simulation, BIM can be utilized to conduct the wind tunnel aerodynamic analysis and computational fluid dynamics (CFD) based on the wind pressure parameters detected by probes [43]. The BIM-based CFD can also be utilized to analyze indoor wind speed and airflow distribution under specific environmental conditions, which

can assist stakeholders in assessing the ventilation and air quality in different areas of the building [45].

Moreover, natural daylight simulation is also an essential BIM capability to improve the environmental quality. Through BIM-based natural daylight analysis, the stakeholders can simulate the average daily daylight hours and daylight intensity for different areas [41]. This viewpoint was confirmed by Zeng and Ou [48]. In some northern regions of China, characterized by hot summers and cold winters, daily lighting faces challenges such as glare control in summer and insufficient natural light in winter. Zeng and Ou [48] developed a lighting optimization module suitable for northern China in its case study. This module utilizes BIM and the HYBPA 2024 performance analysis platform to conduct multiple rounds of iterative simulation and optimization of building lighting performance [48]. Zeng and Ou [48] constructed a BIM model of the building and, incorporating building material parameters, window and door structural parameters, and meteorological data, created a building performance analysis environment. Based on this, the model was imported into the HYBPA platform to conduct static daylighting, dynamic daylighting, and glare simulations [48]. The analysis focused on indicators such as daylight factor, indoor illuminance, daylight uniformity, annual compliance duration, and glare index. This process was repeated multiple times. Through continuous iteration and evaluation, the optimal daylighting optimization scheme was determined. Based on BIM-based solar simulation, researchers successfully increased the average illumination coefficient to 4.8%, improved indoor illuminance uniformity from 0.35 to 0.68, achieved 68.7% of the annual standard sunshine hours (≥ 300 lx), and reduced artificial lighting energy consumption by 27.3% by introducing a hybrid system of “side lighting + top lighting guidance” and optimizing louver arrangement [48].

Based on the site environment, building location and orientation, building structure and interior layout, and component properties information provided by the BIM model, the construction personnel can perform an annual cumulative solar radiation analysis of the entire building and simulate the solar radiation facing facades at different orientations [41]. BIM can not only perform lighting simulation for individual buildings but also optimize lighting for entire urban areas. Considering the dense buildings and high-rise buildings in China’s urban centers, Liu et al. [49] explored a lighting simulation and optimization module integrating building information modeling (BIM), Geographic Information System (GIS), and environmental simulation models. This module integrates script-based parametric modeling, BIM-based cloud-based daylight simulation, and GIS interactive geospatial visualization, achieving a seamless connection between the three through scripts [49]. Experiments have demonstrated that this module can accurately assess aperture-based daylight modeling (ABDM) and climate-based daylight modeling (CBDMM) indices for the interiors of various buildings in the target area, thereby effectively analyzing the impact of dynamic changes in the urban environment on daylight performance [49].

From the perspective of thermal environmental analysis, the building envelope’s thermal performance can be simulated by BIM [42,47]. To improve the accuracy of the building envelope thermal performance assessment, Ham and Golparvar-Fard [44] develop the thermal properties renewal approach. This method is performed by measuring actual heat transfer property, conducting 3D thermography, and automatically associating and renewing the measured data with BIM elements in the gbXML schema, which can be utilized to evaluate the variations in building envelope thermal performance with the building materials’ deteriorations [44].

Based on BIM’s lighting, wind, and thermal environment simulation functions, stakeholders can use BIM to protect and optimize the urban natural environment, enhance the

interior environment of buildings, improve the ecological diversity, and enhance the living experience of residents and pedestrians.

The reviewed studies generally indicate that BIM-based environmental simulation can support green building design and environmental performance assessment, particularly in relation to daylighting, ventilation, thermal comfort, and energy efficiency. However, the focus and scope of existing studies vary considerably. Some studies concentrate on building-scale performance optimization, such as daylighting improvement and thermal envelope assessment, whereas others extend BIM applications to district-scale or urban-scale environmental analysis through integration with GIS and other spatial technologies. This variation suggests that BIM-based environmental simulation is being applied across different analytical scales, although the maturity of these applications may differ significantly.

Another observation is that BIM rarely functions as an independent environmental simulation tool. Most of the reviewed studies rely on the integration of BIM with external technologies, including GIS platforms, CFD simulation software, environmental databases, remote sensing systems, and building performance analysis tools. While such integration expands the analytical capabilities of BIM, it also increases implementation complexity and creates additional requirements for data quality, interoperability, and technical expertise. Consequently, the effectiveness of BIM-based environmental simulation often depends not only on BIM itself but also on the performance of the broader digital ecosystem in which it operates.

Differences can also be observed between simulation-based evidence and practical implementation evidence. A large proportion of the reviewed studies demonstrate the potential benefits of BIM through simulation experiments, optimization models, or individual case studies. These studies generally report improvements in environmental performance indicators, including daylight availability, ventilation conditions, thermal comfort, and energy consumption. However, relatively few studies evaluate whether these simulated benefits can be consistently achieved throughout the construction and operation phases of actual projects. As a result, the long-term effectiveness and practical applicability of BIM-enabled environmental simulation remain less certain than those of more established BIM functions such as visualization, clash detection, and schedule management.

Furthermore, the reviewed literature suggests that environmental simulation capabilities are highly dependent on other BIM functions, particularly data management and information integration. Compared with information management and schedule control functions, environmental simulation applications generally require more extensive data integration and reliance on external analytical tools. Although the simulation accuracy reported in existing studies is promising, the practical implementation complexity and data requirements may limit their adoption in resource-constrained projects. Reliable environmental analysis requires accurate geometric information, material properties, environmental parameters, and site-related data. Weaknesses in data quality, model completeness, or interoperability may therefore affect simulation accuracy and reduce the reliability of subsequent decision-making processes. This indicates that environmental simulation should not be viewed as an isolated BIM capability but rather as part of a broader capability network that relies on effective information management.

Overall, existing studies demonstrate considerable potential for BIM-based daylighting, wind, and thermal environment simulation. Nevertheless, much of the current evidence remains concentrated in simulation-oriented research and technology-intensive projects. Further empirical studies conducted across different climate zones, building types, and urban environments are needed to better understand the practical applicability,

scalability, and long-term performance of these capabilities in real-world construction projects.

3.2.7. Assessing the Pollution and Toxic Emission in Construction Sites

The variable 'Assessing the pollution and toxic emission in construction sites' is identified as a key BIM capability to improve sustainable environments in several studies [50–56] that consistently reported a positive effect on green performance. During the urban construction process, it is necessary for construction organizations to reduce the negative impact of construction activities on the environment. BIM can be used to assess the pollution generation and toxic emissions on the construction site. Although both this capability and the daylighting/wind/thermal simulation capability contribute to environmental performance improvement, their objectives differ. The daylighting/wind/thermal simulation studies mainly focus on predicting building and environmental conditions such as daylighting, ventilation, and thermal performance, whereas the studies reviewed in this section concentrate on quantifying pollution generation, greenhouse gas emissions, waste production, and other environmental impacts arising from construction activities. Wong et al. [54] propose a BIM-adopted predicted emission estimation model (PEEM) to estimate the CO₂ emissions of construction activities during the pre-construction phase. Through this approach, BIM can visualize the carbon emissions level in the construction site, identify the carbon emission source, and assess the carbon emissions of each construction piece of equipment in the construction process.

Marzouk et al. [52] also propose a BIM-based pollution emission monitoring and assessment module, which uses add-ons in Revit to develop BIM modules; the Copert 4 and Athena Impact Estimator are adopted to define the system. Through this pollution assessment tool, stakeholders can effectively evaluate the pollutant production and greenhouse gas emissions during the construction process, including the influence on greenhouse gas (GHG) footprint, the influence on acidification potential (AP), the effect on human health (HH) particulate matter, the effect on eutrophication potential (EP), the impact on ozone depletion, and the effect on smog [52].

To more efficiently use BIM to assess greenhouse gas emissions, Nahangi et al. [53] propose a protocol to optimize BIM GHG emissions, including the following: I. modeling the entire scope of construction work (rather than a single building). II. Simulating equipment usage and on-site duration, combined with estimating the fuel usage of each piece of equipment during construction. III. The prediction results of the preconstruction model should be integrated as a scaling factor in the BIM assessment protocol [53]. Considering the significant negative impact of the construction and demolition waste (CDW) treatment process on the greenhouse effect, Xu et al. [55] propose a BIM-based CDW information management system (IMS) to provide stakeholders with accurate CDW data and a precise information estimation procedure. By combining BIM-based CDW IMS with mathematical formulas, this module can achieve high-precision measurement and evaluation of CDW information and greenhouse gas emissions [55]. The researchers use the BIM-based CDW assessment module to estimate the CO₂, CH₄, and N₂O transport emissions of concrete waste, thereby quantifying and reducing all relevant GHG emissions in CDW disposal and assisting construction personnel in formulating targeted prevention and control measures based on pollution emissions in each area [55].

The GHG emission assessment method based on automatic semantic repair of the BIM model can be adopted to estimate greenhouse gas emissions before the pre-construction phase [50]. This method can accurately match the LCA information attributes of element types and materials to the corresponding model elements and use the Natural Language Processing (NLP) model to realize the automatic matching process of the corresponding

units between the Industrial Foundation Class (IFC) elements and the LCA knowledge database [50]. Through this approach, the accuracy of GHG emission assessment can be effectively improved.

In addition, BIM-based waste generation analysis has also identified the BIM function that can make a significant contribution to construction and demolition (C&D) projects. Construction waste control is an important issue for the construction industry in China [57]. During the construction and demolition phases, BIM can effectively count the amount and type of waste generated [51]. This approach can facilitate stakeholders to anticipate and assess the quantities and categories of waste generated by construction activities and contribute to performing the statistical and cyclic utilization of recyclable waste to reduce waste and pollution [51]. For the urban construction sites where air pollutant detectors are installed, BIM can integrate and visualize data from each pollutant monitoring module on the site based on the distributed sensor network to achieve effective monitoring, early warning, and emergency response to air pollution on the construction site [56]. With the contribution of green BIM-based construction, BIM can effectively mitigate the negative environmental impact of carbon emissions, noise pollution, resource consumption, and waste generation.

The reviewed studies generally agree that BIM can support pollution assessment and environmental impact management throughout the construction process. However, different studies emphasize different environmental objectives and assessment boundaries. Some studies focus primarily on greenhouse gas emissions and carbon accounting, using BIM to integrate quantity takeoff, lifecycle assessment (LCA), and emission factor databases to estimate carbon footprints during construction activities [50,53]. Other studies concentrate on construction and demolition waste management, seeking to improve waste quantification, recycling planning, and emission estimation associated with waste treatment processes (such as Hu et al. [51]; Xu et al. [55]). More recent studies have begun to incorporate sensor networks and real-time monitoring technologies into BIM platforms, extending environmental assessment from static prediction toward continuous monitoring and early-warning applications [56]. This evolution suggests that BIM-based environmental assessment has gradually expanded from post hoc environmental evaluation to more proactive forms of environmental management.

Differences can also be observed in the maturity of various pollution assessment applications. Carbon emission estimation and waste quantification have been investigated relatively extensively and are supported by established assessment methods such as LCA and quantity-based calculations. In contrast, BIM-enabled real-time environmental monitoring and dynamic pollution management remain less mature and are still primarily demonstrated through prototype systems, pilot projects, or technology-oriented case studies. Consequently, the practical effectiveness of these advanced applications under large-scale construction conditions remains less certain.

Another recurring theme in the literature is the strong dependence of pollution assessment capabilities on external data sources and supporting technologies. Accurate environmental assessment often requires integration between BIM and LCA databases, sensor networks, emission factor repositories, monitoring equipment, or other analytical platforms. As a result, the reliability of assessment outcomes depends not only on BIM models themselves but also on the quality, completeness, and consistency of external environmental data. Differences in assessment boundaries, emission factors, and calculation methods across studies may therefore contribute to variations in reported results and make direct comparison difficult.

Overall, the reviewed evidence suggests that BIM has considerable potential to support construction pollution assessment, carbon management, and environmental monitoring.

Nevertheless, much of the current evidence remains derived from individual case studies and project-specific applications. Further empirical research is needed to examine the applicability of these approaches across different construction contexts and to evaluate their long-term effectiveness in supporting sustainable urban construction.

3.2.8. Tracking the Position, Condition, and Installation Results of the Building Components

Multiple articles show that ‘Tracking the position, condition, and installation results of the building components’ is a BIM capability applicable to urban construction to optimize the environment [58–62]. For prefabricated buildings, BIM can track the location, condition, and installation results of each building component to improve the accuracy and efficiency of prefabricated building installations [58,60,61]. Prefabricated building construction adopting BIM can achieve model consistency, efficient information transmission and integration during the delivery process, and efficient collaboration between subcontractors. Moreover, by combining BIM with third-party facilities such as NFC (near field communication) tags, GPS sensors, monitors, UAVs, and barcodes, the accuracy of prefabricated structure tracking and positioning can be effectively improved [62].

By equipping construction workers with smart trinity tags and GPS sensors, smart construction environments can be established to avoid the tracking loss caused by conventional RFID [62]. Combined with intelligent gateway technology, the Internet of Things-enabled BIM platform (IBIMP) proposed by Zhai et al. [62] can support various construction contractors to accurately track the status, location, quality, and cost of prefabricated modules in real-time. In addition, the IBIMP can identify potential risks and emergencies arising from the transportation and installation of prefabricated components in real-time and automatically formulate issue-response schemes [62].

In the case study of Hao et al. [59], the researchers implement BIM to track the transportation and on-site construction of prefabricated components to evaluate the carbon emissions of prefabricated construction activities. Through BIM-based full life cycle tracking, researchers obtain the carbon emissions of each prefabricated component (including balcony partitions, prefabricated shear walls, prefabricated filled internal/external walls, laminated beams/boards, and stairs) during the production, transportation, and installation stages [59]. Through the component tracking of BIM, stakeholders can accurately locate and track various components and equipment in urban construction, fully understand the component installation status and project progress, and thus avoid environmental pollution and ecological damage caused by assembly errors.

The available research indicates that BIM-based tracking of component location, status, and installation results is primarily applied to prefabricated and modular construction scenarios. RFID is a widely used technology, mainly for automatic identification and location tracking of components during production, transportation, and on-site installation. For example, some researchers (such as Abbott and Chua [58]) combine RFID with BIM for component logistics management and on-site installation coordination, thereby reducing errors caused by manual recording. Compared to traditional methods relying on manual statistics, this approach has advantages in terms of component information update efficiency.

Building on this foundation, other studies have begun to focus on quality feedback and condition management at construction sites. Related research (such as Hou et al. [60]) utilizes BIM-RFID integrated systems to quickly locate components with quality issues and feed defect information back into the model, thereby improving the efficiency of quality inspection and rework. This indicates that current research is no longer solely focused on locating components but is gradually expanding to more specific construction management

issues, such as real-time monitoring of component status and timely identification of problems arising during assembly/transportation.

Furthermore, some studies (e.g., Zhai et al. [62]) are attempting to further integrate technologies such as IoT and GPS into BIM platforms to achieve real-time information interaction during component production, transportation, and installation. Compared to simple component identification, this type of research emphasizes dynamic collaboration capabilities during construction. Some IoT-enabled BIM platforms can already achieve construction progress updates, on-site status feedback, and information sharing among multiple stakeholders [62,63]. However, based on current research, most of these systems are still focused on case studies and platform development, and their long-term stability in complex projects and actual deployment costs still need further verification.

In conclusion, the available research has sufficiently demonstrated that BIM combined with sensing technologies such as RFID and IoT can improve component tracking efficiency and information coordination on construction sites. However, current research mainly focuses on prefabricated and modular building scenarios. It is necessary to develop more empirical research in the future to validate its applicability to a wider range of construction projects.

3.2.9. Construction Safety Management

Multiple studies highlighted that ‘Construction safety management’ is an important BIM capability in urban construction to influence the sustainable environment [64–71]. The BIM-adopted construction safety management can improve the safety of construction personnel and reduce property loss and casualties caused by natural disasters and construction risks. BIM is believed to be able to implement its advanced functions to promote a paradigm shift in the safety management model of urban construction projects [67]. From a safety perspective, the construction phase is the most dangerous phase of a project because the vast majority of construction accidents occur on the construction site. Akram et al. [66] believe that 3D modeling and visualization, simulation with integrated timelines, checking the risks and safety of proposed schemes, and data exchange capabilities provided by BIM can provide the necessary support for BIM-based safety management methods.

To enhance BIM-based construction safety management, Zhang et al. [70] develop a building safety ontology that integrates three main domain ontology models (including the building product model, building process model, and building safety model) to achieve formal management of safety management guidelines, which can achieve the automatic safety schemes development in the urban construction phase. The improved automatic safety rule-checking algorithm framework established by Zhang et al. [71] can support the urban construction personnel in the early identification and elimination of potential fall hazards in the construction schedule during the project planning stage.

BIM can assist urban construction personnel in identifying current disasters and risks and areas with potentially hazardous conditions and in identifying sources of danger. In the aspect of disaster management, BIM can be utilized to perform disaster prevention and mitigation, disaster response, and post-disaster reconstruction by integrating BIM with third-party technology (such as GIS and remote sensing)/devices (such as sensors) [64,65,69]. The BIM-GIS integration model established by Agliata et al. [65] can be used to assess the sensitivity of buildings under hydro-meteorological disasters. The HBIM model is used to process information about the buildings and their components in the assessment area and to realize the three-dimensional display of the buildings [65]. The GIS-based database is used to manage space-related information. By bringing in hazard event data, the model can link the structural and type characteristics of selected buildings with the surrounding

environment to assess the potential hazard profile (such as hazard type, location of trigger points, hazard path, etc.) and the structural sensitivity of the buildings.

Furthermore, BIM can contribute to stakeholders locating affected people, automatically generating escape/evacuation/rescue routes, and formulating rescue schemes for rescue organizations [68]. Deng et al. [68] develop an automatic disaster escape guidance system using BIM and computer vision positioning, which can achieve accurate indoor positioning with errors of less than 1.5 m. Deng et al. [68] also propose a rescue route planning method based on a BP neural network considering the safety performance of the rescue route, which can automatically generate the rescue route using real-time images. Based on BIM's simulation capabilities, stakeholders can simulate the affected areas and damage to the target area in the event of various categories of disasters (e.g., floods, fires, mudslides, etc.) [65].

The analysis in this section reveals that early research (such as Zhang et al. [70]; Zhang et al. [71]) primarily focused on utilizing BIM for hazard identification and construction safety planning, such as fall-from-height risk identification and semantic construction safety knowledge base components. This type of research emphasized rule-based safety inspections and construction risk assessment. With the development of artificial intelligence and automated analysis technologies, the latter research has begun to further integrate machine learning and dynamic hazard identification methods to explore areas such as automated hazard analysis, potential disaster risk assessment, and disaster/hazard evacuation management (e.g., Deng et al. [68]; Akram et al. [67]). The research focus has shifted from BIM's auxiliary role in safety identification/safety education to intelligent construction safety management and risk control based on BIM and artificial intelligence. The application scope of BIM construction safety management has also expanded from single construction sites to more complex disaster scenarios such as earthquakes, floods, and landslides [65].

However, most research focuses on BIM-based construction safety management under single risks; further exploration of collaborative management across multiple risk environments during the construction process is needed. Moreover, BIM-based construction risk management relies on the cooperation of third-party devices (such as RFID, monitoring devices, or remote sensing). Further research is still needed to explore how to achieve seamless integration of BIM with third-party equipment.

3.2.10. Simulating the Surrounding Environmental Impacts Caused by Different Construction Activities

The variable 'Simulating the surrounding environmental impacts caused by different construction activities' is recognized as a significant BIM capability in urban construction to protect the environment [65,72–76]. This capability differs from the daylighting, wind, and thermal simulation capabilities discussed earlier. While environmental simulation (daylighting, wind, and thermal) primarily evaluates building environmental performance and occupant comfort, the studies reviewed in this section focus on predicting the external environmental consequences of construction activities, including geological disturbance, land-use impacts, environmental risks, and site-level ecological effects. BIM can effectively simulate the impact of construction activities on the surrounding natural environment (e.g., terrain, forests), thus mitigating the pollution of the natural environment caused by construction activities [73,74,76]. Furthermore, considering that improper construction activities may lead to ground subsidence, landslides, or mudslides, this feature can also effectively help stakeholders avoid safety hazards due to the negative impacts of construction activities on the surrounding geology [65]. Wiegel et al. [77] explored how to integrate probabilistic 3D subsoil models into a BIM environment to address uncertainties in borehole interpolation modeling. This study utilized geostatistical methods such as Sequential Gaussian Simulation (SGSIM) and Sequential Indicator Simulation (SISIM) to perform

3D probabilistic modeling of subsurface strata and achieved GeoBIM integration through IFC [77]. It effectively explored and analyzed the uncertainty expression of subsurface geological prediction, providing support for risk assessment and decision-making during construction [77]. Based on the provided geological model, the construction organization can effectively simulate the impact of construction activities on geology and implement geological forecasting.

The construction simulation tool integrated with BIM and unmanned aerial vehicles (UAVs) can also effectively simulate the impact of construction activities on the local land environment [75]. The researchers use mobile drones to record mixed images of the construction site and match the images using the Structure from Motion (SfM) photogrammetry method to provide data support for the establishment of a three-dimensional model of the construction site [75]. Through the integration of BIM hoisting modules, on-site real scenes, and crane models, the activity path and potential collision risks of crane hoisting tasks are simulated to simulate the physical impact of crane activities on the surrounding land environment. Providakis et al. [72] establish a 3D BIM-geology interaction method to simulate ground settlement caused by construction projects. Through BIM, engineering parameter information related to settlement risk factors is obtained, and MATLAB tools are used to analyze the impact of construction activities on building settlement. Through this automatic settlement sensitivity inspection platform, potential settlement locations and times can be promptly alerted to construction engineers [72].

The reviewed studies suggest that BIM can support the simulation and assessment of environmental impacts generated by construction activities. However, the focus of existing research varies considerably. Some studies emphasize the development of BIM-based simulation tools and visualization techniques, aiming to improve the prediction of geological changes, construction risks, and environmental disturbances through the integration of BIM with GIS, UAV technologies, and 3D geological models (e.g., Agliata et al. [65]; Providakis et al. [72]; Tian et al. [75]; Yao et al. [76]). Other studies place greater emphasis on sustainability-related objectives, including the reduction in resource consumption, environmental pollution, and ecological disturbance during construction activities (e.g., Tao et al. [74]; Yao et al. [76]). These differences suggest that BIM-based environmental simulation is being applied to address a broad range of environmental management challenges rather than a single environmental objective.

From a maturity perspective, applications related to visualization, site monitoring, and construction process simulation appear to be relatively well established. In contrast, the integration of BIM with advanced environmental assessment approaches, such as lifecycle environmental impact evaluation, predictive risk assessment, and comprehensive ecological analysis, remains less developed and is still primarily reported through individual case studies and pilot projects. As a result, the practical effectiveness of these advanced applications under different construction conditions remains uncertain.

Another observation from the reviewed literature is that BIM-based environmental simulation is highly dependent on external technologies and data sources. Many studies rely on the integration of BIM with GIS platforms, UAV-based data collection, photogrammetry, geological modeling tools, or environmental assessment methods to generate simulation results. Consequently, the quality and reliability of environmental simulations are influenced not only by BIM itself but also by the availability, accuracy, and compatibility of supporting datasets and analytical tools. This dependency may partly explain the differences in findings reported across studies.

Overall, the reviewed evidence indicates that BIM has considerable potential to support the prediction and management of environmental impacts associated with construction activities. Nevertheless, most existing studies remain project-specific and are conducted

under relatively controlled conditions. Further empirical research is needed to evaluate the applicability and effectiveness of BIM-based environmental simulation approaches in more complex construction environments and across different project types.

3.2.11. Clash Detection

The ‘clash detection’ is highlighted as an important BIM capability in urban construction to optimize the environment [78]. Given the uncoordinated multidisciplinary design and difficulties in coordinating the sequence of multidisciplinary construction, the stakeholders might meet the issues of pipeline clashes [78]. The clash detection capability in BIM is deemed the practical method to mitigate clashes in the urban design and construction process. In the whole life cycle of buildings, BIM can achieve the optimization of underground pipeline clashes based on multiple disciplines. Based on the given collision rules, BIM can help stakeholders to conduct automatic irrelevant clash (tolerable clash) filtration to improve the efficiency of clash detection and resolution [78].

Once the clash detection is complete, BIM can utilize the 3D modeling capabilities to visualize stakeholders’ locations and the condition of the clashes to help them develop optimization schemes [78]. Luo et al. [78] propose a clash detection and management system suitable for urban construction projects in the pipeline clash optimization framework based on BIM spatial component identification in their research. The clash optimization framework includes the initial collision detection and analysis, conflict detection rule definition, collision detection based on rule bases, rule contribution rate evaluation, rule-based collision filtering, and collision optimization result analysis [78]. In the case study, the researchers implement the BIM-based clash rule base to achieve efficient invalid collision filtering and allow all parties to participate in pipeline optimization tasks in the early stages of the project [78]. BIM-based clash detection can effectively reduce rework and construction errors in urban construction, thereby reducing the damage to the land environment and ecological diversity caused by demolition activities and secondary construction and alleviating their pollution of air, water, soil, and biological resources.

Machine learning plays a significant role in improving the accuracy and efficiency of clash detection. Even while current software systems automatically identify conflicts, they frequently produce an overwhelming number of unrelated conflicts and are unable to rank them according to danger [79]. So, there are many studies that applied BIM in BIM-based clash detection to filter the irrelevant clashes and perform the clash ranking activities. Ailem and Boton [80] apply machine learning to BIM-based clash detection to achieve automatic identification of real and false clashes. The researchers use a metadata extraction plugin to collect the data needed to train the machine learning model, cultivate the model’s ability to identify and classify clashes, and embed the model into BIM software to carry out AI-driven clash detection [80]. Using various attribute combinations in building information modeling (BIM), Oduro et al. [79] assess the effectiveness of many machine learning (ML) methods in clash relevance and risk level prediction. Gradient Boosting had the highest accuracy in danger level predictions, while Random Forest was the best at predicting clash relevance across all attribute combinations among the studied algorithms.

From the perspective of BIM-applied clash detection, the mainstream of research focuses on clash identification, clash rule formulation, and automated clash resolution. Some studies aim to establish and improve clash detection rules to enhance the efficiency of underground pipeline design coordination and reduce design errors and rework [78]. In addition to these, there are partial studies (such as Oduro et al. [79]) that are devoted to exploring the integration of machine learning methods with clash management, automatically assessing the risk level of clashes to reduce the manual screening work required for handling numerous invalid clashes in conventional clash detection. This indicates that cur-

rent research, in addition to focusing on clash detection itself, is increasingly emphasizing the intelligent classification and optimization of clash results.

However, it must be acknowledged that much current research still focuses on case studies and model testing, with insufficient exploration of its applicability in different engineering environments. Furthermore, machine learning-based BIM clash detection relies heavily on data quality and clash annotations, which require future research to address.

3.2.12. Construction Site Layout Planning

‘Construction site layout planning’ has been recognized by many studies as a BIM capability suitable for urban construction to protect the environment [74,81–83]. Based on multi-dimensional modeling and dynamic simulation, the BIM-implemented construction site layout planning function supports stakeholders in comprehensively planning the construction site layout and route planning. Stakeholders need to consider safety, transport costs, and efficiency to perform construction site route planning [83]. BIM can help stakeholders to collaborate on on-site routing and visualize all categories’ space on the site (including but not limited to construction office areas, material staging areas, mechanical equipment placement areas, and space that cannot be undertaken for transportation activity) and obstacles (e.g., buildings, equipment, construction workers, etc.) [82,83]. Through the abovementioned contribution, the BIM-implemented tools can assist stakeholders in achieving route optimization in urban construction sites. Furthermore, stakeholders can implement BIM-based automated solutions to develop logical schemes for setting up material staging areas and temporary facility staging to optimize site logistics planning (SLP) [82].

Considering the significance of layout planning in the early urban construction stage on the later urban construction site layout, Tao et al. [74] propose a BIM-based dynamic multi-objective construction site layout planning module to achieve the dynamic balance between construction expenditure and land environment. This site layout tool uses BIM to obtain construction progress data in real-time and adopts multi-objective particle swarm optimization (MOPSO) to achieve a dynamic balance between noise pollution level and vehicle transportation cost. Compared with no optimized construction site planning and static construction site layout, the BIM-based dynamic construction site layout plan (CSLP) effectively assists the construction organization and reduces transportation [74]. Iqbal et al. [81] propose a comprehensive construction site layout framework that integrates robotics, IoT, and BIM. The comprehensive framework effectively integrates BIM data extraction, computer application processing, and IoT-driven mobile robot printing and optimizes their interoperability [81]. The prototype robot can perform construction layout markup work using site data provided by BIM. Based on this BIM-IOT comprehensive framework, construction contractors improve the accuracy and efficiency of the construction site layout printing process, reduce the workload of construction personnel, avoid errors caused by manual operation, and effectively reduce the carbon emissions caused by urban construction sites [81].

Based on the reviewed research, it is evident that BIM applications in construction site layout planning primarily focus on construction logistics organization, transportation route planning, and site adjustments. Some studies integrate 4D BIM with resource allocation information and real-time construction progress to implement dynamic optimization of the construction site, thereby improving transportation efficiency and reducing site conflicts [82,83]. Other studies shift their focus to transportation cost optimization and noise pollution control, emphasizing multi-objective optimization of BIM-based construction site layout [74]. Furthermore, with the development of intelligent construction, some studies (such as Iqbal et al. [81]) have begun to explore the introduction of IoT and automated robotics technologies into BIM-based construction site layout, improving on-site

construction accuracy and efficiency and reducing human error through synchronized and collaborative automated layout of multiple equipment.

However, it must be admitted that different studies vary in terms of the accuracy and optimization objectives of construction plans. And there is currently an insufficient unified standard system, which obstructs the promotion and application of related methods. Therefore, the application of BIM in construction site layout planning still needs further improvement.

4. Discussion

4.1. Critical Analysis of BIM Capabilities for Sustainable Urban Construction

4.1.1. Maturity and Practical Applicability of BIM Capabilities

The literature reviewed in this study shows that BIM capabilities have not developed at the same pace. While some functions have already become common practices in the construction industry, others are still largely confined to research projects and pilot applications. This difference suggests that the contribution of BIM to sustainable urban construction should not be evaluated solely based on its technical potential. The maturity, implementation requirements, and practical applicability of different BIM capabilities also need to be considered.

Among the identified capabilities, 3D modeling and visualization, clash detection, schedule management, and cost management appear to be the most mature. These functions have been discussed extensively in the literature and have been applied in a wide range of project settings over the last decade [12,17,33,78]. Their workflows are relatively standardized, and most mainstream BIM platforms already provide built-in support for these functions. Previous studies have reported improvements in design coordination, stakeholder communication, construction planning, and project control through the use of 3D, 4D, and 5D BIM technologies [11,35,39]. Compared with many other BIM applications, these capabilities have accumulated stronger practical evidence and appear to be closer to routine industry adoption.

The situation is somewhat different for BIM applications associated with environmental analysis and sustainability assessment. Research has shown that BIM can support daylight simulation, thermal performance analysis, natural ventilation evaluation, embodied carbon assessment, and environmental impact analysis [41–43,49,50]. However, these applications often require additional simulation tools, environmental databases, GIS platforms, or optimization algorithms. Their implementation is therefore more dependent on data quality, interoperability, and specialist knowledge. Although many studies report encouraging results, most evidence still comes from simulation exercises, prototype systems, or individual case studies. Large-scale and long-term implementation evidence remains relatively limited.

The findings also suggest that BIM capabilities do not contribute to sustainability in the same way. Some capabilities, such as embodied carbon assessment, environmental monitoring, construction waste management, and energy performance optimization, can directly support environmental objectives [54,56,59,84]. Other capabilities contribute more indirectly by improving information quality, project coordination, and resource allocation. For example, 3D visualization, clash detection, schedule management, and data management may not directly reduce environmental impacts, but they can create conditions that enable more efficient and sustainable project delivery. This indicates that sustainability benefits often emerge from the combined use of multiple BIM capabilities rather than from any single function alone.

Another notable finding is the strong dependence among different BIM capabilities. Environmental simulation, lifecycle assessment, construction waste management, and

safety monitoring all rely on accurate project information and reliable data management processes [26,27,50]. Likewise, many sustainability-oriented BIM applications require integration with GIS, IoT, RFID, machine learning techniques, or environmental simulation software [24,32,62]. In practice, this means that advanced BIM applications cannot function effectively without a solid information foundation. Weaknesses in data quality or interoperability can easily affect the performance of higher-level analytical functions.

Several limitations can also be identified from the existing body of research. A large proportion of studies focus on demonstrating technical feasibility, while relatively few investigate long-term implementation outcomes. In addition, many sustainability-related BIM applications have only been tested in specific projects or controlled research environments. Questions regarding scalability, transferability, and long-term effectiveness therefore remain open. Interoperability challenges are also repeatedly reported in the literature and continue to affect data exchange between BIM platforms and external analytical systems [22,43,85]. These issues suggest that there is still a noticeable gap between the capabilities demonstrated in research and their widespread application in practice.

Overall, the reviewed evidence suggests that BIM should be understood as a group of interconnected capabilities rather than a set of independent functions. The effectiveness of many advanced applications depends on the successful implementation of supporting capabilities, particularly those related to information management and interoperability. This interconnected nature of BIM provides a useful basis for exploring potential capability synergies in sustainable urban construction, which are discussed in the following section.

4.1.2. Implications for BIM Implementation in China

Although the reviewed studies were conducted in different countries and under different project conditions, several observations may still be relevant to the Chinese construction industry.

One notable finding is that BIM capabilities have reached different levels of maturity. Functions such as 3D modeling, clash detection, schedule management, and cost management have already been widely applied and supported by relatively mature implementation procedures. Compared with more advanced BIM applications, these capabilities generally involve lower technical barriers and implementation risks. Some studies have reported that these capabilities can improve project coordination, information sharing, schedule control, and resource management, suggesting that they may be more readily transferable to practice than some emerging BIM applications [17,27,33,78]. For organizations that are still in the process of expanding BIM adoption, these capabilities may provide a more practical entry point for integrating BIM into sustainable urban construction projects.

The review also shows that many sustainability-related BIM applications depend heavily on data quality and information exchange. Applications such as environmental simulation, embodied carbon assessment, and lifecycle analysis require not only accurate BIM models but also effective integration with external databases and analytical tools [46,47,53]. As green and low-carbon development continues to receive attention in China, the ability to manage and exchange project information efficiently may become increasingly important for realizing the environmental benefits of BIM in practice.

Another finding is that sustainability outcomes are rarely generated by a single BIM function. In many cases, the reported benefits were achieved through the combined use of several capabilities, including information management, project coordination, schedule control, and environmental analysis. Multiple studies have emphasized that BIM often creates greater value when integrated with complementary technologies and management approaches rather than being used as a standalone tool [24,29,79]. This suggests that BIM

implementation may be more effective when different capabilities are considered as part of an integrated system rather than as independent technical tools.

Compared with many developed countries where BIM adoption is often driven by market demand and organizational initiatives, BIM implementation in China has been strongly influenced by government policies, regulatory requirements, and national development strategies. Recent efforts related to digital construction, green development, smart cities, and construction industrialization have increased interest in BIM-enabled information management, environmental assessment, project coordination, and lifecycle management. As a result, the practical significance of different BIM capabilities may vary across institutional and regulatory contexts.

In addition, several characteristics of China's urban construction environment may influence the applicability of BIM capabilities. The large scale of urban development projects, the rapid growth of prefabricated construction, the increasing complexity of megacity infrastructure systems, and the emphasis on sustainable urban development all create conditions in which BIM-based coordination, information integration, environmental simulation, and resource management may become particularly important. These contextual factors suggest that the implementation priorities of BIM in China may differ from those reported in some international studies.

In addition to these, some identified BIM applications remain at a relatively early stage of development. Although their potential has been demonstrated in research and pilot projects, evidence from large-scale implementation is still limited. More empirical studies based on actual construction projects in China would therefore be valuable for examining how these emerging BIM applications perform under local regulatory requirements, industry practices, and organizational conditions. It should be noted that the reviewed studies were drawn from multiple countries and regions rather than exclusively from China. Therefore, the discussion presented in this section should be interpreted as potential implications for BIM implementation in China rather than direct China-specific empirical conclusions.

4.2. Conceptual Perspectives on BIM Capability Integration

The reviewed studies show that BIM capabilities are rarely used as completely independent functions in practice. Instead, many applications combine multiple capabilities to address different project requirements simultaneously. For example, information management, project coordination, schedule control, environmental analysis, and resource management are often applied together during the construction process. This suggests that the contribution of BIM to sustainable urban construction may be better understood by examining how different capabilities work together rather than by considering each capability separately.

Based on the findings presented in Section 3 and the discussion in Section 4.1, this section provides several conceptual perspectives on the potential integration of BIM capabilities in sustainable urban construction. These perspectives are not direct findings derived from individual studies. They represent the authors' interpretation of how different BIM capabilities may interact with and support one another when applied in practice. Therefore, they should be regarded as conceptual discussions rather than validated frameworks.

The perspectives were developed with reference to the BIM capabilities identified in the reviewed literature and the potential connections observed among them. By grouping related capabilities together, the following discussion explores several possible ways in which BIM may contribute to sustainability objectives through the combined use of different functions. The intention is not to propose fixed implementation models, but to provide

additional viewpoints that may support future discussion and research on BIM-enabled sustainable urban construction.

4.2.1. Design–Construction–Environment Interaction Perspective

The findings presented in Sections 3.2.1, 3.2.6 and 3.2.7 suggest that several BIM capabilities associated with visualization, environmental simulation, and construction pollution assessment may be closely related when applied in sustainable urban construction. Previous studies have shown that BIM-based 3D modeling and visualization can provide the information foundation for daylighting analysis, wind environment simulation, thermal performance assessment, and construction pollution evaluation. In addition, visualization functions can facilitate the interpretation of simulation results by presenting environmental conditions and potential impacts more intuitively.

Based on these observations, it is possible to view 3D modeling and visualization, environmental simulation, and pollution assessment as a group of complementary capabilities rather than as separate functions. From this perspective, BIM may support the evaluation of different design options by integrating information on building form, environmental performance, and potential construction impacts. Such integration may assist project teams in comparing alternative solutions and identifying design adjustments at an earlier stage of project development.

This perspective may be particularly relevant in densely developed urban areas where environmental constraints and construction impacts often require careful consideration. By combining building models with environmental simulation and pollution assessment tools, stakeholders may be able to examine how design decisions influence factors such as daylight access, ventilation conditions, thermal performance, and potential environmental disturbances. The resulting information may then be used to support further design refinement and decision-making.

This view is supported by the research of Gan et al. [86], Kang et al. [85], and Lundqvist et al. [87]. In the proposed BIM-VR-based modeling system of Gan et al. [86], it combines OpenStreetMap and Dynamo to achieve rapid urban modeling of modular buildings. On this basis, the urban environment simulation system can simulate the outdoor wind environment around modular buildings through CFD, and then simulate and analyze the humidity and temperature levels, natural ventilation, and air pollutant transmission of the environment [86]. Compared with conventional construction approaches, this method allows non-professionals to intuitively feel the flow of outdoor airflow in urban spaces, thereby assisting decision-making and improving building ventilation and energy saving. In the study of Lundqvist et al. [87], the researchers used BIM to model the internal and external environment of the building in three dimensions, and used CFD and thermal environment simulation plug-ins to evaluate the thermal performance of the building and the thermal comfort inside the building. Based on BIM three-dimensional modeling and wind/thermal environment simulation, Lundqvist et al. [87] analyzed the defects of the heating system by visualizing the predicted percentage of dissatisfaction (PPD) and the predicted mean vote rate (PMV).

In the BIM-CFD-based risk assessment study of Kang et al. [85], the researchers modeled the entire project through BIM, and conducted pollution/hazard assessments through BIM simulation functions based on wind environment/thermal environment data. Kang et al. [85] establish the BIM-based disaster information platform in their research to achieve disaster visualization and assess the consequences of disaster events, and then formulate disaster prevention and control measures or modify structural design/facility layout. Considering that in China, first-tier and second-tier cities are mostly high-density urban areas, and these cities usually have stricter supervision on environmental friendliness and

ecological protection. So, in high-density cities in China, the narrow construction sites and sensitive surrounding environments in these cities require the construction organizations are necessary to perform digital pre-rehearsal to avoid ecological risks, which is in line with the mandatory requirements of the sustainable environment for “four savings and one environmental protection”.

4.2.2. Integration of Prefabrication and Refined Management

The findings discussed in Sections 3.2.5, 3.2.8 and 3.2.12 show that prefabricated construction is often associated with several BIM capabilities, particularly schedule management, component tracking, construction site planning, and project coordination. Existing studies suggest that these functions are rarely used in isolation. Instead, they are usually combined to support information sharing, logistics coordination, construction planning, and quality control during different stages of prefabricated construction projects. These capabilities reveal a close connection between prefabricated construction and refined management. Component tracking can provide real-time information on the location and status of prefabricated elements, while schedule management helps coordinate manufacturing, transportation, and installation activities. At the same time, construction site layout planning and clash detection can assist in organizing site operations and identifying potential conflicts before installation takes place. Rather than functioning as separate technical tools, these capabilities often work together to support project coordination and information management.

The integration of BIM with RFID, laser scanning, digital monitoring technologies, and Just-In-Time (JIT) delivery approaches supports prefabricated construction management. In such applications, BIM acts as a common information environment that links data generated during design, manufacturing, transportation, and installation. This integrated information can help project teams track component status, compare planned and actual conditions, and improve coordination among different participants throughout the construction process. One example is the Beijing 2022 Winter Olympic Speed Skating Stadium project. In this project, BIM and 3D laser scanning technologies were adopted to compare point-cloud data with the design model and assess construction accuracy [88]. Point-cloud data obtained from the cable-net roof and glass curtain wall were analyzed against the design model, and geometric deviations were calculated for a large number of measurement points [88]. The reported results showed that most cable clamp deviations remained within acceptable tolerance ranges [88]. Although this case does not verify the perspective proposed in this study, it demonstrates how BIM-enabled information integration can support quality control and precision construction in complex projects.

This perspective may also be relevant to current developments in China. The 14th Five-Year Plan for Building Industrialization Development set clear targets for expanding the adoption of prefabricated buildings, reflecting the increasing emphasis placed on industrialized construction [89]. As prefabricated projects become more common, coordination among design, manufacturing, transportation, and on-site assembly activities is likely to become increasingly important. In this regard, BIM capabilities related to information management, schedule coordination, component tracking, and site planning may offer useful support for project delivery.

In addition to these, interoperability remains a recurring issue in both the reviewed literature and industry practice. Difficulties in information exchange between design software, management platforms, and prefabricated construction systems continue to affect project coordination. Improving data standards and information-sharing mechanisms, therefore, remains an important task. Existing initiatives, such as The Delivery Standard For Building Information Modeling [28] and The 13th Five-Year Plan for Prefabricated

Buildings [90], provide a policy and technical foundation for addressing these challenges and promoting greater integration across different stages of the construction process.

4.2.3. Data-Driven Resource Optimization

The results presented in Sections 3.2.2, 3.2.4, 3.2.5 and 3.2.12 show that data management is involved in many BIM applications related to cost estimation, schedule control, and construction site planning. Across the reviewed studies, BIM was frequently used as a platform for storing, updating, and sharing project information, allowing data generated at different project stages to be connected within a common information environment. This observation suggests that data management plays a supporting role in a range of BIM-enabled resource management activities. Functions such as cost estimation, project schedule management, and construction site layout planning all depend on the availability of accurate and up-to-date project information based on BIM (as illustrated in Figure 4). When information from different sources is brought together, project teams can gain a clearer understanding of resource allocation, construction progress, and site conditions, which may help improve coordination during project delivery.

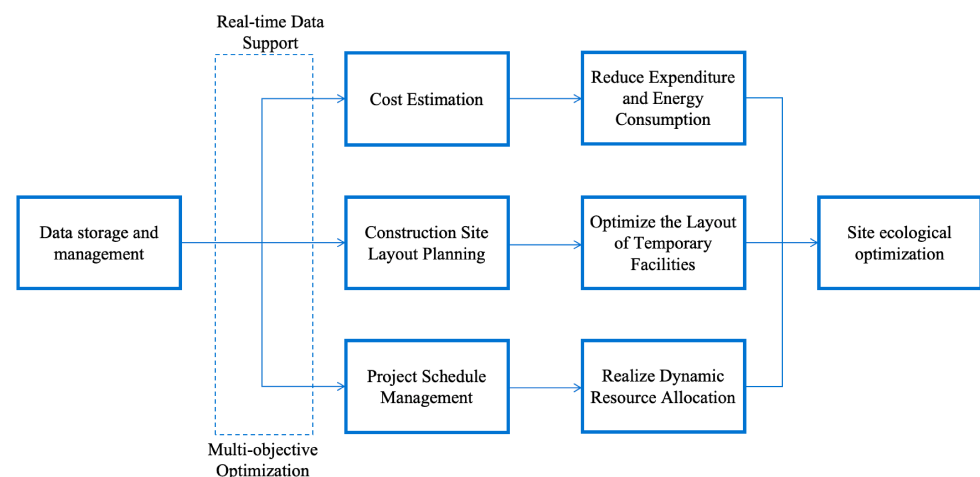


Figure 4. Conceptual illustration of data-driven resource optimization.

Cao et al. [91] have described the use of BIM-based information platforms to integrate data from multiple sources and support construction management activities. By continuously updating project information, BIM can provide information on material consumption, equipment utilization, construction progress, and site operations. Previous research has also reported that access to such information can help identify inefficient resource use and support more informed decision-making during construction [84,92,93]. Another observation is that resource optimization rarely depends on a single BIM capability. Instead, it often emerges from the interaction of several functions. For example, schedule management can be linked with resource information to support construction planning, while site layout planning can incorporate both spatial constraints and environmental considerations.

These observations may be particularly relevant to the Chinese construction industry. In recent years, digital construction, resource efficiency, and green development have become increasingly important topics within the sector. As projects continue to become larger and more complex, the effective use of project data is likely to play a greater role in supporting construction management. The findings reviewed in this study suggest that BIM-based information integration could provide useful support for coordinating project objectives related to cost, schedule, quality, and environmental performance.

4.3. *The Challenge of BIM Implementation Urban Construction in China to Improve Environment*

Incompatible software formats hinder collaboration among stakeholders. Designers cannot seamlessly share environmental simulation data with contractors, and regulatory agencies struggle to obtain real-time emissions data, which impedes effective collaboration among stakeholders involved in the construction process. In many cases, this prevents the implementation of carbon reduction strategies developed in the early stages of construction. Furthermore, this challenge makes it difficult for stakeholders to track data during construction and at completion, hindering data support for project optimization. To overcome data interoperability barriers, governments can establish and enforce unified standards and processes for public projects. Additionally, construction bureaus or science bureaus can fund the development of format conversion tools and build cloud-based BIM collaboration platforms, enabling seamless and accurate data flow across organizations and stages, avoiding delays caused by traditional communication processes.

The high cost of hardware and software investment and training makes it prohibitive for small and medium-sized enterprises. Although the implementation of BIM in green construction can bring long-term benefits to stakeholders (such as reducing waste and protecting the environment), these environmental and ecological benefits are difficult to achieve in the short term, especially in public projects with low profit margins. Moreover, the long-term ecological benefits often belong to the owner and government, but the high software and hardware expenditures and human training costs of implementing BIM in green construction often need to be borne by contractors/construction organizations, which may make contractors unwilling to accept BIM. In view of the cost concerns of contractors, it is recommended that the government construction authorities organize unified BIM training institutions to train BIM technicians for enterprises. The input-output mismatch issue can be solved by specifying the green benefit-sharing mechanisms in the contract. Contractors can require third-party institutions to assess the generated ecological and environmental benefits and the return of green benefits proportionally to the contractors.

The contradiction between the conventional “each responsible for one period/each responsible for one division” project management model and the collaborative characteristic of BIM is also an important challenge for BIM implementation. This requires the construction organization to change its construction model or change the construction organization structure, which may be difficult for those construction organizations that have formed path dependence to accept. The psychological resistance of the construction organization to change is also one of the important challenges hindering the implementation of BIM. In the face of resistance, the “dual track” transition strategies can be implemented: while retaining the existing departmental structure, add cross-functional BIM coordinators to coordinate BIM collaboration among departments; develop corresponding BIM collaboration indicators and incorporate them into departmental assessment standards to gradually reduce the organization’s resistance to work model changes through gradual reform.

5. Conclusions

BIM has shown considerable potential in supporting sustainable urban construction. Through a systematic review of the existing literature, this study identified the main BIM capabilities associated with sustainable urban construction and examined how these capabilities have been applied in different project contexts. The review brings together the current research findings and provides a clearer picture of the roles BIM can play in improving environmental performance, resource utilization, construction quality, and project management. The reviewed studies indicate that BIM is no longer limited to visualization and design coordination. Its applications have gradually expanded to the optimization of construction quality and sustainable performance throughout the entire life

cycle. The findings also suggest that different BIM capabilities can complement each other when applied together, creating opportunities to address sustainability-related challenges more effectively throughout the construction process.

Furthermore, some obstacles remain in the implementation of BIM. Common issues reported in the research include difficulties in data exchange, high investment costs, insufficient professional expertise, and resistance to changes in traditional working methods. Further efforts are still needed to improve technical standards, strengthen professional training, and promote collaboration among different project participants.

There are still a few limitations in this study. Regarding the reviewed document sources, this paper primarily uses English databases such as WOS, Scopus, and Engineering Village. And this study focuses on documents published in English. Some industry reports, conference documents, and unpublished engineering practice results that do not meet the above criteria may not be included in the research process. Therefore, the research results may not fully reflect all applications in actual engineering projects. Furthermore, due to differences in the development of the construction industry, construction technology capabilities, and BIM implementation levels across different countries and regions, the relevant research conclusions may also be influenced by regional context. In terms of the types of literature sources, many studies still focus on BIM application case analysis and BIM technology development for specific scenarios. Due to the differences in project conditions and technological maturity among different studies, this increases the difficulty of making horizontal comparisons between the results of various studies. Although predefined inclusion and exclusion criteria were applied throughout the screening process and uncertain cases were reviewed by a second author, title/abstract screening and full-text assessment were primarily conducted by a single reviewer. Therefore, independent dual screening and inter-rater reliability statistics were not available, which may introduce a degree of selection bias. In addition, because the literature search was conducted in May 2026, only a limited number of studies published in 2026 were included. Relevant studies published after the search date were not reviewed in this study and may provide further insights into this topic. Future research can be conducted while accounting for these limitations to further explore and analyze the BIM capabilities in urban construction in China.

Based on the review findings, several important implications can be drawn for China. As BIM adoption continues to expand and green development remains an important priority within the construction sector, the BIM capabilities identified in this study may provide practical reference for future BIM implementation. The experiences reported in the reviewed studies may also help stakeholders better understand how BIM can be used to support sustainable urban construction under different project conditions.

The review further suggests that combining different BIM capabilities may generate greater benefits than applying individual functions separately. Better coordination among project participants, improved resource management, and enhanced environmental performance were among the common advantages reported in the literature. These aspects are closely related to the current demand for green and low-carbon urban development in China. The conceptual frameworks proposed in this study were developed based on the review findings and the authors' interpretation of potential relationships among different BIM capabilities. Although further empirical studies are needed to examine these frameworks, they may provide a useful basis for future research and practical applications in the Chinese construction industry.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su18136692/s1>, PRISMA 2020 Checklist. Reference [94] is cited in the Supplementary Materials.

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Appendix A

Table A1. The Specific Assessment Information for the Documents Reviewed in this Study.

No.	Author(s)	Article Title	Data Source Reliability	Methodological Rigor	Evidence Strength	Overall Quality
1	Hou et al. 2022 [8]	A Visual Management System for Structural Health Monitoring Based on Web-BIM and Dynamic Multi-Source Monitoring Data-Driven	High	High	High	High
2	Jeong et al. 2020 [9]	Thermal Performance Visualization Using Object-Oriented Physical and Building Information Modeling	High	High	Medium	High
3	Li et al. 2021 [10]	Utilization of BIM in the Construction of a Submarine Tunnel: A Case Study in Xiamen City, China	High	High	High	High
4	Mayouf et al. 2024 [11]	Revolutionising the 4D BIM Process to Support Scheduling Requirements in Modular Construction	High	High	High	High
5	Nguyen et al. 2024 [12]	Building Information Modeling (BIM) for Construction Project Schedule Management: A Review	Medium	Medium	Medium	Medium
6	Park et al. 2017 [13]	Database-Supported and Web-Based Visualization for Daily 4D BIM	High	High	High	High
7	Wang & Huang 2024 [14]	Automated Generation and Internal Force Visualization for Box Culvert Based on Building Information Modeling	High	High	Medium	High
8	Zou et al. 2019 [15]	Risk Information Management for Bridges by Integrating Risk Breakdown Structure into 3D/4D BIM	High	High	High	High
9	Awe et al. 2025 [16]	Towards 4D BIM: A Systematic Literature Review on Challenges, Strategies and Tools in Leveraging AI with BIM	High	High	Medium	High
10	Rehman et al. 2025 [17]	Systematic Review of 4D BIM Benefits in Construction Projects	High	High	High	High
11	Afzal & Shafiq 2021 [18]	Evaluating 4D-BIM and VR for Effective Safety Communication and Training	High	High	High	High
12	Zeng et al. 2023 [19]	4D BIM-Enabled Look-Ahead Scheduling for Early Warning of Off-Site Supply Chain Disruptions	High	High	High	High

Table A1. Cont.

No.	Author(s)	Article Title	Data Source Reliability	Methodological Rigor	Evidence Strength	Overall Quality
13	Andritsou et al. 2024 [20]	BIM, 3D Cadastral Data and AI for Weather Conditions Simulation and Energy Consumption Monitoring	High	High	Medium	High
14	Kern et al. 2022 [21]	BIM-FM in Existing Buildings: A Case Study on Educational and High-Rise Residential Buildings	High	High	Medium	High
15	Lee et al. 2021 [22]	Rules and Validation Processes for Interoperable BIM Data Exchange	High	High	High	High
16	Zhu et al. 2022 [23]	The Application of Graph in BIM/GIS Integration	High	High	Medium	High
17	Zhu & Wu 2022 [24]	BIM/GIS Data Integration from the Perspective of Information Flow	High	High	High	High
18	Průša et al. 2025 [25]	From BIM to BEM—Modern Thermal Simulations Using a Building Information Management Model	High	High	Medium	High
19	Abanda et al. 2025 [26]	BIM Ontology for Information Management (BIM-OIM)	High	High	High	High
20	Wang et al. 2025 [27]	The Impact of Building Information Management (BIM) on Intelligent Landscape Design	High	Medium	Medium	Medium
21	Elghaish et al. 2021 [29]	Revolutionising Cost Structure for Integrated Project Delivery: A BIM-Based Solution	High	High	High	High
22	Mayer et al. 2021 [30]	Assessing the Duration of the Lead Appointed Party Coordination Tasks and Evaluating the Appropriate Team Composition on BIM Projects	High	High	Medium	High
23	Piroozfar et al. 2019 [31]	Facilitating Building Information Modelling (BIM) Using Integrated Project Delivery (IPD): A UK Perspective	High	High	High	High
24	Banihashemi et al. 2022 [32]	Machine Learning-Integrated 5D BIM Informatics	High	High	Medium	High
25	Hwang et al. 2019 [33]	Effect of BIM on Rework in Construction Projects in Singapore	High	High	High	High
26	Khosakitchalert et al. 2019 [34]	Improving the Accuracy of BIM-Based Quantity Takeoff for Compound Elements	High	High	High	High
27	Vigneault et al. 2020 [35]	An Innovative Framework of 5D BIM Solutions for Construction Cost Management	High	High	Medium	High
28	Das et al. 2025 [36]	The Impact of BIM on Project Time and Cost: Insights from Case Studies	High	High	High	High
29	Dong 2017 [37]	The Application of BIM Technology in Building Construction Quality Management and Talent Training	Medium	Medium	Medium	Medium
30	Wei et al. 2022 [38]	Integrated Vision-Based Automated Progress Monitoring of Indoor Construction Using Mask Region-Based Convolutional Neural Networks and BIM	High	High	High	High
31	Whitlock et al. 2021 [39]	4D BIM for Construction Logistics Management	High	High	Medium	High
32	Perera et al. 2025 [40]	Construction Schedule Planning to Incorporate Social Distancing Regulations during Pandemics—A BIM-Based Approach	High	High	High	High
33	Amoruso et al. 2019 [41]	Integrated BIM-Parametric Workflow-Based Analysis of Daylight Improvement for Sustainable Renovation	High	High	High	High

Table A1. *Cont.*

No.	Author(s)	Article Title	Data Source Reliability	Methodological Rigor	Evidence Strength	Overall Quality
34	Chen et al. 2020 [42]	Optimising Embodied Energy and Thermal Performance via an Automated BIM Tool	High	High	High	High
35	Delavar et al. 2020 [43]	Automated BIM-Based Process for Wind Engineering Design Collaboration	High	High	High	High
36	Ham & Golparvar-Fard 2015 [44]	Mapping Actual Thermal Properties to Building Elements in gbXML-Based BIM	High	High	High	High
37	Lin et al. 2019 [45]	Green BIM Assessment Applying for Energy Consumption and Comfort in the Traditional Public Market	High	High	Medium	High
38	Poh et al. 2019 [46]	Airflow Modelling Software Development for Natural Ventilation Design	High	High	Medium	High
39	Seghier et al. 2022 [47]	BIM-Based Retrofit Method (RBIM) for Building Envelope Thermal Performance Optimization	High	High	High	High
40	Zeng & Ou 2025 [48]	Daylighting Performance Simulation and Optimization Design Based on BIM Technology	High	High	High	High
41	Liu et al. 2026 [49]	Cloud-Based Application for Indoor Daylight Performance Analysis through BIM-GIS Integration	High	High	High	High
42	Forth et al. 2023 [50]	Calculation of Embodied GHG Emissions in Early Building Design Stages Using BIM and NLP-Based Semantic Model Healing	High	High	High	High
43	Hu et al. 2022 [51]	Smart Building Demolition and Waste Management Frame with Image-to-BIM	High	High	High	High
44	Marzouk et al. 2017 [52]	Assessing Environmental Impact Indicators in Road Construction Projects in Developing Countries	High	High	High	High
45	Nahangi et al. 2021 [53]	Embodied Greenhouse Gas Assessment of a Bridge	High	High	High	High
46	Wong et al. 2013 [54]	Toward Low-Carbon Construction Processes	High	High	Medium	High
47	Xu et al. 2019 [55]	A BIM-Based Construction and Demolition Waste Information Management System	High	High	High	High
48	Xu et al. 2022 [56]	Design and Integration of Air Pollutants Monitoring System for Emergency Management in Construction Site Based on BIM and Edge Computing	High	High	High	High
49	Wang et al. 2025 [57]	Dynamic TPB-BN Framework for Construction Waste Reduction	High	Medium	Medium	Medium
50	Abbott et al. 2020 [58]	The Intelligent Use of RFID and BIM in Prefabricated, Prefinished, Volumetric Construction Work Flow	High	High	Medium	High
51	Hao et al. 2020 [59]	Carbon Emission Reduction in Prefabrication Construction during Materialization Stage: A BIM-Based Life-Cycle Assessment Approach.	High	High	High	High
52	Huo et al. 2023 [60]	Design and Application of Intelligent Construction Quality Inspection System Based on BIM-RFID	High	High	High	High
53	Wang 2023 [61]	Integrated Application of Prefabricated Building Construction Information Based on BIM and RFID Technology	High	Medium	Medium	Medium
54	Zhai et al. 2019 [62]	An Internet of Things-Enabled BIM Platform for Modular Integrated Construction: A Case Study in Hong Kong	High	High	High	High

Table A1. *Cont.*

No.	Author(s)	Article Title	Data Source Reliability	Methodological Rigor	Evidence Strength	Overall Quality
55	Wang et al. 2022 [63]	Exploring a Body of Knowledge for Promoting the Building Information Model for Facility Management	High	High	High	High
56	Ado et al. 2022 [64]	Landslide Susceptibility Mapping Using Machine Learning: A Literature Survey	High	High	Medium	High
57	Agliata et al. 2022 [65]	The Impact of the Aggregation Formula on Indicator-Based Method for the Assessment of Building Susceptibility to Hydro-Meteorological Hazards	High	Medium	Medium	Medium
58	Akram et al. 2019 [66]	Exploring the Role of Building Information Modeling in Construction Safety through Science Mapping	High	High	Medium	High
59	Akram et al. 2022 [67]	Exploring the Role of BIM in Construction Safety in Developing Countries: Toward Automated Hazard Analysis	High	High	High	High
60	Deng et al. 2021 [68]	BIM and Computer Vision-Based Framework for Fire Emergency Evacuation Considering Local Safety Performance	High	High	High	High
61	Xu et al. 2019 [69]	A Prediction Method of Building Seismic Loss Based on BIM and FEMA P-58	High	High	High	High
62	Zhang et al. 2014 [70]	Ontology-Based Semantic Modeling of Safety Management Knowledge	Medium	Medium	Medium	Medium
63	Zhang et al. 2015 [71]	BIM-Based Fall Hazard Identification and Prevention in Construction Safety Planning	High	High	High	High
64	Providakis et al. 2019 [72]	Predictions of Settlement Risk Induced by Tunnelling Using BIM and 3D Visualization Tools	High	High	High	High
65	Tabejamaat et al. 2024 [73]	Boosting Large-Scale Construction Project Risk Management	Medium	Medium	Medium	Medium
66	Tao et al. 2022 [74]	Dynamic Multi-Objective Construction Site Layout Planning Based on BIM	High	High	High	High
67	Tian et al. 2021 [75]	Crane Lifting Optimization and Construction Monitoring in Steel Bridge Construction Project Based on BIM and UAV	High	High	High	High
68	Yao et al. 2020 [76]	Evaluating the Environmental Impact of Construction within the Industrialized Building Process	High	High	High	High
69	Wiegel et al. 2023 [77]	Perspectives of 3D Probabilistic Subsoil Modeling for BIM	High	High	Medium	High
70	Luo et al. 2022 [78]	A Sustainable BIM-Based Multidisciplinary Framework for Underground Pipeline Clash Detection and Analysis	High	High	High	High
71	Oduro et al. 2026 [79]	Comparative Analysis of Machine Learning Algorithms for Clash Relevance and Risk Level Prediction in BIM Design Coordination	High	Medium	Medium	Medium
72	Ailem & Boton 2026 [80]	Automating Clash Relevance Filtering in BIM-Based Multidisciplinary Coordination Using Machine Learning	High	High	High	High
73	Iqbal et al. 2023 [81]	Integrating BIM–IoT and Autonomous Mobile Robots for Construction Site Layout Printing	High	High	High	High
74	Kolarić et al. 2023 [82]	Analyzing the Level of Detail of Construction Schedule for Enabling Site Logistics Planning in BIM Environment	High	Medium	Medium	Medium
75	Song & Marks 2019 [83]	Construction Site Path Planning Optimization through BIM	Medium	Medium	Medium	Medium

Table A1. Cont.

No.	Author(s)	Article Title	Data Source Reliability	Methodological Rigor	Evidence Strength	Overall Quality
76	Gan et al. 2022 [86]	Integrated BIM and VR for Interactive Aerodynamic Design and Wind Comfort Analysis	High	High	High	High
77	Kang et al. 2022 [85]	Utility of BIM-CFD Integration in the Design and Performance Analysis for Buildings and Infrastructures	High	High	Medium	High
78	Lundqvist et al. 2019 [87]	Air Heating System Design for a Sub-Arctic Climate Using a CFD Technique	High	Medium	Medium	Medium
79	Cao et al. 2022 [91]	Green Building Construction: A Systematic Review of BIM Utilization	High	High	High	High
80	Cheng et al. 2022 [84]	BIM-Enabled Life Cycle Assessment of Concrete Formwork Waste Reduction through Prefabrication	High	High	High	High
81	Han et al. 2021 [92]	BIM for Construction and Demolition Waste Management in Australia: A Research Agenda	High	Medium	Medium	Medium
82	Salgin et al. 2017 [93]	Construction Waste Reduction Through BIM-Based Site Management Approach	Medium	Medium	Medium	Medium

As shown in Table A1, the majority of the included studies (83%) were assessed as high quality, while only a limited number were rated as medium quality. These studies were spread across different BIM capability areas and did not substantially influence any single subsection. For this reason, the main findings and capability-level conclusions were considered sufficiently robust, and no additional sensitivity analysis was conducted.

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