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Review

Green Building Construction: A Systematic Review of BIM Utilization

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Abstract: As a multi-function method, Building Information Modeling (BIM) can assist construction organizations in improving their project's quality, optimize collaboration efficiency, and reduce construction periods and expenditure. Given the distinguished contributions of BIM utilization, there is a trend that BIM has significant potential to be utilized in the construction phase of green buildings. Compared with traditional buildings, green buildings have more stringent requirements, including environmental protection, saving energy, and residents' comfort. Although BIM is deemed an effective method to achieve the abovementioned requirements in the construction process of green buildings, there are few systematic reviews that explore the capabilities of BIM in the construction phase of green buildings. This has hindered the utilization of BIM in the construction of green buildings. To bridge this research gap and review the latest BIM capabilities, this study was developed to perform a systematic review of the BIM capabilities in the construction phase of green buildings. In this systematic review, the PRISMA protocol has been used as the primary procedure for article screening and review. The entire systematic review was performed from January 2022 to April 2022. In this process, 165 articles were included, reviewed, and discussed. Web of Science (WoS) and Scopus were adopted as the databases. Through this systematic review, it can be identified that BIM capabilities have significant advantages in project quality improvement, lifecycle data storage and management, collaboration optimization, planning, and schedule management optimization in the construction phase of green buildings. Through the discussion, it can be concluded that BIM utilization can be adopted from the pre-construction phase to the post-construction stage in the green building construction process. Besides these, the barriers to BIM utilization in the green building construction phase are also revealed in the discussion section, including the non-uniform data format, insufficient interactivity, ambiguous ownership, insufficient BIM training, and hesitation toward BIM adoption. Moreover, the challenges and future directions of BIM utilization in green building construction are identified. The findings of this study can facilitate construction personnel to be acquainted with BIM capabilities in the construction of green buildings to promote the utilization and optimization of BIM capabilities in the green building construction process.

Keywords: building information modeling; information technology; green building; sustainable building; construction

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1. Introduction

As a multi-function method, Building Information Modeling (BIM) makes a significant contribution to the Architectural Engineering and Construction (AEC) industry. According to the British Standards Institution [1], BIM uses shared digital representations of building assets to promote the design, construction, and operational process and form a reliable basis for decision making. It is the process of generating and managing data about projects from the pre-construction phase to the post-construction phase [2]. In this process, the BIM that is three-dimensional, used in real time, and dynamic is adopted to improve the productivity and quality of projects in their lifecycle [2]. Despite no uniform definition of BIM across different countries and generations, there is a consensus in the AEC industry that BIM is not just a tool and software installed on a computer [3]; rather, it is a combination of software and process [3]. In summary, BIM is the multiple function method that integrates business process, digital representation, organization, and control of the process. It can provide three-dimensional (3D) modeling of the project, manage the project schedule throughout the whole lifecycle, provide a communication platform for all stakeholders, estimate and calculate project costs, detect clashes, and allow stakeholders to inspect and manage buildings throughout their building lifecycle [4].

As an effective information technology method in the AEC industry, BIM can provide a significant contribution to the construction of green buildings [5,6]. Green buildings are also known as healthy buildings. They are the buildings that can prompt positive influence and reduce the negative impact on the natural environment in the lifecycle of assets [7]. According to the Evaluation Standard for Green Building [8], green buildings contain one or more of the following features and standards:

1. Efficient utilization of resources and energy.
2. Utilization of renewable energy, such as wind and geothermal energy.
3. Adoption of pollution- and waste-reduction measures.
4. Utilization of non-toxic, ethical, sustainable, recycled, and re-used materials.
5. Quality indoor environment and comfortable residential experience.
6. Suitable for the local environment and climate.

Given the strict standards and requirements of green buildings, it is difficult for construction organizations to achieve the green buildings' requirements through traditional construction methods [9,10]. To overcome the obstacles of the conventional construction process, an increasing number of AEC participants recommended that BIM should be integrated into the construction of green buildings [4,11,12]. As an effective information technology tool, BIM was deemed the efficient solution to assist AEC corporates in overcoming the barriers in the construction process of green buildings [3,4,11–14]. Ghaffarianhoseini et al. [5] comprehensively summarized the benefits of BIM application: "these benefits range from its technical superiority, interoperability capabilities, early building information capture, use throughout the building lifecycle, integrated procurement, improved cost control mechanisms, reduced conflict and project team benefits." Moreover, BIM is the essential method for implementing full automation of information integration, collaboration and intellectual property issues, multi-party involvement, and collaboration [15].

Although the application of BIM in the AEC industry has had tremendous positive influences on the technology involved to provide effective and optimal parameters to facilitate users to achieve project requirements, the integration of BIM and green buildings in construction activities is still deficient [9,16–18]. The major hindrance to BIM utilization in green building construction was the unfamiliarity with the BIM capabilities of the construction organizations [19–23]. According to the statistics of Akhmetzhanova et al. [24] and Tatygulov et al. [25], 44% of respondents refused to adopt BIM because they were unfamiliar with BIM functions and had not received the appropriate training. Given the abovementioned content, it can be concluded that construction personnel generally suffer from a lack of familiarity with BIM within the AEC industry. To enhance familiarity with BIM capabilities that can be utilized in the green building construction process, this study was developed to perform a systematic review of BIM capabilities in the construction phase of green buildings.

Moreover, there are a few review articles that reviewed the BIM application in the construction phase of green buildings [3,26–29]. However, most of these review articles did not utilize a systematic review method in their research. According to Lu et al. [4], most reviews of BIM utilization in the construction phase are conducted by traditional and bibliometric review. Most traditional reviews lack the explicit retrieve and screen protocol of the literature in their studies [30,31]. Thus, the article-screening processes in traditional reviews are usually not transparent enough for the audience [31]. Moreover, no fixed and formal article search process guidance is identified in the traditional review, which has led to confusion in the article selection process in the traditional review to some extent [32,33].

From the perspective of a bibliometric review, this review is conducted through the quantitative analysis of bibliographic material (data) [34]. Although the bibliometric review can perform a more quantitative description and discussion of the research area, it has insufficient qualitative exploration and analysis of the particular study in this research [35]. Compared with the abovementioned review methods, the systematic review can provide a complete summary of the current literature relevant to the research questions and develop a reliable evaluation of future development directions [36,37]. Moreover, BIM software is evolving rapidly, and BIM features are changing and iterating continually. To fill the research gap of the insufficient systematic review of the BIM capabilities in green building construction, it is necessary to perform a contemporary systematic literature review to retrieve, summarize, discuss, and analyze the latest BIM capabilities that can be utilized during the construction stage of green buildings.

Given the abovementioned background content, this study was developed with the aim of performing a systematic literature review on BIM capabilities that can be utilized during the construction stage of green buildings. To achieve this aim, three objectives were developed:

1. Identify the BIM capabilities that can be utilized in the construction of green buildings.
2. Discuss and analyze the methods that BIM capabilities performed in green building construction.
3. Summarize the advantages, challenges, and future direction of BIM utilization in the construction of green buildings.

This study consists of the following sections. The introduction is presented in Section 1. The research methodology is illustrated in Section 2, in which the process of article retrieval and screening is demonstrated. Moreover, the search string and the inclusion and exclusion criteria for the study are also presented in Section 2. The results of the systematic review are shown in Section 3. Here, the reviewed BIM capabilities are categorized into four categories, including project quality improvement, lifecycle data storage and management, collaboration optimization, and planning and schedule management optimization. Moreover, the utilization methods of these BIM capabilities in green building construction are reviewed in Section 3. The discussion and analysis are conducted in Section 4, in which the authors discuss and analyze the BIM capabilities from the pre-construction phase to the post-construction phase of green buildings. Besides these, the future direction, advantages, and challenges of BIM utilization in green building construction are provided in Section 4. Section 5 is the conclusion, and also discusses the contributions and limitations of this study.

2. Research Methodology

This study aimed to perform a systematic literature review on BIM capabilities that can be utilized during the construction stage of green buildings. Given the precise scientific design insisted upon in the systematic review process, it can assist researchers in mitigating biases and random errors in the review process [38]. Moreover, a systematic review can facilitate authors to become familiar with the primary knowledge retrieved in the screened articles, and develop the research model through a robust approach, to explore the future research directions more precisely [39–41].

To achieve the abovementioned aim, the preferred reporting items for systematic reviews and meta-analyses (PRISMA) model [42] was used to conduct the systematic review. In this study, the PRISMA was conducted through four phases, as per the systematic literature review studies by Cho et al. [43] and Lee et al. [40]:

1. Determine the search database and keywords.
2. Develop the search strings based on the keywords, inclusion criteria, and exclusion criteria. Conduct the primary article screening through the search strings.
3. Conduct the qualitative screening of titles, keywords, and abstracts according to the inclusion criteria and exclusion criteria.
4. Perform the qualitative assessment and literature review of the full content of the remaining articles.

The process of the systematic literature review in this study is shown below.

Phase 1: To ensure the retrieved articles can meet the requirements of the systematic literature review, Web of Science (WoS) and Scopus were determined as the databases in this study. Articles that had not been peer reviewed were not permitted to be included in this study. The keywords were determined as follows: "Building Information Modeling", "Building Information Model", "BIM", "Green Building", "Sustainable Building", and "Construction".

Phase 2: In this phase, the search strings (as shown in Table 1) were developed to conduct the initial article search of this study. Moreover, the inclusion criteria and exclusion criteria (as shown in Table 2) were formulated for further qualitative screening. In this study, the retrieved articles included conference papers, articles, review articles, and proceedings papers that can be searched for through WoS and Scopus. Other types and database sources of articles were excluded in this process. Moreover, non-English articles were also excluded from the retrieval process. Through the initial article search and review, the overview of BIM capabilities in the construction process of green buildings was formed.

Table 1. Search string and initial search results.

Search Engine	Search String	Results
WoS	TS = (("building information modeling" OR "building information modelling" OR BIM) AND (green building OR sustainable building) AND (construction OR construct))	974
	Document Types: Articles or Proceedings Papers or Review Articles	969
	AND LANGUAGES: (ENGLISH)	965
Scopus	"TITLE-ABS-KEY (("building information modelling" OR "building information modeling" OR BIM) AND (green AND building OR sustainable AND building) AND (construction OR construct))	459
	AND (LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "cr"))	445
	AND (LIMIT-TO (LANGUAGE, "English"))	437
Sum of the papers = 1402 Duplicates = 137 Invalid = 109 After removing duplicates and invalid papers = 1156 After title and keyword screening = 537 After abstract screening = 249 After review of full content of papers = 165 Total = 165		

The initial article search was conducted in April 2022. In this process, 1433 articles were retrieved from WoS and Scopus (974 in WoS, 459 in Scopus). Then, 137 duplicated articles and 109 invalid articles (articles that cannot be provided as an online version of the full content) were removed by the author. In the end, 1156 articles remained after this phase was complete. The remaining articles were carried over into the next step to conduct further qualitative screening of the titles, keywords, and abstracts.

The detailed search strings and initial search results are presented in Table 1, and the clear inclusion and exclusion criteria are presented in Table 2.

Phase 3: This phase involved performing the qualitative analysis based on the above-mentioned inclusion and exclusion criteria. In phase 3, the titles and keywords of the remaining articles were firstly screened manually according to the secondary inclusionary and exclusionary criteria. In this step, 619 articles were eliminated, and 537 articles remained. Then, abstract analysis was performed manually on the remaining 537 articles based on the secondary inclusionary and exclusionary criteria. In total, 288 articles were removed because their abstracts failed to meet the requirements of the secondary inclusion and exclusion criteria (mentioned in Table 2). After phase 3 was accomplished, 249 articles remained and were brought into the next phase.

Table 2. Inclusion criteria and exclusion criteria.

Primary Criteria		Secondary Criteria	
Inclusionary	**Exclusionary**	**Inclusionary**	**Exclusionary**
Journal articles that can be searched in Web of Science (WoS) or Scopus	Duplicated papers	Articles that contain BIM capabilities in the construction of green buildings	Articles that contain no BIM capabilities in the construction of green buildings
Conference paper and proceeding papers that are searchable through WoS or Scopus	Invalid articles (articles that cannot provide the online version of full-text content)	Articles that can support authors to accomplish research objectives	The articles that cannot provide support for authors to accomplish research objectives
Review articles that are searchable through WoS or Scopus			
Published in English	Non-English edited articles or papers		

Phase 4: The qualitative assessment was performed on the remaining 249 articles and a literature review of the full content based on the secondary inclusionary and exclusionary criteria was carried out (mentioned in Table 2). Moreover, these articles were also reviewed manually by the authors to identify whether they contain quality content on BIM utilization in green building construction. In this process, the inclusion and exclusion of an article relied on the subjective decisions of the authors without firm objective standards. In the end, 165 articles were included in the study, and were brought over to the next stage of the process (Section 3), namely, the systematic literature review.

The entire search and screening process of this study is presented in Figure 1.

Through the full-text review of the included studies, the BIM capabilities can be categorized according to their contribution areas (see in Table 3).

Table 3. Process of categorization determination.

Identify the BIM capabilities that can be utilized in the green building construction through full-text review.
Categorize the BIM capabilities according to their contribution areas.
Develop the classifications of BIM capabilities in green building construction.
Check for consistency by referring to other studies.
Verify the developed classifications in this study.

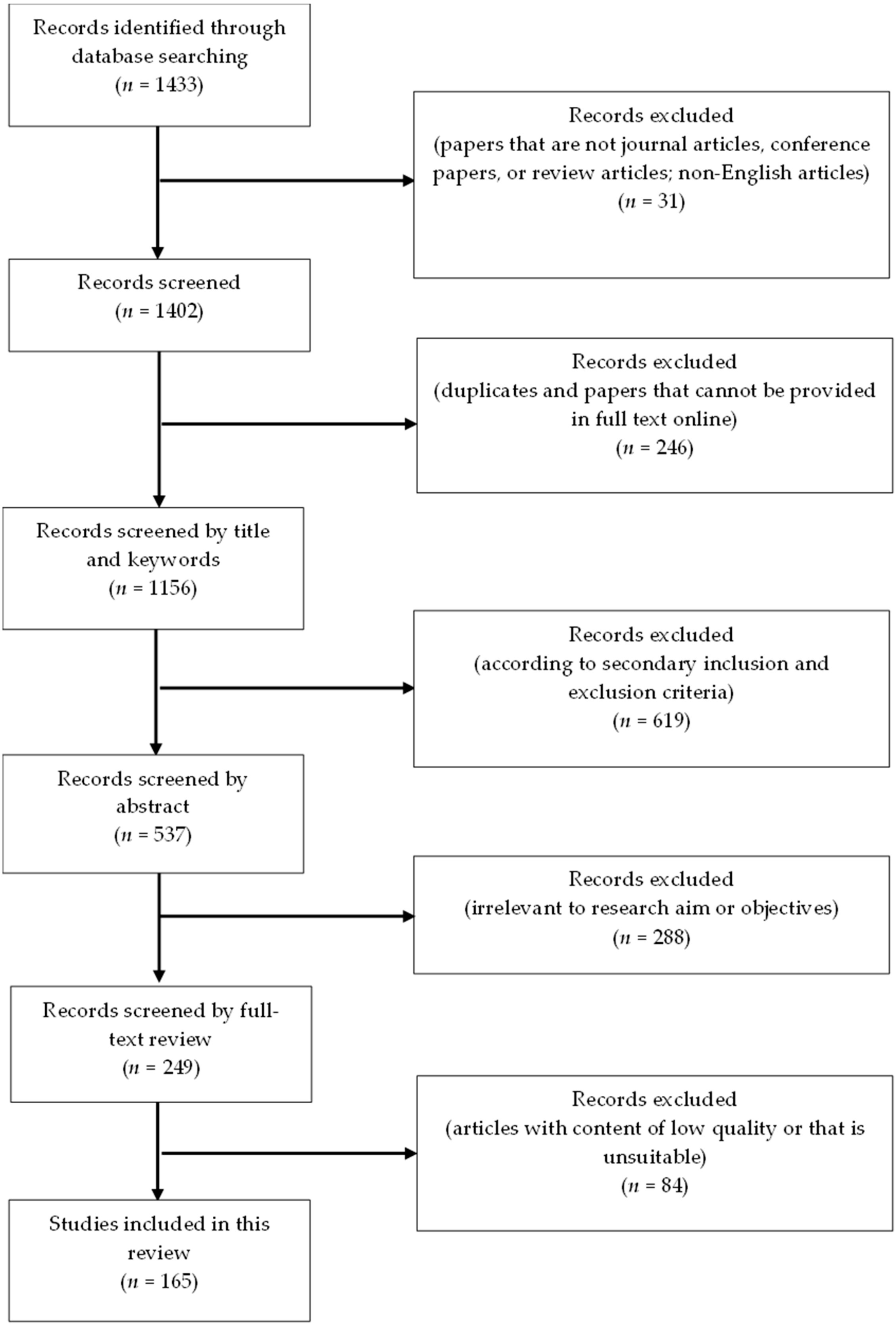

Figure 1. Flowchart of article screening process used in this study.

3. Results

3.1. Descriptive Analysis

After the search and screening carried out in Section 2, 165 articles were retrieved and included in this systematic review. In Section 3, these included articles were systematically reviewed and summarized by the authors.

The publication dates of the reviewed articles are presented in Figure 2. According to Figure 2, it can be identified that the earliest publication of the articles reviewed was 2010. From 2010 to 2015, the research on BIM capabilities in green building construction was still in the infancy stage. From 2010 to 2015, although the number of articles in this area generally shows moderate growth, the overall number of publications is still relatively few (from one to five).

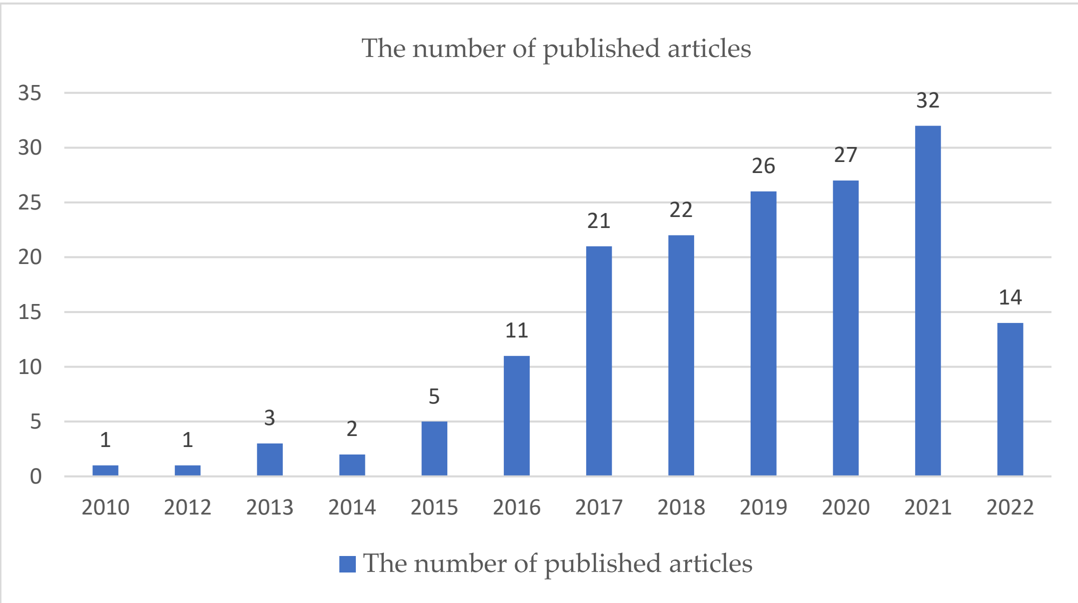

Figure 2. Number of reviewed articles per year.

Eleven of the reviewed articles were published in 2016, and the research on BIM utilization in green building construction was becoming more popular and attractive. From 2017 to 2021, BIM utilization in the construction phase of green buildings had become a prominent discipline and received wide and significant attention from researchers. The included articles published exceeded 20 per year and gradually increased in this period (from 21 in 2017 to 32 in 2021).

The number of included articles that were published in 2022 was 14. However, given that this study was performed between January 2022 and April 2022, it can be concluded that all reviewed articles were published in the first four months of 2022. Any articles published after April could not be reviewed because of the publication date limitations. Therefore, the decline in the number of reviewed articles in 2022 does not indicate that the BIM capabilities in green building construction are obsolescent. Moreover, among the reviewed articles in this study, 14 were published in the first four months of 2022. This phenomenon can also indicate indirectly that this field is still valued and vital in 2022.

From the perspective of publication journals, these 165 reviewed articles were taken from 64 journals and 12 conferences. According to the number of reviewed articles published in each journal, the rank of journals is presented below (due to the length of the study, only the top 10 journals are listed): *Automation in Construction* (25), *Sustainability* (11), *Procedia Engineering* (8), *Advanced Engineering Informatics* (6), *Buildings* (6), *Journal of Cleaner Production* (6), *Journal of Building Engineering* (6), *Renewable and Sustainable Energy Reviews* (5), *International Journal of Project Management* (4), and *Journal of Civil Engineering and*

Management (4). The ranking of journals according to the number of the reviewed articles being published is demonstrated in Figure 3 (Only the journals that ranked in the top ten for the number of articles in this study are included).

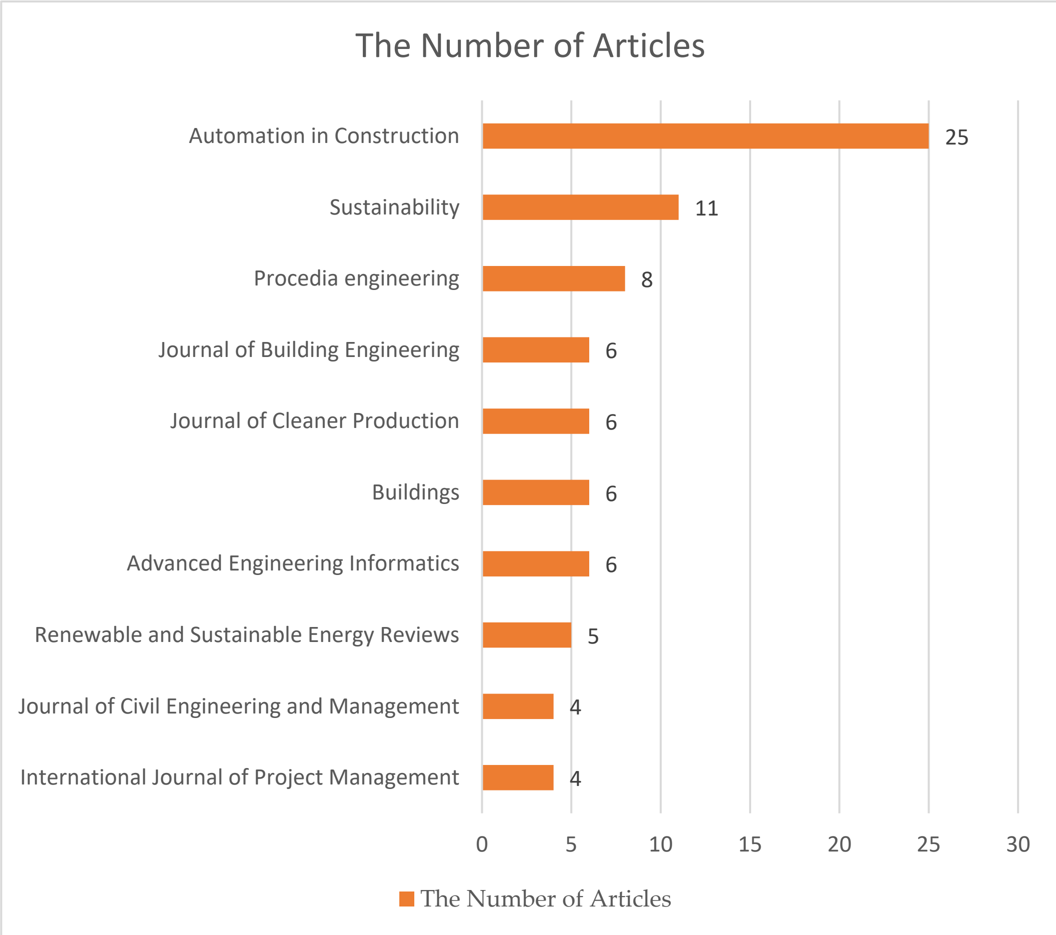

Figure 3. Number of reviewed articles published per journal.

3.2. Results Analysis

BIM is considered to be a potential technology in the construction stage of green buildings. To encourage the adoption and development of BIM in the AEC industry, the importance and potential of BIM implementation have been highlighted by many researchers [44]. Ghaffarianhoseini et al. [5] comprehensively summarized the benefits of BIM application: "these benefits range from its technical superiority, interoperability capabilities, early building information capture, use throughout the building lifecycle, integrated procurement, improved cost control mechanisms, reduced conflict and project team benefits."

In this study, 165 articles were included in the systematic review and analysis by the authors. Through the systematic review, the BIM capabilities are summarized and categorized according to their benefits and advantages during the construction phase of green buildings. In this study, the classification of BIM capabilities in the green building construction phase is as follows: project quality improvement, lifecycle data storage and management, collaboration optimization, and planning and schedule management optimization. Detailed information on the reviewed studies in terms of the four aspects mentioned above is presented in Appendix A.

3.2.1. Project Quality Improvement

BIM has made significant contributions to improving the project quality in the process of green building construction. As an object-orientated 3D model, BIM can integrate the knowledge of various disciplines to provide a quality platform for parametric modeling, spatial visualization, and asset-process simulation [45]. Based on the abovementioned functions, the situations of components can be demonstrated through BIM, which can facilitate the architects' and engineers' ability to conduct clash detection [46]. In green building construction, the clash detection in BIM can save up to 10% of the contract value and reduce the construction schedule by 7% [5]. In addition, the comparison between different design schemes can be conducted by BIM tools. It assists stakeholders in developing construction schemes with better efficiency and sustainability [17]. Moreover, BIM can provide the 3D demonstration at the initial stage of green building construction so that the clients can become familiar with the intent of the design in a timely manner [47]. This advantage helps the designers and civil engineers to effectively make changes in time to meet the clients' requirements. Based on the statistics from Noor et al. [48], the most efficient contributions from BIM are "better visualization compared to traditional CAD technology", "the ability of BIM in visualization", and "helps to ensure that the quality-related activities are being performed effectively", with mean values of 3.7500, 3.6471, and 3.9853, respectively. As a reference, a mean value between 3.5 and 4.49 can be defined as "much" in the mean scale formulated by Aguila et al. [49]. According to the questionnaire survey from Huang et al. [14], 87.8% (180/205) of respondents endorsed BIM facilitating designers' ability to integrate designs. Furthermore, 84.4% (173/205) of respondents agreed that the acceleration of model generation and modification could be achieved through BIM, which can improve working efficiency and quality [14].

For the construction organizations that adopted BIM in the green building construction process, the advantages of BIM can be extended from the pre-construction phase to the projects' final acceptance and retrofit phases [50]. From pre-construction to retrofit, BIM can assist stakeholders in performing construction activities' documentation, information real-time storage and exchange, monitoring and surveillance, emergency control, and asset demolition [5]. Moreover, BIM has a remarkable effect on the renovation of green buildings with the support of as-built data acquisition tools (such as laser scanning and infrared thermography) [51]. In the retrofit process, Najjar et al. [52] put forward that BIM utilization in lifecycle assessment can encourage architects to incorporate environmental criteria into their decision-making process. This characteristic enables the stakeholders from various aspects to consider ecological requirements reasonably when making decisions [52]. BIM also has practical functions in supporting the assessment of energy consumption and residential comfort in various renovation instructions [53]. In the interior retrofit case of the Diagnosis and Treatment Centre of the University Hospital of Jaén, through thermal simulation, daylight simulation, and energy analysis, the annual energy consumption in the renovated building dropped by 120.94 kWh/m^2 [54]. In the energy-efficient retrofit project of Xindian Central Public Retail Market in Taiwan, the air conditioner system load was reduced by 100 kWh due to the support of BIM [55].

Moreover, green buildings are required to meet the green building evaluation standards. Through the simulation and knowledge-storage functions in BIM, BIM-based green building assessment models were proposed to record the energy consumption during construction and to predict the energy performance of the building during the post-construction phase [56–59]. In the case study of Wu et al. [60], the researcher inputted the green building evaluation standard into the BIM to check the compliance of the green building item by item, and then determined the corresponding green building rating of the target projects.

3.2.2. Collaboration Optimization

Due to the strict quality and technology requirements of green building construction, the practical cooperation and collaboration of multiple stakeholders from various organizations in sustainable construction are required [10]. Collaboration is deemed one of the most critical features of BIM. Collaboration aims to achieve the best results in a cost-effective and timely manner by bringing together a variety of people and resources and using their collective knowledge and capabilities to accomplish tasks that would be difficult for an individual organization to perform [61]. Due to the massive scale and high complexity of green building construction, it is necessary for the various stakeholders in the lifecycle of projects to couple with other participants through project-specific collaborative relationships [13,62,63]. The practical cooperation between multi-disciplines has significant contributions to rework elimination, the reduction in clashes and misunderstandings, waste mitigation, and the definition of risks and uncertainties [64,65].

The collaboration between multi-disciplines and various stakeholders (or organizations) can be effectively conducted through BIM. As a collaboration and communication platform, BIM can develop a comprehensive shared operating environment intergraded by multiple discipline models [64,66,67]. Through the cooperation platform in BIM, the project information of their lifecycle is can more easily be updated, modified, inserted, and extracted by various stakeholders. These stakeholders pertain to multiple disciplines and organizations, and possess specific skill sets to fulfil BIM-related project requirements [68]. With the transparency of the BIM cooperation environment, the ownership of data through the lifecycle of projects is shared by various stakeholders [69]. To eliminate the barriers and ensure interoperability in collaboration, Industry Foundation Classes (IFC) are generally utilized as the standard file format specification [70]. In addition, the gbXML schema (Green Building XML) was formulated to enhance the transfer of building data from BIMs to engineering analysis software [26].

In BIM-utilized green building construction processes, the collaboration among various disciplines and stakeholders is basically achieved through the BIM-based construction network (BbCN) [64]. The BbCN contains team members from multiple organizations to conduct BIM-related activities on BIM-enabled projects [64]. Cao et al. [71] revealed that the enhancement of internal collaboration within the BbCN had been a particularly effective selling point for BIM. In the cooperation process in BbCN, some prerequisites need to be integrated, including the context, team, process, task, and actor [72]. With the assistance of effective management and transparent and shared information exchange, collaboration can be deemed a central element of success throughout the lifecycle of construction projects [73,74]. In addition to BbCN, Wang et al. [75] introduced the stake source system based on social network analysis (SNA), which can automatically recommend suitable stakeholders through SNA. Through this system, stakeholders can easily become familiar with others' responsibilities, work progress, and position.

In conclusion, BIM can effectively improve collaboration quality. As a digital representation tool and database inventory, all stakeholders can work on a sharing cooperation platform through the BIM application, which enhances the quality of the decision-making process [4]. The essential issues in the cooperation management process can be described as: "which building elements, from which trades, should be developed at what time and at what level?". This issue can be addressed by the Level of Detail (LOD) decision plan, which is conducted through BIM [76]. In state-owned assets projects and public–private partnership projects, satisfaction from the government is necessary for collaboration. According to the statistics from Zuhairi et al. [77], the most important driving factor in BIM implementation in Malaysia is "the advocation and enforcement in the implementation of BIM by the government" with relative importance indicators (RII) of 0.950. BIM implementation can effectively improve the government's satisfaction, thus improving the quality of cooperation. According to statistics from Huang et al. [14], 86.34% (177/205) of respondents believed that BIM played an essential role in the establishment of collaborative platforms. According to the questionnaire survey of the Collaboration Management (CM)-based BIM model developed by Lin and Yang [66], 92% of the respondents were satisfied with CM-based BIM creation work, and 86% of the respondents believed that it could enhance the management of model creation work in the collaboration process.

3.2.3. Lifecycle Data Storage and Management

In the process of green building construction, it is necessary for the construction organizations to obtain the data and information on corresponding green buildings that are produced in their design phase. If the information delivery is deficient, the construction schedule might be delayed.

BIM can be formulated as a multifunction repository that stores data throughout the project lifecycle [15,52,78]. The digital presentation and remarkable interoperability capabilities facilitate the exchange and revision of data by users throughout the entire green building construction process. This benefit can help stakeholders to capture comprehensive building information [4]. With the development of BIM, the international BIM information storage and exchange standard Industry Foundation Classes (IFC) were introduced into BIM [79]. This effectively eliminated the format barriers involved in collaboration using BIM [79].

BIM's knowledge storage and management function can effectively overcome the fragmented information issues that have developed in the green building construction process [80,81]. In the research of Solihin et al. [82], they integrate spatial operations into standardized SQL queries that are easy to query. This makes the data in BIM more accessible, and better assists stakeholders in making decisions. Lu et al. [4] maintained that one BIM model could contain information from multiple disciplines, which can continuously incorporate sustainability measures into the project throughout the design process. BIM can also make users familiar with the intricate relationship between stakeholders. Zheng et al. [83] propose a novel method based on the Stakeholder Value Network (SVN) that could quantify and visualize the value exchange between critical stakeholders when adopting BIM in sustainable constructions. This allows users to visualize and quantify the perceived value of BIM stakeholders [83].

Moreover, with the integration of BIM and third-party devices, BIM can achieve effective data collection and management in the construction phase of green buildings [84,85]. With the integration of BIM and GIS, BIM can assist the construction organization in obtaining information on the construction site and surrounding environment, including topography, terrain, soils, vegetation cover, road layout, and infrastructure layout [63,86–89]. Besides that, with the connection of BIM and the Internet, BIM can effectively retrieve and integrate weather conditions on green building construction sites, thus mitigating the natural hazard damage and ensuring the safety of construction personnel [90]. In addition to these, with the BIM, RFID, barcodes, 2D imaging, and photogrammetry, BIM can automatically capture and store the utilization situation, stock quantities, and input and output information of materials and equipment on the green building construction site [87,91–94].

3.2.4. Planning and Schedule Management Optimization

Quality scheduling and project management in green building construction can be efficiently guaranteed through BIM implementation. BIM can enhance the construction schedule management for stakeholders [95]. Not only can the resource requirements, equipment requirements, and excepted expenditure for the next step be obtained through BIM, but the percentage of progress, the number of expenses, and the deviation from the budget can also be predicted by BIM [96]. Moreover, real-time updates and quality visualization performance can be achieved by BIM to enhance planning activities [97,98]. The project duration and expenditure can be efficiently reduced through the project management of BIM. According to the summary from Ghaffarianhoseini et al. [5] in the aspect of project management, BIM can eliminate 40% of unforeseen modifications, provide cost estimates with a 3% error threshold, and reduce the generation time by up to 80%. In addition, Gao and Pishdad-Bozorgi [99] put forward that BIM can facilitate the integration of AEC knowledge, which has a significant advantage for the contractors and subcontractors of green building construction projects to enhance their management personnel training.

The use of BIM in the planning and schedule management of green building construction can be started at the pre-construction stage. Before the construction activities begin, the feasibility studies of green building construction plans can be verified through BIM simulation, to eliminate rework and waste for the subsequent activities [17]. In addition, Wang and Liu [100] highlighted that engineers and constructors could propose optimized methods and simulate their performance to conduct feasibility verification and trial and error if there are defects in previous plans. By evaluating the impact of construction activities on the surroundings, the corresponding environmental protection measures can be adopted to mitigate the negative influence of the construction [101]. In the site-planning process, BIM can compare various siting alternatives to determine the most suitable construction site layout with the most negligible impact on the surrounding environment [102]. In this process, BIM provides an appropriate framework for decision making by bringing together the necessary information at the right time, and clarifying details and existing conditions [102]. A meta-heuristic algorithm is used to optimize the construction site's layout after thoroughly considering all factors [88,103].

In multiple dimensions of BIM modeling, the stakeholders can utilize BIM to formulate schedules and conduct project management in the green building construction process. BIM is a multi-dimensionality tool. The BIM applications can be divided into BIM 3D, BIM 4D, BIM 5D, and BIM 6D according to their functions and application aspects [54,104–108]. To clarify, 3D means that BIM can provide detailed 3D model simulations of buildings [109–116]. BIM 4D integrates BIM 3D with the time dimension, so BIM 4D can simulate the green building construction process to support the schedule development and revision, constructability analysis, clash detection, and other functions [117–122]. BIM 5D is based on BIM 4D, with the addition of cost-related information [123,124]. Through BIM 5D, the construction organizations can effectively forecast and account for the expenditure of the green building construction project at different phases, and predict the return-on-investment (ROI) ratio [125–128]. BIM 6D is based on BIM 5D and adds sustainability management functions, which improves the sustainable efficiency and quality of the green building construction process [104,129].

As an advanced scheduling and modeling tool, BIM 4D can effectively conduct the integration of 3D visual modeling and project schedules. Compared with the regular Gantt chart, the construction schedules and sequence of tasks can be visually demonstrated in BIM, which helps stakeholders to become familiar with the green building construction sequences [130]. Through the integration of geometric information with the schedule and material information, Jupp [131] revealed the potential of BIM to identify work sequence errors and conflicts quickly. With the combination of the BIM management system, surveillance, barcode, and radio-frequency identification, materials that are transported, transferred, and utilized within the construction site can be automatically recorded and updated in the bill of materials (BOM) [132]. To eliminate the uncertainties in green building construction schedule plans, Yuan et al. [133] developed the Monte Carlo method (MCM) and BIM-based construction schedule early warning model (MCM-BIM-CSEWM) to address the logical relationships between construction activities and provide timely risk warnings. Irizarry et al. [134] also revealed that the supply chain is arranged in a better precise, efficient, and cost-effective method with the integration of BIM and geographic information systems (GIS). From the perspective of safety management and planning, through BIM 4D's simulation and visualization of the green building construction progress, BIM can conduct risk identification and safety training for management personnel and construction workers [135–139]. Moreover, through the BIM 4D hazard identification component established by Heidary et al. [140], BIM can assist green building construction managers in identifying and demonstrating the potential construction hazards in the early stages of green building projects [140].

In the BIM-generated schedule, the components and schedules of each sub-progress and each task can be contained and demonstrated in the entire construction schedule [141,142]. Based on the abovementioned functions, the intercomparison of construction schedules and the detection of recurring processes can be conducted expediently through BIM 4D [143]. Moreover, through the visualization in BIM, the construction progress can be visually simulated, including engineering design, field environment, projected material consumption, and machinery utilization [100]. This method enhances the predictability of construction and transforms the traditional pattern of construction plans [100]. By simulating the construction progress and potential construction accidents, personnel training and safety education can be provided by BIM utilization [135,136,144]. Nicał and Wodyński [129] put forward that the impact of construction activities on the surrounding environment can be simulated through BIM 6D, which is necessary to support green buildings to conform to specific green building evaluation standards.

In the process of scheduling and project management, some repetitive tasks can be conducted using the same or a similar method in the green building construction process [143], and BIM 4D can provide predefined process templates to execute the required tasks without wasting time or production [143]. To improve the generality of the template, the IFC was adopted to provide required object definitions in BIM 4D [145]. In addition to these, case-based reasoning (CBR) was utilized as an effective machine learning method in BIM [146]. The faults can be settled by utilizing or adjusting the previous solutions to tackle similar tasks [146]. In the process of CBR, new problems and malfunctions can be matched and solved by the most similar solution through the typical four phases of the CBR (retrieve, reuse, reserve, and modify), and then the new solution schemes can be retained for future similar disposal [147]. To improve the accuracy of the match between disputes and solutions, Sigalov and König [143] asserted that the graph indexing is settled in partial BIM software.

One of the prominent features of BIM is simulation. In traditional AEC tools, with the increasing size and complexity of green building construction processes, it is challenging to generate sufficient suitable design and construction schemes with the distraction of various undefined risks and uncertainties [148,149]. Therefore, the predictions about project progress and results are hard to keep accurately [148,149]. However, these barriers can be partially mitigated by the simulations of BIM. Based on virtual modeling, without the consumption of materials, reliable simulations and predictions of projects can be developed through the thorough consideration of factors and potential risks [150].

From the finance perspective, BIM can support green building construction teams to generate bills of quantities automatically, perform procurement plans and logistical layout, and conduct materials and equipment management. Given that the BOM can be updated in BIM in real time, BIM can reflect real-time expenditure. Moreover, the construction activities' feasibility research can be conducted with the support of a data repository, 3D visualization demonstration, and simulation in BIM [151]. In addition, BIM can provide quality procurement management and optimization for construction organizations. In the research of Vilas-Boas et al. [152], they proposed a four-dimensional BIM model to analyze and optimize procurement. This model provides procurement suggestions by comprehensively analyzing and comparing the following dimensions:

1. Product-based. Assess the properties, quality, and compliance of the purchased materials.
2. User-based. Assess whether the material accords with the green assessment criteria and whether it meets the requirements of stakeholders and participants.
3. Manufacturing-based. Test the operation status of the procured material, and check whether these materials have clashed with other parts.
4. Value-based. Calculate the value of each material and procurement link, and evaluate their cost performance. For stakeholders, value includes tangible and intangible benefits.

4. Discussion

Through the systematic review in Section 3, it can be determined that BIM capabilities have significant advantages in the construction phase of green buildings. BIM can develop apparent benefits to green building construction, including improving the quality of the projects, optimizing collaboration between different stakeholders, performing lifecycle data storage and management, and assisting construction organizations in conducting and optimizing their planning and schedule management in the process of constructing green buildings.

In this section, these abovementioned capabilities are discussed and analyzed by the authors. Through the discussion and analysis, it can be concluded that the implementation of BIM can be utilized in the green building pre-construction phase, construction phase, and post-construction phase. The detailed discussion and analysis processes are shown below.

4.1. BIM Capabilities in the Green Building Pre-Construction Phase

Given the enormous complexity, extensive information and uncertainty in pre-construction, the pre-construction phase of green buildings is always an area to which construction teams and subcontractors attach great importance [50,65,153,154]. According to the systematic review and discussion in this study, the BIM implementation in the pre-construction phase of green buildings can be adopted from the perspectives of information and knowledge delivery, feasibility study, construction team setup, construction plans and schedule formulation, construction cost estimation and budget formation, construction material supplement and transportation, and construction equipment management.

Given the extensive information and the complex structural construction of green buildings, it is vital for construction organizations to obtain detailed information about targeted green buildings before formal construction [9,155–157]. BIM can help the construction teams to transfer the green building model and related information generated during the design phase to the construction personnel in an error-free, omission-free manner [4,15,45,47,52,78–83]. For green building projects that do not adopt BIM in their design phase, BIM can also be utilized to automatically capture the related information to generate the green building information model by identifying CAD drawings, or integrating with photography, GIS, and 3D scanning [63,86–94].

In the aspect of feasibility studies, construction plans, and schedule formulation, through the simulation function of BIM, the consequences and impact of different green building construction plans can be simulated [5,17,48,99,100,117–122]. Moreover, it can assist the project managers in comparing different green building construction plans [102,103]. Through the BIM's comparison of the quality, estimated construction period, and environmental protection and resource-saving conditions of various alternatives, the most suitable green building construction plan can be selected [102,103]. In addition, based on green building project planning, construction site conditions, and feedback from subcontractors, BIM can assist the construction teams in developing the requirements and configurations of personnel, materials, and equipment [4,5,99,100,130,141–143,150]. Based on the abovementioned information, the logistics and transportation routes can also be automatically formulated through BIM [158–162]. Finally, through the information mentioned above, the estimated cost and budgets can be put forward by BIM [123,124,151].

Despite the various benefits of BIM utilization in the green building pre-construction phase, there are still some obvious challenges. Given that many formats can be adopted in BIM applications, the green building construction organizations might have format mismatch issues in the information delivery process from the design phase to construction [6,14]. Moreover, another hindrance is that project management personnel often refuse to adopt BIM in the construction process [22,77,163]. According to Akhmetzhanova et al. [24], 55% of companies refused to utilize BIM because clients or management do not support the adoption of the technology.

4.2. BIM Utilization in the Green Building Construction Phase

Compared with the BIM utilization at the pre-construction and post-construction phases, the most significant contributions of BIM capabilities are in the construction phase.

Through the discussion of reviewed BIM capabilities in Section 3, it can be determined that the BIM contributions in the construction phase can be summarized as below.

In the process of green building construction, 3D visual modeling is of significant importance to the construction organization [48,54,97,98,104–112,116]. It can demonstrate the entire green building project, the interior structures, and components in 3D [4,5,51,54,76,77,104–106]. Moreover, In BIM 4D, the stakeholders can become familiar with the conditions of buildings at different periods through visual 3D demonstrations [100,117–122,142,143,145,164]. From the perspective of safety management, BIM's visualization can assist construction teams in identifying the clashes and potential risks in a visual manner, so as to provide the corresponding safety training and avoid delay, construction waste production, and rework [5,14,46,99,133,135,136,138–140].

As a multi-function database, BIM can provide information and knowledge collection, storage, and management in the entire green building construction process, and integrate fragmented information in a unified format in the corresponding file [4,15,52,78–83,145]. Besides storing and categorizing the data that are generated in the green building construction process, BIM can automatically provide solutions to issues for stakeholders through CBR [143,146,147]. With the integration of BIM and third-party devices, the construction site's natural environment, climate, infrastructure, and the utilization conditions of human resources and materials are all available to stakeholders [5,63,85–94].

Moreover, simulation is an important characteristic of BIM utilization in green building construction. Simulation includes not only the simulation of the construction activities' impact on the surrounding environment, but also the prediction of construction processes and risks [4,5,10,17,46,100,101,117–122,129,131,133,141]. Given that green buildings are required to meet the green buildings' assessment standards, through the simulation function of BIM, the construction organization can perform comparisons of different construction schemes and select the scheme that can match the evaluation standards of green buildings in the most positive sense [52–55,102,103]. Based on the simulation and information management, the bills of quantity can be automatically generated by BIM to estimate the consumption of materials and the overall cost of the project [5,95,96,99,100,123–128,132,151,152].

BIM can provide an effective collaboration platform for all stakeholders to communicate and collaborate in the construction process of green buildings [10,13,26,62–67,69–71,73,74,122,165]. Through BIM, all project changes can be reflected in a timely manner, and decisions made by one stakeholder are immediately uploaded to the BIM platform and communicated to all other stakeholders [4,14,66,73,76,165]. Moreover, BIM can demonstrate the positions, responsibilities, and current status of all stakeholders, thus assisting stakeholders in obtaining an overview of other stakeholders' situations [64,72,75]. In addition, construction organizations can utilize BIM to communicate with design organizations and facilitate the management requirements of green buildings, and to develop their requirements about the corresponding green building projects [13,61,62,66–68,71]. Through the integration of BIM with the Internet of Things (IoT), the construction team can be assisted remotely by professionals worldwide to improve the projects' quality and solve existing issues [64,72,75].

Despite the significant advantages of BIM implementations in the green building construction phase, the challenges are still non-negligible. In the process of BIM utilization, many stakeholders cooperate using the same BIM platforms or files, which leads to the obscure copyright of the developed data in the green building construction process [165–170]. It is difficult for project managers to define the ownership of involved data [167,168]. Moreover, given the relative independence of the design and construction organization, some information required in the green building construction process might not be obtained in the delivered BIM files [6,14]. In the green building construction process, the main contractors might be required to cooperate with other subcontractors. In the context that the uniform regulatory framework is absent, the interactivity between the main contractors and subcontractors might be insufficient [24].

4.3. BIM Utilization in the Green Building Post-Construction Phase

The post-construction phase is the final phase of green building construction. It includes all of the final processes to hand over these green building projects to the building owner and facility management organizations [171]. Through the systematic review and discussion of the BIM utilization in green building construction, the BIM's contribution during the post-construction phase can be summarized as follows: final acceptance, information handover, and green building certificate inspection.

From the perspective of information handover and final acceptance, all building-related information and construction activities can be stored, categorized, and retrieved in BIM. This information is integrated into one single file in a given format (usually the IFC format) [4,15,45,47,52,78–83,172–174]. Moreover, through the 3D visualization demonstration of BIM, the entire 3D model of green buildings can be demonstrated for the final acceptance personnel to check [109–112,116]. Through BIM 4D, the specific situations of the target green building projects at different points in time can be provided [100,117–122,130].

The green buildings must meet the green building evaluation standards. Regardless of the various countries' green building evaluation standards, the construction organizations can adopt BIM's simulation function to examine these buildings [175,176]. Utilizing BIM to simulate and evaluate the energy consumption, environmental performance, material utilization, and residents' comfort of the green building can help to assess the compliance of the green building to the green building evaluation standards [13,59,177–181].

In the post-construction phase, there are still barriers that impede BIM utilization. In the process of information handover between green building construction organizations and green building facility management organizations, information omissions and mismatched formats are still the main challenges for both parties [6,14]. Moreover, given the high expenditure on BIM training, the facility management organizations might lack sufficient BIM operators. This issue can also disturb the handover of BIM documents [14,182,183].

5. Conclusions

Given the significant performance of BIM, there has been a dramatic increase in construction organizations that utilize BIM in the green building construction phase. Despite many studies exploring BIM utilization in green building construction, review articles in this area are relatively rare. To enhance the understanding of AEC practitioners in terms of the BIM capabilities in the green building construction phase and to bridge the abovementioned research gap, this study performed a systematic review of these BIM capabilities. Through the review of the retrieved articles, it can be summarized that the BIM implementations in green building construction are categorized into the following benefits: project quality improvement, lifecycle data storage and management, collaboration optimization, and planning and schedule management optimization. Moreover, through the discussion and analysis of the reviewed BIM capabilities, it can be concluded that BIM can make significant contributions in the pre-construction phase, construction phase, and post-construction phase of green building projects.

In spite of the tremendous abovementioned BIM benefits, there are still some obstacles when using BIM in the green building construction phase, including non-uniform data formats, insufficient interactivity, ambiguous ownership, insufficient BIM training, and BIM adoption hesitancy. Despite the abovementioned shortcomings of BIM at the present stage, through the comparison of the benefits and challenges of BIM capabilities in the green buildings' construction phase, it can be concluded that the BIM application still has significant potential benefits and improvements for green building construction. Through the systematic review, this study provided a comprehensive overview and understanding of BIM capabilities in the green building construction phase to promote and optimize BIM utilization in this area. Moreover, this study also pointed out the challenges and future direction of BIM capabilities in green buildings to encourage other researchers to overcome these issues.

In addition to the contributions mentioned above, this study also has some limitations. The limitations are presented below.

1. In this study, some reviewed BIM capabilities can be utilized in not only the construction phase of green buildings, but also in the design and facility management phase of other building types. This reduces the pertinence of the study to some extent. However, to provide a comprehensive systematic review and avoid the omissions of BIM capabilities in green building construction, these BIM capabilities are included in this study.
2. Due to the language skills limitations of the authors, only English articles were reviewed in this study. Non-English articles were excluded from the article screening process.
3. In this study, the majority of the reviewed BIM capabilities are on BIM utilization in the pre-construction phase and the construction of green buildings. Rarely are BIM functions reviewed that have been utilized in the post-construction phase of green building projects specifically. It is recommended that other researchers perform the corresponding studies to explore BIM utilization in the green building post-construction phase.

In conclusion, this study develops a comprehensive systematic review and discussion of BIM capabilities in the construction of green buildings. Given that the evolvement of BIM is rapid, the BIM capabilities are updated correspondingly with the development of internet technology. Thus, other researchers are welcome to further explore and review the BIM utilization in the construction of green buildings based on this study.

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Appendix A

Table A1. Reviewed studies in Section 3.2.1 (sorted by order of appearance).

Title of the Article	Publication Year
BIM in Off-Site Manufacturing for Buildings	2017
A Scientometric Review of Global BIM Research: Analysis and Visualization	2017
Building Information Modelling (BIM) Uptake: Clear Benefits, Understanding Its Implementation, Risks and Challenges	2017
Effect of BIM on Rework in Construction Projects in Singapore: Status Quo, Magnitude, Impact, and Strategies	2019
Applications of BIM: A Brief Review and Future Outline	2018

Table A1. *Cont.*

Title of the Article	Publication Year
Adoption of Building Information Modelling (Bim): Factors Contribution and Benefits	2018
Contribution and Obstacle Analysis of Applying BIM in Promoting Green Buildings	2021
BIM-Based Approach for Optimizing Life Cycle Costs of Sustainable Buildings	2018
Integration of BIM and LCA: Evaluating the Environmental Impacts of Building Materials at an Early Stage of Designing a Typical Office Building	2017
Measuring the Feasibility of Using of BIM Application to Facilitate GBI Assessment Process	2019
Sustainability and Energy Efficiency: BIM 6D. Study of the BIM Methodology Applied to Hospital Buildings. Value of Interior Lighting and Daylight in Energy Simulation	2020
Green BIM Assessment Applying for Energy Consumption and Comfort in the Traditional Public Market: A Case Study	2019
Integrating BIM-Based LCA and Building Sustainability Assessment	2020
Step-by-Step Implementation of BIM-LCA: A Case Study Analysis Associating Defined Construction Phases with Their Respective Environmental Impacts	2019
LCA and BIM: Visualization of Environmental Potentials in Building Construction at Early Design Stages	2018
Recommendations for Developing a BIM for the Purpose of LCA in Green Building Certifications	2020
Developing a Green Building Evaluation Standard for Interior Decoration: A Case Study of China	2019

Table A2. Reviewed studies in Section 3.2.2 (sorted by order of appearance).

Title of the Article	Publication Year
Critical Success Factors for Small Contractors to Conduct Green Building Construction Projects in Singapore: Identification and Comparison with Large Contractors	2020
Differing Perspectives on Collaboration in Construction	2012
Relationship Network Structure and Organizational Competitiveness: Evidence from BIM Implementation Practices in the Construction Industry	2018
BIM-Based Green Building Evaluation and Optimization: A Case Study	2021
Developing an Integrated BIM + GIS Web-Based Platform for a Mega Construction Project	2022
Collaboration Barriers in BIM-Based Construction Networks: A Conceptual Model	2019
BIM Tool Development Enhancing Collaborative Scheduling for Pre-Construction	2020
A Framework for Collaboration Management of BIM Model Creation in Architectural Projects	2018
Building Information Modelling in Construction: Insights from Collaboration and Change Management Perspectives	2018
Communications in Hybrid Arrangements: Case of Australian Construction Project Teams	2017

Table A2. *Cont.*

Title of the Article	Publication Year
Modelling Building Ownership Boundaries within BIM Environment: A Case Study in Victoria, Australia	2017
Interoperability Analysis of IFC-Based Data Exchange between Heterogeneous BIM Software	2018
Review of BIM's Application in Energy Simulation: Tools, Issues, and Solutions	2019
Identifying and Contextualizing the Motivations for BIM Implementation in Construction Projects: An Empirical Study in China	2017
Collaboration in BIM-Based Construction Networks: A Bibliometric-Qualitative Literature Review	2017
Sorting out the Essence of Owner–Contractor Collaboration in Capital Project Delivery	2015
The Conditions for Successful Automated Collaboration in Construction	2014
Collaborative Relationship Discovery in BIM Project Delivery: A Social Network Analysis Approach	2020
Building Information Modeling (BIM) for Green Buildings: A Critical Review and Future Directions	2017
Use of LoD Decision Plan in BIM-Projects	2017
Exploring the Barriers and Driving Factors in Implementing Building Information Modelling (BIM) in the Malaysian Construction Industry: A Preliminary Study	2014
Contribution and Obstacle Analysis of Applying BIM in Promoting Green Buildings	2021

Table A3. Reviewed studies in Section 3.2.3 (sorted by order of appearance).

Title of the Article	Publication Year
Transition from Building Information Modeling (BIM) to Integrated Digital Delivery (IDD) in Sustainable Building Management: A Knowledge Discovery Approach Based Review	2021
Enhancing a Building Information Model for an Existing Building with Data from a Sustainable Facility Management Database	2021
Integration of BIM and LCA: Evaluating the Environmental Impacts of Building Materials at an Early Stage of Designing a Typical Office Building	2017
Building Information Modeling (BIM) for Green Buildings: A Critical Review and Future Directions	2017
Comparative Analysis of Energy Performance Assessment for Green Buildings: China Green Building Rating System vs Other Major Certification Systems	2016
BIM-Based Performance Monitoring for Smart Building Management	2021
Blockchain-Enabled IoT-BIM Platform for Supply Chain Management in Modular Construction	
A Simplified Relational Database Schema for Transformation of BIM Data into a Query-Efficient and Spatially Enabled Database	2017
Quantifying and Visualizing Value Exchanges in Building Information Modeling (BIM) Projects	2019

Table A3. *Cont.*

Title of the Article	Publication Year
Application of ND BIM Integrated Knowledge-Based Building Management System (BIM-IKBMS) for Inspecting Post-Construction Energy Efficiency	2017
Improving Maintenance Performance by Developing an IFC BIM/RFID-Based Computer System	2021
3D Environmental Urban BIM Using LiDAR Data for Visualization on Google Earth	2022
Research Trend of the Application of Information Technologies in Construction and Demolition Waste Management	2020
Reducing Noise Pollution by Planning Construction Site Layout via a Multi-Objective Optimization Model	2019
Using BIM to Improve Building Energy Efficiency–A Scientometric and Systematic Review	2021
Developing an Integrated BIM + GIS Web-Based Platform for a Mega Construction Project	2022
Toward Sustainable Energy-Independent Buildings Using Internet of Things	2020
The Intelligent Use of RFID and BIM in Prefabricated, Prefinished, Volumetric Construction Work Flow	2020
Building Information Modeling (BIM)-Based Modular Integrated Construction Risk Management–Critical Survey and Future Needs	2020
An ICT-Enabled Product Service System for Reuse of Building Components	2019
Analysis of the Benefits, Challenges and Risks for the Integrated Use of BIM, RFID and WSN: A Mixed Method Research	2022

Table A4. Reviewed studies in Section 3.2.4 (sorted by order of appearance).

Title of the Article	Publication Year
A BIM-WMS Integrated Decision Support Tool for Supply Chain Management in Construction	2019
Research on Construction Schedule Management Based on BIM Technology	2017
Life Cycle Energy Efficiency in Building Structures: A Review of Current Developments and Future Outlooks Based on BIM Capabilities	2017
Real-Time Visualization of Building Information Models (BIM)	2015
Building Information Modelling (BIM) Uptake: Clear Benefits, Understanding Its Implementation, Risks and Challenges	2017
BIM-Enabled Facilities Operation and Maintenance: A Review	2019
Effect of BIM on Rework in Construction Projects in Singapore: Status Quo, Magnitude, Impact, and Strategies	2019
Research on the Project Management of BIM Project from the Perspective of Enterprise Strategy	2016
Integration of BIM and GIS in Sustainable Built Environment: A Review and Bibliometric Analysis	2019
Critical Success Factors for Implementing Building Information Modelling (BIM): A Longitudinal Review	2018
BIM-Based Applications of Metaheuristic Algorithms to Support the Decision-Making Process: Uses in the Planning of Construction Site Layout	2017

Table A4. *Cont.*

Title of the Article	Publication Year
Reducing Noise Pollution by Planning Construction Site Layout via a Multi-Objective Optimization Model	2019
Sustainability-Based Lifecycle Management for Bridge Infrastructure Using 6D BIM	2020
Building Performance Optimization Using CFD for 6D BIM Application—A Case Study	2021
Sustainability and Energy Efficiency: BIM 6D. Study of the BIM Methodology Applied to Hospital Buildings. Value of Interior Lighting and Daylight in Energy Simulation	2020
Evaluation of the Open Diversion Channel Capacity on Margatiga Dam Construction Project Using 6D BIM Analysis	2021
Integration of Aerobiological Information for Construction Engineering Based on LiDAR and BIM	2022
Permanent Magnet, Toroidal Winding Generator for 6D BIM Applications	2021
Research on PKIM Energy Construction Engineering Software System Based on Building BIM Technology	2022
Automated 3D Volumetric Reconstruction of Multiple-Room Building Interiors for as-Built BIM	2018
Green Construction Evaluation System Based on BIM Distributed Cloud Service	2021
Green Building Investment Control System Based on a Three-Dimensional Parametric Model of the Green Building	2021
Utilizing BIM and GIS for Representation and Visualization of 3D Cadastre	2019
A BIM Oriented Model to a 3D Indoor GIS for Space Management—A Requirement Analysis	2019
A Full Level-of-Detail Specification for 3D Building Models Combining Indoor and Outdoor Scenes	2018
Truss Construction of Green Fabricated Steel Structure Based on BIM Intelligent Technology	2021
Integrated EDM and 4D BIM-Based Decision Support System for Construction Projects Control	2022
Supporting Constructability Analysis Meetings with Immersive Virtual Reality-Based Collaborative BIM 4D Simulation	2018
Impacts of 4D BIM on Construction Project Performance	2021
The Effects of BIM Maturity Level on the 4D Simulation Performance: An Empirical Study	2021
BIM-Based Framework to Quantify Delays and Cost Overruns Due to Changes in Construction Projects	2022
4D Modelling Using Virtual Collaborative Planning and Scheduling	2021
Quantity Surveying and BIM 5D. Its Implementation and Analysis Based on a Case Study Approach in Spain	2021
Implementing 5D BIM on Construction Projects: Contractor Perspectives from the UK Construction Sector	2020
Machine Learning-Integrated 5D BIM Informatics: Building Materials Costs Data Classification and Prototype Development	2022
Cash Flow System Development Framework within Integrated Project Delivery (IPD) Using BIM Tools	2021

Table A4. *Cont.*

Title of the Article	Publication Year
A BIM-database-integrated system for construction cost estimation	2021
Application of BIM Technology in Construction Cost Management of Building Engineering	2021
Enhancing Facility Management through BIM 6D	2016
The Adoption of 4D BIM in the UK Construction Industry: An Innovation Diffusion Approach	2017
4D BIM for Environmental Planning and Management	2017
Integrating BIM and GIS to Improve the Visual Monitoring of Construction Supply Chain Management	2013
Improving Effectiveness of Safety Training at Construction Worksite Using 3D BIM Simulation	2020
Information Technology and Safety: Integrating Empirical Safety Risk Data with Building Information Modeling, Sensing, and Visualization Technologies	2016
An Automated Safety Risk Recognition Mechanism for Underground Construction at the Pre-Construction Stage Based on BIM	2018
A Research Framework of Mitigating Construction Accidents in High-Rise Building Projects via Integrating Building Information Modeling with Emerging Digital Technologies	2021
A Research Framework of Mitigating Construction Accidents in High-Rise Building Projects via Integrating Building Information Modeling with Emerging Digital Technologies	2021
Using BIM as a Tool to Teach Construction Safety	2017
Semi-Automatic Construction Hazard Identification Method Using 4D BIM	2021
BIM-Based Framework for Automatic Scheduling of Facility Maintenance Work Orders	2018
Investigating Benefits and Criticisms of BIM for Construction Scheduling in SMEs: An Italian Case Study	2018
Recognition of Process Patterns for BIM-Based Construction Schedules	2017
BIM-Based Augmented Reality Inspection and Maintenance of Fire Safety Equipment	2020
Automated Schedule and Progress Updating of IFC-Based 4D BIMs	2017
Retrieving Similar Cases for Construction Project Risk Management Using Natural Language Processing Techniques	2017
BIM-Based Risk Identification System in Tunnel Construction	2016
Construction Planning, Programming and Control	2013
Knowledge-Based Schedule Generation and Evaluation	2010
BIM-Integrated Construction Operation Simulation for Just-In-Time Production Management	2016
Informetric Analysis and Review of Literature on the Role of BIM in Sustainable Construction	2019
Outlining a New Collaborative Business Model as a Result of the Green Building Information Modelling Impact in the AEC Supply Chain	2019

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