buildings

Systematic Review

Application of Building Information Modeling for Energy Efficiency: A Systematic Review

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Abstract

As global warming worsens, reducing energy use is becoming increasingly crucial. In recent years, 34% of the world's energy use has been consumed by buildings. Therefore, improving building energy efficiency is essential for halting climate change and promoting sustainability. In this regard, Building Information Modeling (BIM) is steadily emerging as a valuable tool for promoting energy efficiency. This research adopts a systematic review approach, and 87 articles were included for review. This research identified seven areas in which BIM plays a role in energy efficiency. For each area, workflows for the adoption of BIM were explored. Meanwhile, the advantages and disadvantages of each adoption of BIM were critically examined. In conclusion, visualization is the most helpful feature of BIM and is beneficial for almost all applications. In addition, software compatibility issues and high initial setup costs are the most common drawbacks of adopting BIM. This research makes several contributions to the literature. First, the results of this study help provide a better understanding of the importance of BIM in energy efficiency improvement. Secondly, our research supplements the energy field that identifies seven BIM use categories. Thirdly, this article critically examines the use of BIM in the building energy field.

Keywords: building information modeling (BIM); building energy analysis; building energy models; building lifecycle assessment (LCA); Internet of Things (IoT)

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1. Introduction

As global warming intensifies, reducing energy consumption is becoming more and more important [1]. In recent years, energy consumption in buildings has accounted for 34% of global energy consumption [2]. Therefore, facilitating energy-efficient buildings plays a significant role in combating climate change and advancing sustainability. In this regard, Building Information Modeling (BIM) is gradually becoming an efficient tool for facilitating energy efficiency [3]. BIM is a digital representation of building facilities. BIM enables real-time collaboration among all the stakeholders of a building project throughout the building lifecycle. BIM shows significant advancement in enhancing energy efficiency across the building lifecycle [4].

In this article, the application of BIM for energy efficiency has been categorized into seven parts:

(1) BIM application in generative design. Generative design can generate a massive range of design alternatives based on goals, constraints, and inputs. Designers can evaluate the energy efficiency of each solution and select the optimal scheme. This process can vastly reduce energy consumption at an early stage. BIM can be an efficient tool for generative design. As a famous BIM software, Revit started to support generative design in Revit 2021.
(2) BIM application in building energy prediction. BIM can serve as a comprehensive data repository. BIM models contain highly detailed geometric information about a building. The exact shape, size, and orientation of the building are accurately defined. Meanwhile, BIM models contain material information, and each material has specific thermal properties. This allows for the accurate prediction of building energy consumption by importing BIM models into building energy prediction software.
(3) BIM application in building energy consumption optimization. In the early design stage, BIM provides designers with detailed data on a building's geometry, orientation, and materials. Energy professionals can analyze energy consumption using BIM software. After that, they can optimize the design easily by using parametric BIM tools.
(4) BIM application in building energy analysis. During the initial design phases, designers can use BIM-based energy analysis tools to evaluate different design options quickly. By inputting different design variables into BIM-based energy analysis software, designers can receive immediate feedback on energy performance. This can enable them to make informed decisions early in the design process when changes are more cost-effective.
(5) BIM application in the digital twin. BIM models contain detailed and accurate 3D models of buildings. In a digital twin, this 3D model serves as a visual and spatial foundation. It enables stakeholders to visualize the physical environment in a realistic way.
(6) BIM application in the Internet of Things (IoT). BIM provides a detailed 3D model of a building, offering a spatial and geometric context for IoT-generated data. IoT sensors can collect real-time data. BIM maps this data to specific building components or areas. This visual representation helps facility managers quickly understand the physical implications of the data.
(7) BIM application in building lifecycle assessment (LCA). BIM significantly enhances building LCA by providing a comprehensive and detailed platform for data management, analysis, and decision-making throughout the building lifecycle. BIM models contain extensive information about building components. This data is crucial for LCA, as it forms the basis for calculating environmental impacts.

This article carried out a round of checks to identify similar themes. The most recent publications examining BIM applications for energy efficiency were identified, and it was found that Pereira and Santos [4] conducted research most similar to ours. The aim of this article is to identify the areas in which BIM contributes to energy efficiency. However, they overlooked the application of these technologies in enhancing building energy efficiency.

The purpose of the review is to critically investigate the application of BIM for energy efficiency. The main objectives are to

(1) Collect the relevant publications based on a preset literature search strategy and conduct a comprehensive systematic review;
(2) Examine the potential of each BIM application in improving energy efficiency;
(3) Generate the workflow of each BIM application to improve energy efficiency;
(4) Explore the advantages and disadvantages of adopting BIM in each application.

2. Materials and Methods

2.1. The Systematic Review Approach

This research adopts a systematic review approach. To review the application of BIM for energy efficiency, this research adopts four steps (See Figure 1):

- Step 1: Identification. This research conducted a comprehensive literature search using the "title/abstract/keyword" search method. The keywords used in the literature search were "Building Information Modeling"/"BIM"/"Building Information Models" and "Energy"/"Energy Efficiency"/"Energy Conservation". Databases, including Web of Science, ScienceDirect, and Scopus, were used for the literature search. Publications from 2020 to 2025 were selected. Only publications in English were selected. As a result, 1245 publications were identified. Finally, 366 duplicate records were removed, and 879 records were left for screening.
- Step 2: Screening. A round of title and abstract reviews was conducted. A total of 678 records were found that were not related to the construction industry. Some of the records were related to the pharmaceutical field. Therefore, these 678 records were excluded, and 201 records were left.
- Step 3: Eligibility. The thematic analysis began with coding BIM-related data to identify specific functions. These codes were grouped into clusters based on shared purposes and then refined to eliminate overlap and align with industry understanding. After a round of validation to ensure comprehensiveness, seven distinct functional categories emerged, each capturing a core BIM capability for energy efficiency across the AEC lifecycle. In this step, seven categories of BIM application were identified, including "Generative Design", "Building Energy Prediction", "Building Energy Consumption Optimization", "Building Energy Analysis", "Digital Twin", "Internet of Things", and "Building Lifecycle Assessment". Then, a round of full-text article assessment was conducted, and 114 records were excluded because they were unrelated to these seven BIM application categories.
- Step 4: Quality appraisal. This research used AMSTAR 2 to assess the quality of the records. The criteria of quality assessment are as follows: (1) data input accuracy; (2) BIM software validity; (3) workflow transparency; (4) outcome consistency. This structured approach ensures that the appraisal is rigorous, consistent, and transparent, helping decision-makers judge whether the findings of a systematic review are trustworthy and applicable to practice. First, assess the systematic review against AMSTAR 2's 7 critical criteria; if any is unmet, the review is provisionally "critically low" quality. Next, evaluate the 9 non-critical criteria and rate each as "met," "partially met," or "not met." Finally, confirm quality: If all critical criteria pass, use non-critical results to assign high/moderate/low ratings; if any critical criterion fails, rate the review as "critically low."
- Step 5: Inclusion. After excluding all the records that did not meet the requirements, the final number of records was 87.

2.2. Data Analysis

In this article, a systematic review was carried out. Publications from 2020 to 2025 were collected. As shown in Figure 2, the number of related papers has been increasing year by year, except in 2025. The reason for the decrease in 2025 is that the literature search was carried out at the start of 2025. The increase in the number of publications indicates that BIM application for energy efficiency is receiving increasing attention. The sudden increase in the number of publications in 2024 emphasizes the need to conduct a systematic review of BIM application for energy efficiency at this time.

A variety of highly related journals appeared in the literature search, including, but not limited to *Automation in Construction*, *Applied Energy*, *Building and Environment*, *Case Studies in Thermal Engineering*, *Developments in the Built Environment*, *Energy*, *Energy and Buildings*, *Energy Reports*, *Heliyon*, *Journal of Building Engineering*, *Journal of Cleaner Production*, *Journal of Industrial Information Integration*, *KSCE Journal of Civil Engineering*, *Renewable and Sustainable Energy Reviews*, and *Results in Engineering*. As shown in Figure 3, the number of publications from *Energy and Buildings* is the highest.

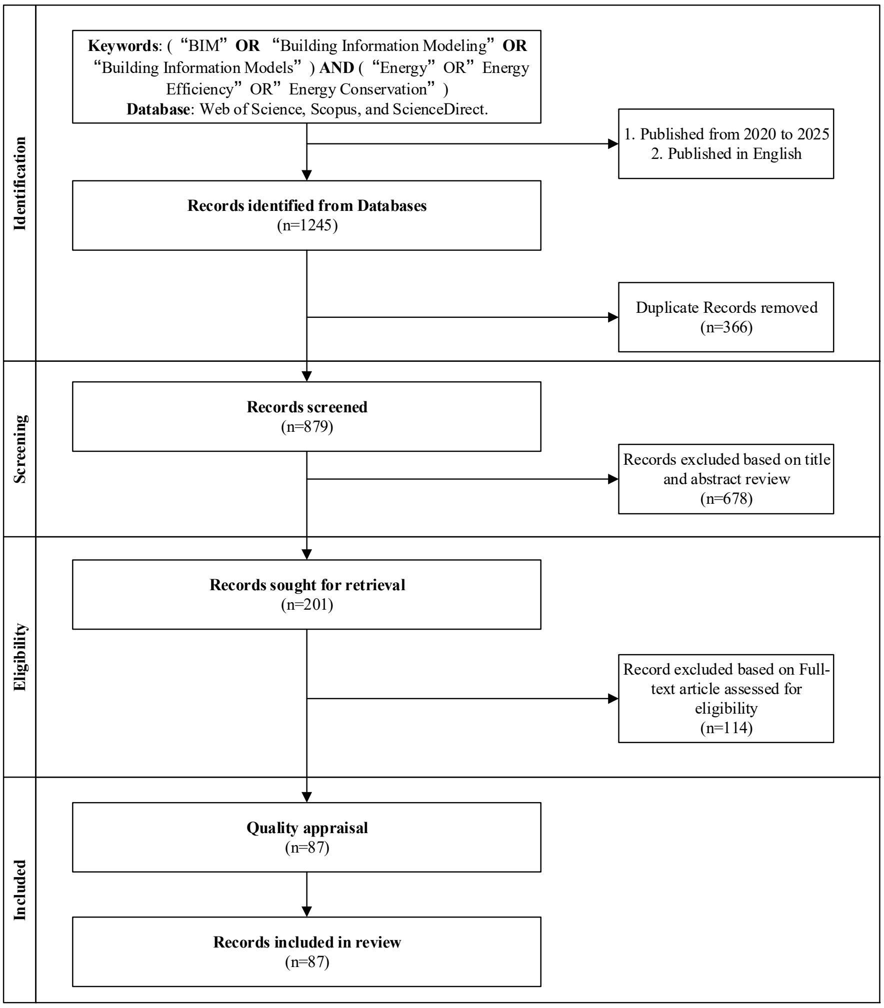

Figure 1. The process of the systematic review.

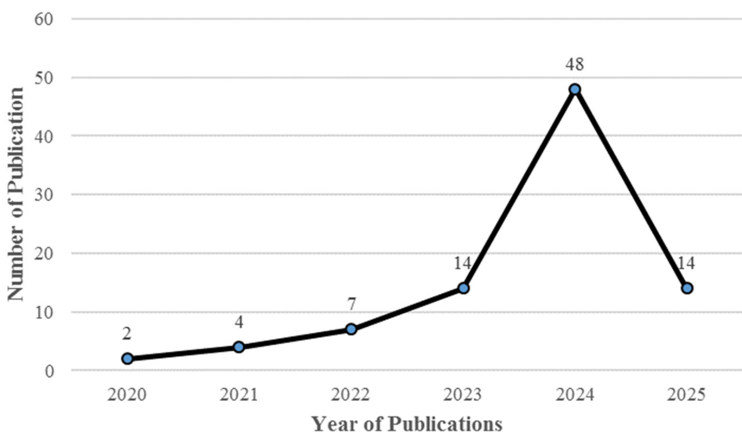

Figure 2. Records included in the review.

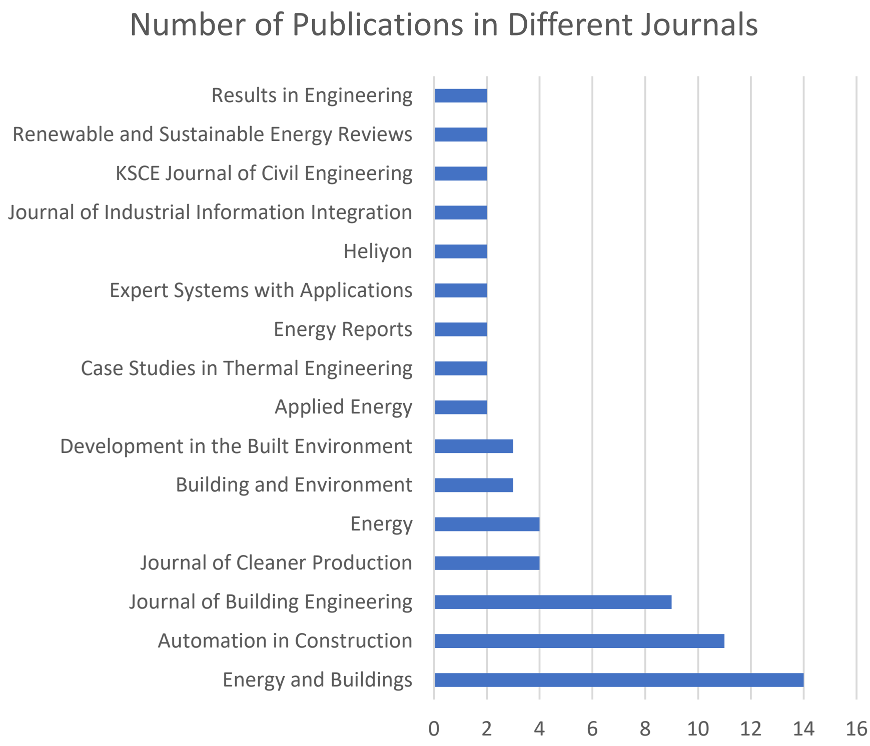

Figure 3. Journals included in this research.

3. Application of BIM for Building Energy Efficiency in the Design Stage

The literature on building energy has highlighted that design stages have a substantial influence on building energy efficiency [3]. More recent attention has focused on the provision of BIM in the building design stage for energy efficiency [5]. Previous research has established that BIM has the potential to reduce building energy consumption through decision-making [6]. New findings in BIM provide further evidence that BIM can visualize building energy and provide optimization measures [7]. Data from several sources have identified the decreased energy consumption associated with the engagement of BIM [7–10]. This is consistent with the data obtained by Khan and Tariq [11]. Therefore, the application of BIM in the design stage is crucial for building energy efficiency.

Based on a systematic review, four aspects of BIM application in the design stage have been found to have the potential to reduce energy consumption:

- BIM-assisted generative design for building façades can achieve optimal energy performance [12]. Traditional building façade design approaches focus on single-objective studies that result in deficiencies in multi-objective optimization and integral design approaches [12].
- Using BIM to predict building energy consumption in the design stage is crucial for increasing the number of energy-efficient buildings [13]. The prediction model is optimized to improve building energy efficiency by refining the energy structure [13].
- BIM-engaged building energy consumption optimization can promote energy savings at the initial stage of the building scheme design [9]. Detailed parametric analysis and measurements need to be used in building energy consumption optimization [8].
- BIM can help in building energy analysis and reduce energy consumption at an early stage. Traditional building energy analysis is usually carried out late in the design stage [14].

Building energy prediction refers to the process of estimating or forecasting a building's future energy consumption. It emphasizes the process of estimating and forecasting.

Building energy consumption optimization refers to the process of optimizing the production, transmission, distribution, and usage of energy in buildings. It emphasizes the process of optimization. Building energy analysis refers to the process of evaluating, examining, and interpreting a building's energy-related data and performance. It emphasizes the process of evaluation.

3.1. BIM Application in Generative Design

Generative design is an exploration process that applies artificial intelligence to generate an extensive range of solutions and ideas for complex problems. The literature on generative design has highlighted the use of generative design for energy efficiency [12]. Wang and Duan [15] introduced a generative design framework to carry out building energy performance optimization. Much of the current literature on generative design pays particular attention to its potential to reduce energy consumption [16]. The generative design process embeds sustainability criteria so that professionals can systematically explore design alternatives that reduce energy consumption [17]. However, the traditional generative design process suffers from design defects caused by missing data [18]. And there is a lack of participation of stakeholders [19]. In the generated schemes, conflicts exist [20]. Design iteration is missing in the traditional process [12].

Recent evidence suggests that BIM-based generative design can achieve optimal energy performance [12]. The process of BIM-based generative design for energy efficiency is illustrated in Figure 4.

- Professionals use Revit to generate a large number of schemes.
- Professionals evaluate the energy performance of each scheme.
- Professionals conduct multi-objective optimization for the scheme.
- Decision makers determine the final scheme.

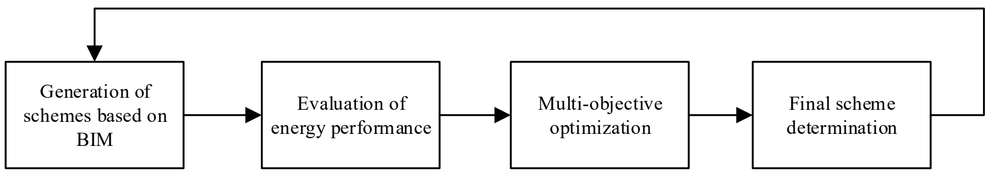

Figure 4. The workflow of BIM-based generative design for energy efficiency.

The literature has highlighted several benefits of adopting BIM in generative design (see Table 1):

- The advantages of data integration and sharing are apparent [18]. BIM models cover all kinds of data throughout the whole lifecycle, such as geometry information, material information, and construction scheduling. These rich data provide a comprehensive foundation for generative design. This enables the generated solutions to consider various factors better and prevent design defects caused by missing data.
- The excellent visualization effect helps with communication [19]. BIM is powerful due to its 3D visualization function, and it can present design schemes in an intuitive form to various stakeholders. In the process of generative design, designers can quickly present various design schemes to owners, construction teams, and others. All stakeholders involved can have a clearer understanding of the design intent and provide timely feedback and suggestions. This vastly improves communication efficiency and decision-making quality.
- Conflict detection and optimization are timely and efficient [20]. In BIM models, software can automatically detect conflicts and collisions between different components and systems. After generating a large number of design schemes in generative design,

the conflict detection function of BIM can quickly screen out conflicting schemes and optimize them. This can largely reduce changes and rework during the construction phase and save time and costs.

- BIM-based design iteration is convenient and efficient [12]. The combination of BIM and generative design can achieve rapid iterative design. After generating a new scheme in the generative design software, designers can quickly import it into the BIM environment for further analysis and refinement. According to the results of the analysis, the designers can adjust the parameters in the generative design to continue generating new schemes. This cycle continues to optimize the design until the optimal scheme is achieved.

Table 1. Advantages of adopting BIM in generative design.

Advantages	Applications	References
Data integration and sharing	Applying BIM in the early design stage can help integrate data and prevent design defects caused by missing data.	[18]
Excellent visualization effect	BIM can be used to visualize building design information for more efficient communication.	[19]
Efficient and timely clash detection and optimization	The use of BIM can quickly locate conflicts and collisions for the schemes generated by generative design.	[20]
Convenient and efficient design Iteration	With the help of BIM, the optimal scheme can be obtained in generative design.	[12]

In contrast, more recent attention has focused on the drawbacks of using BIM in generative design (See Table 2):

- BIM suffers from poor software compatibility and interoperability [21]. There are many types of BIM software, and there are differences in data formats between different software, which may result in data transmission difficulties or loss when combined with generative design software, affecting the smoothness and efficiency of design work. Model damage or partial data loss may occur when BIM models are imported into certain generative design software.
- It is difficult to trade off model accuracy and the number of schemes generated by generative design [22]. BIM models typically require high accuracy and a high level of detail to visualize architectural design accurately; however, in generative design, in order to quickly generate a large number of solutions, it may be necessary to simplify the model. This requires trading off between model accuracy and design efficiency. Otherwise, it may lead to deviations or an inability to implement the generated design solutions in practical applications.
- The successful application of BIM and generative design requires high-quality professionals [23]. Both BIM and generative design require professionals to have a high level of technical expertise and extensive experience. Professionals who are familiar with BIM modeling and analysis, as well as master generative design algorithms and optimization methods, are relatively scarce. The design team faces significant challenges in team building.
- The design team suffers from the high cost of hardware. The BIM model itself has a large amount of data, and generative design requires a lot of calculations and data processing during operation, with high requirements for computer hardware performance. In order to ensure the smooth progress of design work, the design team

must purchase high-performance computer equipment, which increases hardware investment costs.

Table 2. Disadvantages of adopting BIM in generative design.

Disadvantages	Suggestions	References
Poor software compatibility and interoperability	Professionals should reduce the number of software tools they use to avoid importing and exporting models. The use of IFC standard can avoid this issue.	[21]
Poor model accuracy	Professionals should trade off the model accuracy and the number of schemes generated by generative design.	[22]
High requirements for the quality of professionals	The design team should organize BIM training for their team members.	[23]
Increased costs from high hardware performance requirements	The design team should include the purchase of hardware equipment in the budget.	[24]

3.2. BIM Application in Building Energy Prediction

Building energy prediction is a key process for assessing energy-saving potential throughout a building's entire lifecycle. As noted by Lu and Li [25], building energy prediction has become an active research area because it has the potential to improve energy efficiency. Mohan and Pachauri [26] proposed a stacked ensemble model for building energy prediction, and this model is more efficient than traditional ones. Fang and Tan [27] embraced training dataset characteristics to improve the accuracy and interpretability of building energy prediction. Yesilyurt and Dokuz [28] performed a long-term building energy consumption prediction using meteorological, temporal, and meta parameters.

Much of the current literature on building energy prediction pays particular attention to the engagement of BIM [13]. The process of BIM-based building energy prediction for energy efficiency is illustrated in Figure 5.

- Clearly define the goal and identify which parts of the building are under study.
- Collect the building features from the BIM model.
- Process the data, which includes data cleaning, data standardization, and data encoding.
- Select features to conduct correlation analysis, derivative feature creation, and temporal feature extraction.
- Select certain models to conduct regression analysis, machine learning, and deep learning.
- Train the models selected.
- Evaluate the trained models.
- Deploy the trained model into the building management system, and continuously monitor the performance of the deployed models.

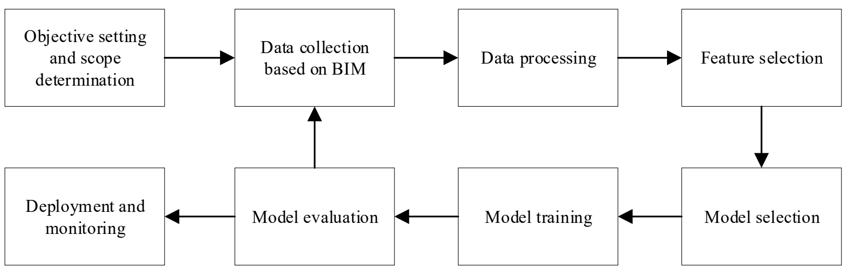

Figure 5. The workflow of BIM-based building energy prediction for energy efficiency.

The literature has highlighted several benefits of adopting BIM in building energy prediction (see Table 3):

- BIM provides an accurate geometric representation for the building energy prediction process [29]. The BIM model contains extremely detailed 3D building geometric information. This enables more exact calculation of crucial factors in the building energy prediction model, such as heat transfer areas and volumes.
- BIM conducts integrated data management for the building energy prediction process [30]. It consolidates data from various design stages and disciplines. All relevant information is integrated into a digital environment. This holistic view provides comprehensive energy simulations to ensure that interactions between various building components are considered when forecasting energy usage.
- BIM is a highly visualized tool and increases the efficiency of stakeholder communication. Energy analysts can present complex energy prediction findings to non-technical stakeholders, such as building owners and investors, in an easily understandable way. BIM software can show color-coded heat maps of energy consumption across different building zones. This supports stakeholders in rapidly locating energy savings.
- BIM can conduct scenario analysis for building energy prediction and is flexible when it comes to design changes. Designers can test the impact of various building features on energy consumption, such as orientation, window-to-wall ratios, and insulation levels. This iterative process helps optimize building designs for energy efficiency in the early design stage.

Table 3. Advantages of adopting BIM in building energy prediction.

Advantages	Applications	References
Accurate geometric representation	Applying BIM in building energy prediction can provide accurate geometric information, which enables more exact calculations of crucial energy factors.	[29]
High integration density	BIM can integrate all building information and provide comprehensive energy simulations.	[30]
High visualization for stakeholder communication	BIM can export color-coded heat maps of energy consumption across different building zones to help stakeholders locate the energy savings.	[19]
Flexible scenario analysis	Applying BIM in scenario analysis can adapt design changes and test the impact of building features on energy consumption.	[31]

In contrast, more recent attention has focused on the drawbacks of using BIM in building energy prediction (see Table 4):

- The design team suffers from the high initial setup cost of BIM [24]. Using BIM software, training staff, and establishing accurate BIM models require significant up-front investment.
- Complex BIM models always cause data overload [32]. BIM models accumulate massive amounts of data from multiple sources and become complex. This can lead to slower simulation and potential issues in the building energy prediction process. Furthermore, managing and validating such vast volumes of data may become a difficult task. Inaccurate input data may cause faulty energy predictions.
- BIM software suffers from compatibility issues when implemented together with other specialized energy analysis tools [21]. This may result in data transfer glitches or the inability to use software fully.
- There is a lack of dynamic real-time data incorporation in the building energy prediction process [33]. Most BIM models are static representations of building designs. The

incorporation of real-time, dynamic data is challenging. Without these live data, the accuracy of long-term energy consumption prediction can be limited.

Table 4. Disadvantages of adopting BIM in building energy prediction.

Disadvantages	Suggestions	References
High initial setup cost	The design team should include the purchase of BIM software in the budget.	[24]
Model complexity and data overload	The design team should upgrade their hardware to adapt to the high requirements of implementing BIM software.	[32]
Software compatibility issues	The design team should reduce the amount of software used to avoid importing and exporting models.	[21]
Lack of dynamic real-time data incorporation	Integrating BIM with a real-time dynamic digital twin platform is needed.	[33]

3.3. BIM Application in Building Energy Consumption Optimization

Building energy consumption optimization is an activity to reduce energy usage and increase energy efficiency and comfort in buildings. The literature on building energy consumption optimization has highlighted the potential to increase energy efficiency [34]. Wang and Xiao [35] proposed a multi-objective optimization method for building energy consumption and thermal comfort. Several comparative studies of building energy consumption optimization methods have been undertaken [36–38]. Professionals select the most suitable method depending on the distinct attributes of the goal and the complexity of the optimization process [36].

Much of the current literature on building energy prediction pays particular attention to the engagement of BIM [9]. The process of BIM-based building energy consumption optimization for energy efficiency is illustrated in Figure 6.

- Professionals should define goals and collect data, including architectural drawings, building materials, and occupancy patterns and document details of the existing system.
- BIM specialists should create the BIM model and import it into building energy consumption optimization software.
- Energy professionals should select analysis software and define boundary conditions.
- Energy professionals should run the initial simulation and establish a baseline of current energy consumption.
- Based on the results of the analysis, a multidisciplinary team brainstorms potential energy-saving measures, and energy professionals incorporate the proposed changes into the BIM model.
- Energy professionals should run new energy simulations for each set of optimization measures and assess the results.
- Energy professionals should choose optimal solutions and update the BIM model with the final design decisions.

The literature has highlighted several benefits of adopting BIM in building energy consumption optimization (see Table 5):

- BIM provides energy professionals with a visualized environment [39]. BIM contains a 3D virtual model that integrates all aspects of a building. This allows the stakeholders to conveniently identify high energy consumption areas.
- BIM models offer accurate data for establishing energy models [40]. BIM models store detailed data about building components. Used in energy simulation software, this accurate information results in more accurate energy usage forecasts.

- Multidisciplinary professionals can collaborate in BIM models. For example, mechanical engineers can collaborate with architects to optimize the building envelope for better natural ventilation.
- BIM can provide professionals with lifecycle energy management. BIM follows the building throughout the whole lifecycle. Real-time energy consumption can be integrated into BIM models. Facility managers can match actual energy use with design projections. They can quickly pinpoint abnormal consumption and make timely optimizations.

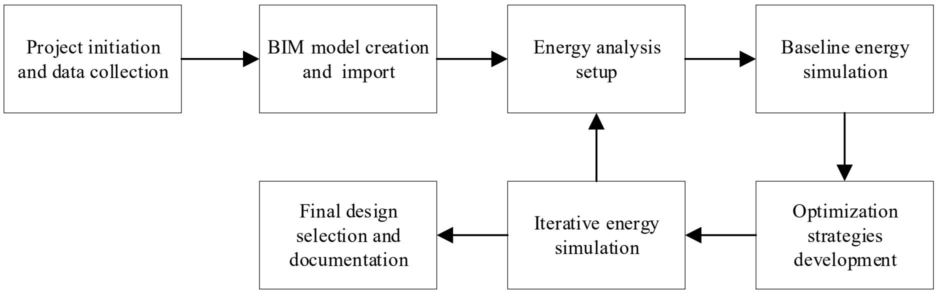

Figure 6. The workflow of BIM-based building energy consumption optimization for energy efficiency.

Table 5. Advantages of adopting BIM in building energy consumption optimization.

Advantages	Applications	References
Comprehensive visualization	Complex ductwork layouts in the HVAC system can be detected for potential inefficiencies.	[39]
Accurate data for simulation	BIM models contain the thermal properties of materials and ensure that the analysis closely mirrors real-world conditions and assists in developing highly targeted energy efficiency strategies.	[40]
Enhanced multi-disciplinary collaboration	Electrical engineers can confirm in BIM models that lighting systems are energy-efficient.	[41]
Lifecycle energy management	Based on BIM, facility managers can adjust the operation schedules of elevators or HVAC units for energy efficiency.	[42]

In contrast, more recent attention has focused on the drawbacks of using BIM in building energy consumption optimization (see Table 6):

- Software compatibility issues exist in the building energy consumption optimization process [21]. Each software program may have its own data format. This feature can cause data loss or inaccurate energy models when importing models from one software to another. This can interrupt the process of building energy consumption optimization.
- Applying BIM for building energy consumption optimization requires a high initial investment [24]. This investment includes purchasing expensive software licenses and high-performance hardware to run complex models, and organizing expensive training for designers.
- BIM models are often out of date [43]. A construction project is subject to frequent onsite design changes. However, updates to BIM models that reflect these changes are time-consuming. If the energy consumption optimization relies on a BIM model that is out of date, the optimization will be inaccurate and the resulting optimization plans will not be applicable to the actual building.

- The design team suffers from a lack of skilled personnel [23]. Professionals who are efficient in both BIM and energy analysis are scarce. Without enough proficient professionals who can fully use BIM for building energy consumption optimization, the potential of BIM in building energy consumption optimization cannot be fully realized.

Table 6. Disadvantages of adopting BIM in building energy consumption optimization.

Disadvantages	Suggestions	References
Software compatibility issues	The design team should reduce the number of software tools used to avoid importing and exporting models.	[21]
High initial investment	The design team should include the purchase of BIM software in the budget.	[24]
Model update delays	BIM specialists should update the model regularly.	[43]
Shortage of skilled personnel	The design team should organize BIM training for their team members.	[23]

3.4. BIM Application in Building Energy Analysis

Building energy analysis is the process of building energy consumption analysis, both in its entirety and in each space in a building. A large and growing body of literature has investigated the complexity of building energy analysis [44]. Choi and Yoon [45] proposed energy performance signature-based clustering for urban building energy analysis. Li and Tian [46] proposed to create time series models for building energy analysis based on machine learning techniques. Nima and Tahsildoost [44] examined the calculation method, inputs, outputs, and capabilities of 25 building energy analysis software, resulting in a decision matrix for tool selection.

Much of the current literature on building energy analysis pays particular attention to the engagement of BIM [14]. The process of BIM-based building energy consumption optimization for energy efficiency is illustrated in Figure 7.

- Energy professionals should define the project. This process includes setting goals and defining the building boundaries.
- Energy professionals should collect data. Such data includes building geometry, occupant data, HVAC system data, lighting system data, and weather data.
- BIM specialists should create BIM models and import them into energy analysis software.
- Energy professionals should calibrate the results of the analysis. These results are obtained from the initial simulation and are compared with actual data.
- Energy professionals should develop different scenarios for energy-saving measures and conduct scenario analysis based on BIM.
- Energy professionals should conduct building energy analysis. This process includes energy consumption prediction and lifecycle cost analysis.
- Energy professionals should present the results. They should create graphs, charts and tables to clearly show the difference between the baseline and various scenarios. Moreover, a detailed report will be compiled, summarizing the results of the analysis.

The literature has highlighted several benefits of adopting BIM in building energy analysis (see Table 7):

- BIM integrates comprehensive building information to facilitate accurate simulation. This allows energy analysis software to obtain detailed parameters, simulate more realistic results, accurately estimate energy consumption, and reduce errors.

- BIM can interfere with building energy analysis in an early stage. At the beginning of the project, designers use BIM to quickly test the energy consumption of different design schemes.
- Based on the BIM platform, the stakeholders can communicate in a visualized environment. BIM software converts obscure energy data into 3D visualization effects.
- BIM runs through the entire lifecycle of buildings. It analyzes energy consumption during the construction period and predicts energy demand at various stages of operation, renovation, and demolition, which helps with long-term energy planning and cost control.

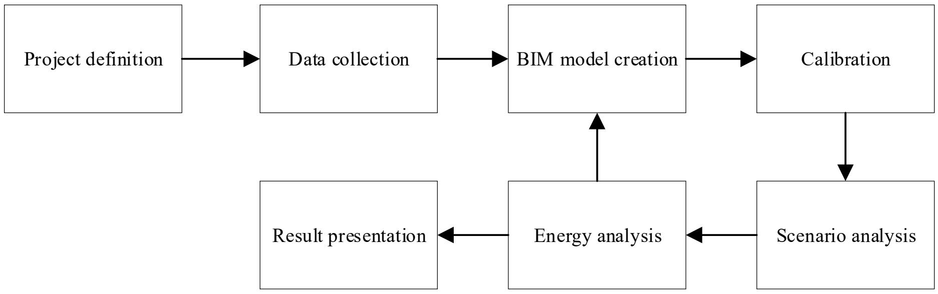

Figure 7. The workflow of BIM-based building energy analysis for energy efficiency.

Table 7. Advantages of adopting BIM in building energy analysis.

Advantages	Applications	References
Accurate simulation	BIM can accurately present comprehensive building information, from wall materials to door and window specifications.	[47]
Early intervention	BIM can adjust the building orientation and window-to-wall ratio, visually compare the energy-saving effects, help select the optimal scheme, and prevent high-cost renovations in the later stage.	[48]
Visualized communication	BIM uses thermal imaging maps to show the location of heat loss.	[19]
Whole lifecycle considerations	BIM can be applied throughout the whole building lifecycle.	[49]

In contrast, more recent attention has focused on the drawbacks of using BIM in building energy analysis (See Table 8):

- The design team suffers from the high initial costs of BIM. Introducing BIM requires procuring professional software, upgrading hardware, and training employees. This limits their willingness and ability to apply it.
- BIM models suffer from complex and error-prone data. The BIM data of complex buildings is massive. Frequent changes during construction do not cause timely updates of BIM models. A mistake in component size and material setting can lead to considerable errors in building energy analysis.
- BIM software suffers from multiple software coordination. Some attributes are lost after importing the model into the new software, requiring manual secondary calibration and increasing workload.
- BIM accumulates massive amounts of data and filters out key valuable information for energy analysis, which is difficult and time-consuming. Excessive, irrelevant data may also interfere with the judgment of professionals.

Table 8. Disadvantages of adopting BIM in building energy analysis.

Disadvantages	Suggestions	References
High initial costs	The design team should include the purchase of BIM software in the budget.	[24]
Complex and error-prone data	The design team should upgrade their hardware to adapt to the high requirements of implementing BIM software.	[32]
Software compatibility challenges	The design team should reduce the number of software tools used to avoid importing and exporting models.	[21]
Information redundancy	BIM modeling process should follow the development specification level.	[50]

4. Application of BIM for Energy Efficiency of Existing Buildings

Much of the current literature on energy efficiency pays particular attention to existing buildings [51]. More recent attention has focused on the provision of BIM in the building operation stage for energy efficiency [52]. A number of studies have begun to examine the potential of BIM in promoting the energy efficiency of existing buildings [53]. New findings in BIM provide further evidence that BIM can integrate building operation data and visualize energy consumption [54]. Data from several studies suggest that BIM is the main tool for stakeholders to improve energy efficiency [55]. This is consistent with the data obtained by Dauletbek and Zhou [56]. Therefore, the application of BIM to existing buildings is essential for building energy efficiency.

Based on a systematic review, three aspects of BIM application have been found to have the potential to reduce energy consumption for existing buildings:

- BIM offers several crucial contributions to digital twins for energy efficiency [57]. These contributions include data foundation, energy visualization and simulation, lifecycle energy management, interoperability, and cost prediction [58].
- BIM models facilitate the effectiveness of the IoT in reducing energy consumption [52]. BIM allows for precise planning of IoT device placement [33].
- BIM plays a critical role in building LCA [59]. BIM serves as a central repository for all building-related data, and this comprehensive data collection is the bedrock of a detailed LCA [60].

4.1. BIM Application in Digital Twin

A digital twin refers to a virtual replica of a physical system. The existing literature on digital twins is extensive and focuses particularly on energy efficiency [61]. Koirala and Cai [62] explored digital twin opportunities for energy efficiency and found that digital twins offer a rich and objective information base throughout the whole lifecycle. Deakin and Vanin [63] developed a digital twin for the distribution system, and this digital twin largely reduced energy consumption. This is consistent with the data obtained by Lu and Zhang [64].

Much of the current literature on digital twins pays particular attention to the engagement of BIM [52]. The process of BIM-based digital twins for energy efficiency is illustrated in Figure 8.

- Professionals should collect the data to create BIM models. This data includes building design data and site-related data.
- Professionals should connect BIM models to specialized energy analysis software.
- Professionals should create a digital twin for building energy efficiency. Based on BIM models and energy analysis results, the digital twin combines the 3D visualization of

BIM models with real-time energy data. The digital twin can be used to visualize the energy consumption of different areas in the building.

- Professionals should integrate real-time data into the digital twin. Sensors are installed in physical buildings to collect real-time or simulated data on energy consumption.
- Professionals should conduct energy efficiency analysis and optimization. They use the digital twin to conduct what-if scenarios for energy efficiency improvement.

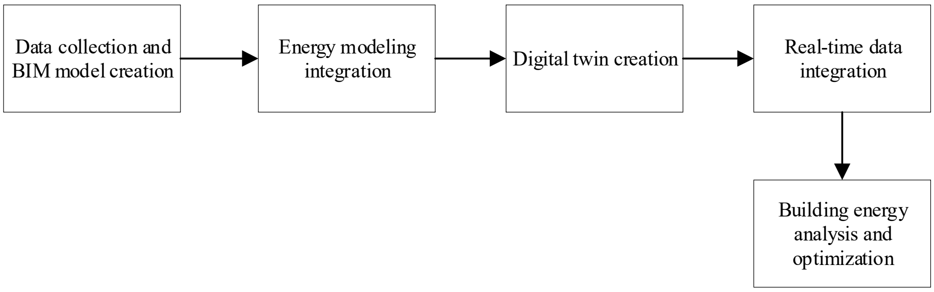

Figure 8. The workflow of a BIM-based digital twin for energy efficiency.

The literature has highlighted several benefits of adopting BIM in digital twins (see Table 9):

- BIM provides accurate basic models for digital twins [65]. BIM models contain detailed geometric information, material properties, and spatial relationships.
- BIM models support whole lifecycle management [66]. Throughout the whole lifecycle of a building, rich data is accumulated during each stage. Digital twins can use this data to achieve continuous monitoring and optimization of building energy.
- BIM promotes multidisciplinary collaboration and coordination [67]. As an integrated platform, BIM can enable multidisciplinary professionals to work together in the same model, reduce design conflicts and errors, and improve work efficiency and quality. The results of this collaboration can also be used by digital twins better.
- It is convenient to conduct simulations using BIM [68]. During the design phase, various simulation analyses can be conducted, such as energy consumption analysis, lighting analysis, and ventilation analysis. These analysis results provide important references and comparative benchmarks for performance evaluation and optimization in digital twins.

In contrast, more recent attention has focused on the drawbacks of using BIM in digital twins (See Table 10):

- Updating the BIM model dynamically is difficult [43]. BIM models are usually created at specific stages and are relatively static, while digital twins require real-time reflection of changes in physical objects. BIM models are challenging to obtain and update dynamic changes in the physical world in real time, such as equipment failures and personnel movements.
- BIM suffers from real-time data integration [58]. BIM itself mainly focuses on design information management and does not have the function of directly connecting physical sensors to obtain real-time data. Additional integration and development work are required to achieve real-time data interaction with digital twin systems.
- The details of BIM models are relatively insufficient in the operation phase [69]. For complex equipment operation and maintenance management, real-time energy monitoring, and other operational needs, BIM models often cannot meet them.
- There are problems such as inconsistent data formats and poor compatibility between different BIM software and digital twin platforms [21]. This makes it difficult to share

and integrate BIM models between different systems, affecting the implementation and application effectiveness of digital twins.

Table 9. Advantages of adopting BIM in digital twins.

Advantages	Applications	References
Provision of accurate basic models	BIM models can be used for real-time data mapping and analysis.	[65]
Support of whole lifecycle management	The rich information contained in BIM models can be used to achieve continuous monitoring and optimization of building energy.	[66]
Promotion of multidisciplinary collaboration and cooperation	BIM platform can provide a model for collaboration among all stakeholders.	[67]
Convenience in conducting simulation analysis	BIM can carry out energy consumption analysis, lighting analysis, ventilation analysis, etc.	[68]

Table 10. Disadvantages of adopting BIM in digital twins.

Disadvantages	Suggestions	References
Difficulty in dynamic model updates	BIM specialists should update the model regularly.	[43]
Lack of real-time data interaction capability	The interface between BIM and digital twin should be developed.	[58]
Limited support for the operational phase	Further integration with other technologies and systems is needed to build digital twins.	[69]
Data compatibility and interoperability issues	The design team should decrease the amount of software to avoid model import and export.	[21]

4.2. BIM Application in the Internet of Things

The IoT is a network of physical items that can connect and exchange data with other IoT devices. The literature on the IoT has highlighted several potential ways to reduce building energy consumption [70]. To pursue energy conservation, the active IoT objects compute in the fog layer rather than locally [71]. Much of the literature on this is concerned with energy management, which is essential for maintaining long-term operation in IoT nodes [72]. Using cutting-edge technologies to improve energy management is made possible by integrating the IoT into smart buildings [73].

The use of BIM is given special consideration in a large portion of the existing IoT literature [52]. The process of BIM-based IoT for energy efficiency is illustrated in Figure 9.

- BIM specialists should create a BIM model. This model includes geometric details, spatial relationships, and information about components. Meanwhile, non-geometric data should be added to the BIM model, such as product specifications, maintenance schedules, and manufacturer details for each building element.
- Operators should select IoT devices and deploy them onsite. Needs assessment should be conducted to identify the monitoring and control requirements of the building. After that, the operators should choose IoT devices that are compatible with the BIM environment. The operators should map the IoT device locations onto the BIM model and install the IoT devices in the building according to the deployment plan.

- BIM and IoT are integrated to facilitate energy efficiency. Operators should establish a connection between BIM and IoT and map the data from IoT devices to the relevant elements in the BIM model.
- IoT devices should collect real-time data and conduct analysis. BIM aggregates incoming data from multiple IoT devices to get a comprehensive view of the building's performance. The collected data should be analyzed and visualized within the BIM environment.
- Operators should make decisions on building operations. The BIM-IoT integrated system provides decision-support information to building operators.
- The BIM-IoT system should conduct continuous monitoring and optimization. It stores historical data, which can be used for long-term trend analysis. Operators should use the insights from long-term monitoring to optimize building operations.

The literature has highlighted several benefits of adopting BIM in IoT (see Table 11):

- BIM can integrate and share information efficiently [74]. BIM integrates various types of information throughout the whole building lifecycle, such as geometric information, material properties, spatial relationships, etc. At the same time, real-time data collected by IoT devices, such as temperature, humidity, energy consumption, etc., can be integrated into BIM models to provide comprehensive and accurate data support for project management and achieve real-time information sharing.
- BIM can get real-time monitoring and precise warning [75]. By deploying IoT devices in buildings, BIM models can reflect the actual status of building projects in real time. Once abnormal situations are detected, such as equipment failures, energy consumption anomalies, safety hazards, etc., the system can immediately issue warnings to help operators take timely measures to prevent potential risks and improve the safety and reliability of the building.
- BIM can optimize decision-making and operation management [52]. Based on the combination of BIM and IoT, a large amount of building operation data can be analyzed to provide a scientific basis for the operation strategy of building projects, thereby improving energy utilization efficiency and reducing operating costs. At the same time, BIM models can provide intuitive guidance and support for operators, enabling them to locate and solve problems more quickly and accurately, improving operation and maintenance efficiency and quality.
- BIM can visualize the process of the IoT [76]. BIM has highly detailed, accurate, and constructible 3D structural models that help visualize projects from concept to completion. This allows the operators to have a more intuitive understanding of the building's operational status and data changes and facilitates spatial analysis and decision-making.

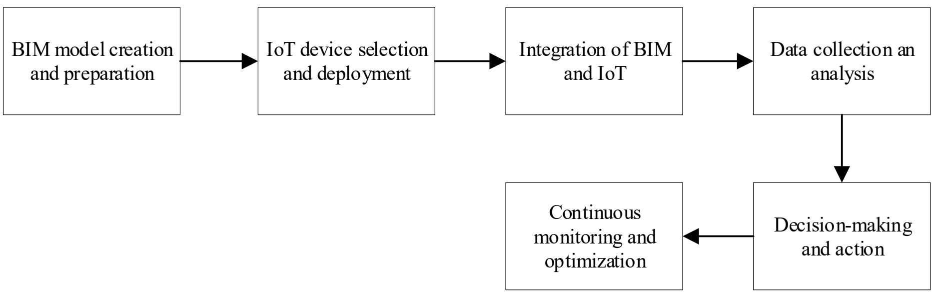

Figure 9. The workflow of BIM-based IoT for energy efficiency.

Table 11. Advantages of adopting BIM in the IoT.

Advantages	Applications	References
Efficient information integration and sharing	BIM can integrate real-time data collected by IoT devices.	[74]
Realize real-time monitoring and precise warning	BIM will immediately issue warnings on equipment failures, energy consumption anomalies, safety hazards, etc.	[75]
Optimize decision-making and operation management	BIM can help optimize equipment operation time and adjust energy allocation.	[52]
Enhance visualization effect	After integrating with IoT, real-time data can be associated with 3D models.	[76]

In contrast, more recent attention has focused on the drawbacks of using BIM in IoT (see Table 12):

- BIM remains a highly technical complexity in the IoT process. BIM and IoT involve massive fields of technology, such as architectural design, engineering management, sensor technology, network communication, data analysis, etc. Integrating BIM and IoT requires cross-disciplinary professional knowledge and technical capabilities, with high technical barriers, complex implementation, and high operator requirements.
- BIM suffers from difficult data management [77]. The data generated by BIM models and IoT devices is massive and complex. The collection, transmission, storage, processing, and analysis of data face challenges.
- There may be compatibility and interoperability issues between different BIM software and IoT devices [21]. This can prevent smooth data sharing and interaction. In practical applications, additional time and effort are required to solve the integration challenges between systems and ensure that each system can work together.
- BIM-based systems suffer from security and privacy risks [78]. The integration of BIM and IoT involves a large amount of user data, and the security and privacy protection of these data are crucial. Once data is leaked or tampered with, it may pose a serious threat to the safety of buildings and the interests of users.
- The application of BIM requires a high initial investment [24]. Integrating BIM and IoT requires the purchase of hardware facilities such as BIM software, IoT devices, sensors, network equipment, and corresponding software systems and technical services. At the same time, a large amount of manpower and material resources are required for system integration, development, and maintenance, resulting in high initial construction costs and later operating costs.

Table 12. Disadvantages of adopting BIM in the IoT.

Disadvantages	Suggestions	References
High technical complexity	The operation team should recruit cross-disciplinary talent.	[79]
Difficulty in data management	BIM requires establishing efficient data management systems and data analysis platforms to ensure data accuracy, completeness, and timeliness.	[77]
System compatibility and integration issues	The design team should decrease the number of software tools to avoid model import and export.	[21]
Security and privacy risks	The BIM system should set corresponding permissions for the end users.	[78]
High investment	The design team should include the purchase of BIM software in the budget.	[24]

4.3. BIM Application in Building Lifecycle Assessment

Building LCA refers to an essential tool for thoroughly examining the environmental effects of buildings during their lifetime. Much of the current literature on building LCA pays particular attention to energy efficiency [80]. Khadim and Agliata [81] developed a unified LCA framework for reducing energy consumption. Nicholson and Ugursal [82] conducted an LCA-based environmental analysis for building energy efficiency in the operation stage. Mousavi and Taki [83] evaluated the energy consumption and environmental impacts in different greenhouse structures using the LCA approach.

Much of the current literature on building LCA pays particular attention to the engagement of BIM [84]. The process of BIM-based building LCA for energy efficiency is illustrated in Figure 10.

- Professionals should define the project and establish assessment goals.
- BIM specialists should collect data and create BIM models.
- Professionals should identify the lifecycle inventory data and map it to BIM models.
- Professionals should select the LCA method and conduct the building LCA.
- Professionals should conduct result analysis, sensitivity analysis, and scenario analysis.
- Professionals should prepare a comprehensive report documenting the LCA findings and communicating with stakeholders.

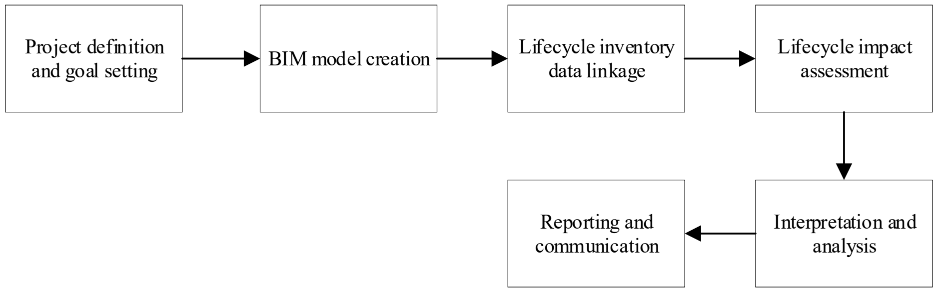

Figure 10. The workflow of BIM-based building LCA for energy efficiency.

The literature has highlighted several benefits of adopting BIM in building LCA (see Table 13):

- BIM is efficient in integrating and sharing data [85]. It provides comprehensive and accurate data for LCA, avoids data duplication and inconsistency, allows all parties involved to obtain and update information in real time, and improves assessment efficiency and accuracy.
- BIM can visualize building data and facilitate convenient communication among all stakeholders [86]. Displaying building models in 3D visualization allows all parties involved to have a more intuitive understanding of the building's whole lifecycle. In the LCA process, all parties can communicate and collaborate more effectively based on the visualized models, and misunderstandings and conflicts can be reduced.
- BIM is powerful in simulation and analysis [87]. During the design phase, it can predict the environmental impact of buildings at different stages, helping designers and engineers choose more environmentally friendly and energy-efficient design solutions and materials, optimize building performance, and reduce lifecycle costs.
- BIM is applied in the building throughout its whole lifecycle [88]. Throughout the whole lifecycle of a building, BIM enables LCA a comprehensive assessment of the environmental, economic, and social impacts of the building at each stage, helping to make more forward-looking and sustainable decisions.
- BIM can improve LCA efficiency and accuracy [89]. The data in BIM models can be directly used for LCA calculations. This can reduce the workload and error rate of

manual data collection. Some BIM software also comes with or can integrate LCA tools, which can automatically perform LCA calculations and result analysis. This largely improves the efficiency and accuracy of LCA.

In contrast, more recent attention has focused on the drawbacks of using BIM in building LCA (See Table 14):

- Problems exist in BIM data quality and integrity [90]. The accuracy and completeness of BIM models depend on the input of designers and construction personnel. If the input data is inaccurate or incomplete, it will affect the results of LCA. Environmental attribute data for some building materials and equipment may be missing or difficult to obtain, which can also pose challenges for LCA.
- Software interoperability challenges the LCA process [21]. There are compatibility and interoperability issues between different BIM software and LCA software. This may result in data loss, format incompatibility, and other issues when converting models between different software. This largely affects the smooth progress of LCA and increases the additional time and cost for data processing and model repair.
- Updating and maintaining BIM models is difficult [43]. During the design and construction process of a building project, the BIM model needs to be constantly updated and modified. However, during practical operation, the update of the model may not be timely or accurate, resulting in inconsistency between the LCA model and the actual building, which affects the reliability of the evaluation results. In the operation stage, continuously updating the BIM model to reflect the actual situation also requires a lot of manpower and time investment.
- The integration of BIM and LCA requires cross-disciplinary talent [23]. Participants need to possess professional knowledge and skills in BIM technology and LCA methods; be familiar with architectural design, construction, and operation management; and have multidisciplinary knowledge in areas such as environmental science and engineering economics. Currently, there is a relative shortage of such versatile talent, which may limit the application and promotion of BIM in LCA.
- Operators suffer from the high initial costs of BIM [24]. The adoption of BIM technology and related software requires the purchase of software licenses, training, deployment of professional personnel, and high-performance hardware equipment, which increases the upfront cost of the project. For some small projects or enterprises with limited funds, this may be difficult to afford.

Table 13. Advantages of adopting BIM in building LCA.

Advantages	Applications	References
Efficient data integration and sharing	The BIM model provides detailed information on each stage of the building's whole lifecycle, such as geometric information, material properties, construction progress, etc.	[85]
Visualization and convenient communication	The engagement of BIM facilitates the identification of potential problems and optimization points.	[86]
Powerful simulation and analysis capabilities	BIM can simulate and analyze the energy consumption, lighting and ventilation, carbon emissions, and other aspects of buildings.	[87]
Comprehensive coverage throughout the whole lifecycle	BIM can be applied in the building throughout its whole lifecycle.	[88]
Improved assessment efficiency and accuracy	LCA functions can be embedded in BIM software.	[89]

Table 14. Disadvantages of adopting BIM in building LCA.

Disadvantages	Suggestions	References
Data quality and integrity issues	BIM standards for information input are needed for highly accurate BIM models.	[90]
Software interoperability challenges	The design team should decrease the amount of software to avoid model import and export.	[21]
Difficulty in updating and maintaining BIM models	BIM specialists should update the model regularly.	[43]
High requirements for professional knowledge and skills	The design team should organize BIM training for their team members.	[23]
High-cost investment	The design team should include the purchase of BIM software in the budget.	[24]

5. Discussion

This research conducted a round of checks to identify similar themes. The latest publications reviewing BIM applications for energy efficiency are listed in Table 15. The study by Pereira and Santos [4] is most similar to our research. However, its purpose is to identify the areas in which BIM plays a role in energy efficiency. They missed examining the application of these technologies in building energy efficiency improvement. Our article critically investigates the application of BIM for energy efficiency. The article [4] can serve as a prelude to our research. Hence, our originality is established.

Table 15. The latest publications reviewing BIM application for energy efficiency.

Review Objects	Methods	References
Application of BIM in facility management	Literature review	[54]
Application of BIM in the early design stage	Literature review	[91]
BIM-computational fluid dynamics integration	Literature review	[92]
The use of BIM for energy efficiency	Systematic review	[4]
BIM adoption in sustainability and energy modeling and implementation	Literature review	[93]
BIM-building performance simulation integration	Literature review	[94]

Based on a comprehensive review, BIM has been found to achieve a certain level of maturity in energy efficiency. Firstly, BIM provides widespread application in the design phase. In the design phase, the BIM energy consumption assessment is mainly utilized to optimize building design schemes. The majority of design units have started to apply BIM technology to energy consumption assessment. It can predict the energy consumption performance of buildings throughout their lifecycle, offering a scientific basis for decision-making. Secondly, BIM provides effective support in the construction and operation phases. In the construction phase, BIM can optimize the construction plan, precisely calculate material requirements, reduce rework, and decrease embodied energy consumption. In the operation phase, the combination of BIM and IoT technology enables intelligent management, achieving real-time monitoring and analysis of building energy use.

However, it also encounters some challenges. Firstly, BIM faces interoperability issues. There are compatibility problems between BIM models and energy consumption analysis software. Different software systems have diverse data structures and formats, resulting in difficulties in data integration and exchange, which affect the efficiency and accuracy of energy efficiency analysis. Secondly, BIM faces a lack of standardized processes. The energy project lacks unified industry standards and specifications. There are differences in the understanding and implementation of BIM applications among various units, which leads to uneven implementation effects and affects overall efficiency. Thirdly, BIM faces a talent shortage. Many project teams have insufficient understanding and application of BIM technology and lack professional training and knowledge accumulation. This makes it impossible to give full play to the role of BIM tools, thus restricting the promotion and application of BIM in energy efficiency.

Based on the review, we found the trends of BIM in energy efficiency. Firstly, BIM will gradually develop its intelligence. With the development of artificial intelligence technology, BIM energy consumption assessment will become more intelligent and automated. AI algorithms can be used to predict energy consumption, automatically identify energy-saving opportunities, and provide intelligent decision-making support. Secondly, BIM will integrate green building standards and policies. In the context of "dual carbon", BIM will be more closely combined with green building standards and policies. It will become a core tool for building energy consumption refined management, promoting the construction industry to develop towards low-carbonization. Thirdly, BIM will make cross-discipline integration. BIM energy efficiency analysis will integrate the knowledge of multiple disciplines such as architecture, energy, and environment. Through cross-disciplinary cooperation, more comprehensive and accurate energy efficiency evaluation and optimization solutions can be provided.

In the process of literature search, seven areas were identified. These areas were mainly focused on in the literature. Before our research, these seven areas were explored separately. We grouped these seven areas to facilitate BIM in energy efficiency. It is important to explore these seven areas so that they can present the state of the art of BIM in energy efficiency.

Based on a comprehensive literature search, BIM applications for energy efficiency were found in the design and operation stages. However, few publications were found for the construction stage. Hence, BIM application for energy efficiency in the construction stage should be further explored in future research.

6. Conclusions

As global warming gets worse and worse, reducing energy consumption is becoming more and more essential. Recently, energy consumption in buildings has accounted for a large proportion of global energy consumption. Hence, improving energy efficiency plays an important role in combating climate change and advancing sustainability. In this regard, BIM is gradually becoming an efficient tool for facilitating energy efficiency. The purpose of the current research was to examine the application of BIM for energy efficiency.

This research adopts a systematic review approach to review the application of BIM for energy efficiency. The research adopted a four-step approach. Firstly, it identified 1245 publications based on the "title/abstract/keyword" search. Secondly, it screened the records by reviewing the abstracts of the recorded publications. Thirdly, the eligibility of these records was examined by assessing the full text of the articles. Finally, this research included 87 articles, excluding all the records that did not meet the requirements.

This research identified seven BIM application areas, including generative design, building energy prediction, building energy consumption optimization, building energy analysis, digital twin, IoT, and building LCA. It also showed the workflow of BIM application in each application area. These findings suggest that, in general, BIM can improve building energy efficiency in those applications.

The second major finding was the advantages and disadvantages of adopting BIM in each area. Taken together, these results suggest that BIM's 3D visualization benefits almost all application areas. These findings have significant implications for understanding the role of BIM in energy efficiency-related applications. The evidence from this study suggests that system compatibility issues and high initial setup costs are the most common problems in these applications. Importing a model from one software into another is difficult. Massive information will be lost in this process. This suggests the integration of specific software and the embrace of Industry Foundation Classes.

After an in-depth review of the literature up to 2025 regarding BIM, it is evident that while software compatibility and high initial costs remain persistent challenges, there have been notable shifts in the nature of these issues and new strategies emerging to address them. Firstly, in the past, software compatibility was mainly about different BIM software not being able to communicate effectively. For example, data loss often occurred when transferring a model from one BIM software to another. However, currently, with the growth of cloud-based BIM platforms, the issue has expanded. Now, it also includes compatibility between on-premise legacy software and new cloud-based collaborative tools. Additionally, as more non-traditional stakeholders, such as facility managers using specialized software, enter the BIM ecosystem, ensuring seamless data flow across a wider range of software types has become crucial. Recent literature suggests the adoption of open-source BIM software frameworks. These frameworks, like FreeCAD, are designed with compatibility in mind from the ground up. They allow for easier integration with other software due to their open—ended architecture. Also, there is an increased emphasis on using Industry Foundation Classes (IFC) as a universal data format. More software developers are optimizing their products to better import and export IFC files, thereby reducing data loss during format conversions. For instance, some major BIM software companies are now investing in research to improve the fidelity of IFC-based data exchanges.

Secondly, high initial costs were primarily associated with purchasing expensive BIM software licenses and upgrading hardware to run the software. However, as the industry has evolved, the costs related to training and change management have become more prominent. With the complexity of BIM workflows, training employees not only in software usage but also in new collaborative processes has added a significant financial burden. Also, the cost of maintaining BIM-enabled systems over time, including software updates and license renewals, has become a long-term consideration. Cost-sharing models are emerging as a solution. Some construction firms are forming consortia to jointly purchase BIM software licenses, reducing per-company costs. For example, a group of small- to medium-sized contractors in a local area might pool their resources to buy a multi-user license of a popular BIM software. Cloud-based software-as-a-service (SaaS) models are also gaining traction. Instead of making large upfront purchases, companies can subscribe to BIM software on a monthly or annual basis, spreading out the cost. In terms of training, more firms are turning to online, self-paced courses. Platforms like Coursera and LinkedIn Learning offer BIM-related courses at a fraction of the cost of traditional in-person training, making it more accessible for companies with budget constraints.

This research makes several contributions to the literature. Firstly, the results of this study help provide a better understanding of the importance of BIM in energy efficiency improvement. Secondly, our research supplements the energy field that identifies seven BIM use categories. Thirdly, this article critically examines the use of BIM in building energy field.

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Abbreviations

The following abbreviations are used in this manuscript:

BIM	Building Information Modeling
LCA	Building Lifecycle Assessment
IoT	Internet of Things

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