

Research on the Application of BIM Technology in Carbon Emission Accounting and Optimization Throughout the Whole Life Cycle of Building Engineering

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Abstract. Under China's "dual carbon" strategy, precise carbon emission management across the whole life cycle of building engineering has become a critical issue. Based on 500 papers indexed in CNKI (2016–2026), this paper employs CiteSpace software for knowledge graph visualization analysis to systematically investigate the research status and trends of BIM technology in building carbon emissions. Keyword co-occurrence, clustering, and time-zone analyses reveal that "carbon emissions" and "green buildings" constitute the dual core themes, the research has undergone three stages: initial exploration, explosive growth, and deepening consolidation. the integration of BIM with digital twins and big data emerges as a new trend; and whole-life-cycle precise control remains a long-term core direction. Research frontiers identified by CiteSpace highlight challenges including unbalanced life-cycle coverage, lack of cross-stage data collaboration, and poor BIM–LCA compatibility. Accordingly, this paper proposes establishing a full-life-cycle BIM carbon accounting system, addressing data collaboration and compatibility, promoting BIM integration with new technologies, and taking existing building retrofitting and operational optimization as new growth points.

Keywords: BIM technology, building engineering, carbon emissions, whole life cycle, CiteSpace, knowledge mapping

1. Introduction

China's "dual carbon" strategy is now being rolled out across the country. The construction industry uses large amounts of resources and produces substantial carbon emissions. This means that controlling carbon emissions over the whole life cycle of buildings is a key part of green transformation. Building projects go through design, construction, operation, and maintenance. Each stage has its own carbon sources, and the data are closely linked across stages. Traditional accounting methods collect data in a scattered way. They lack sufficient accuracy. They also struggle to coordinate different stages. Digital technologies are needed to build an efficient accounting and optimization system. BIM serves as a core digital tool in construction. It supports parametric modeling, life-cycle data integration, and visual simulation. BIM breaks down information barriers

between stages. It allows engineering data to be fully traced and shared. This gives standardized and detailed support for carbon emission accounting.

BIM has been used to calculate embodied carbon, track construction and operation emissions, and track carbon during operation. These studies confirm that BIM improves the efficiency and accuracy of carbon accounting. Yet current research still has shortcomings. Application scenarios remain fragmented. Data collaboration mechanisms are weak. BIM models cannot carry enough carbon information. A full-life-cycle BIM carbon accounting and optimization system has not yet been built.

This paper focuses on using BIM for carbon emission accounting and optimization across the whole life cycle of building engineering. We review how BIM can be used to control carbon emissions. We analyze key problems in current practice. Then we suggest optimization paths based on industry needs. Our aim is to offer theoretical support for deeper integration of BIM into building carbon reduction. We hope this work will help achieve accurate accounting, dynamic monitoring, and scientific optimization, and in turn support the "dual carbon" goals.

1.1. Research background

Controlling carbon emissions from building projects is a major challenge. The construction industry consumes vast amounts of resources and accounts for a large portion of global carbon emissions. With China advancing its "dual carbon" goals, cutting emissions across the full life cycle of buildings has become an unavoidable task. A building's life consists of several stages: design, construction, operation, and demolition. Each stage releases carbon, though the sources differ. Embodied carbon comes from producing and transporting materials. During the construction period, the use of on-site equipment and power consumption will increase the emission. Once a building is occupied, heating, cooling and lighting will produce operational carbon year after year. Final demolition and waste disposal will also affect the total. These emissions are interrelated. However, the traditional carbon accounting method is difficult to reflect this complexity. The data is scattered, not systematic. Each stage is evaluated independently. Most of the work depends on manual labor. Therefore, it is difficult to accurately track carbon emissions and make timely adjustments.

This can explain why there is an increasing demand for digital tools to support low-carbon management throughout the building life cycle. Digital system can automatically integrate data, share information among different stages, and achieve dynamic carbon control. They can estimate future emissions in advance and test low-carbon strategies.

1.2. The role of BIM in carbon emission management

BIM has three characteristics that are conducive to managing carbon emissions. Support parametric modeling, life cycle data integration and visual simulation. Relying on these functions, BIM can break the information barrier between different stages of the project. Data can track and share the whole life cycle of a building. It has laid a solid technical foundation for better carbon accounting.

BIM can play a certain role in carbon assessment. In the design process, the material quantity and energy data can be obtained directly from the model. Therefore, implicit carbon and operational carbon can be estimated as soon as possible. During the construction process, BIM will be connected with the on-site activity records. Equipment usage and material transportation emissions can then be tracked. For the operation stage, using BIM as the energy model can simulate the demand of heating, cooling and lighting. You can also compare the predicted results with the real

values. Even if BIM is dismantled, waste estimation and recycling planning can be carried out. It is beneficial to reduce the carbon emissions generated in the waste treatment process.

BIM can realize the integration of information at all stages. The shared BIM model can store all carbon-related data in one place, instead of storing design, construction and operation data in different places. Reduce data loss and manual input errors. It also allows different teams to work from the same information base. For life cycle management, BIM can let users know how design choices will affect carbon emissions decades later. It can also feed back the operation data to designers for future improvement. So BIM is not only a drawing tool. This is a platform for managing carbon from beginning to end.

1.3. Research gaps and objectives

Existing BIM reviews often cover sustainability, but few use bibliometrics on carbon emissions [1, 2]. However, there are few bibliometrics that specifically study the carbon emissions of construction projects. Besides, most of the existing comments are not based on China literature. China has its own building practice, carbon policy and research institutions [3, 4]. Therefore, a bibliometric study using China resources is needed.

Another gap is the lack of systematic analysis of the whole life cycle of buildings. Many researches only focus on a certain stage, namely design or construction. Few people connect the stages [5, 6].

This paper tries to make up for these shortcomings. This is our purpose. Firstly, the paper makes a bibliometric analysis on the carbon emission research related to BIM through the literature of China HowNet from 2016 to 2026. Second, use CiteSpace to determine research hotspots, development stages and frontier trends. Third, summarize the main problems reported in the current research. Fourthly, the future research direction of life cycle carbon management based on BIM is put forward.

2. Materials and methods

This section mainly explains our data source, search approach, screening criteria, software parameters and analysis process.

2.1. Data source and search strategy

This paper takes China National Knowledge Infrastructure (CNKI) as the data source. China HowNet is the largest academic database in China at present. It includes periodicals, papers and conference papers.

We conducted the search in March 2026. The search terms were "BIM" AND Building Engineering AND Carbon Emissions. The time range is from January 1, 2016 to March 31, 2026. Only articles in academic journals are included. Excluding conference abstracts, news, book reviews and non-research projects.

2.2. Screening criteria and data processing

A total of 687 initial records were obtained. Two rounds of screening are adopted, the first round is to eliminate duplicates, and the second round is to look at titles and abstracts. Exclude papers that have nothing to do with building information model (BIM) or carbon emissions, and exclude

literature with unclear research content. After the above steps, 500 valid papers are obtained as sample sets.

2.3. Bibliometric tool and analytical procedure

We use CiteSpace (version 6.2.R6) for bibliometric analysis [1]. CiteSpace is one of the most widely used tools. It can visualize the trends and patterns in scientific literature. It can produce co-occurrence network, cluster diagram and burst detection.

Our parameters are set as follows. The time slice is set to 1 year. The threshold of G exponent is 25. The LRF is 3.0. L/N=10. LBY was five years old. E takes 1.0. The network is pruned by path finding algorithm.

Six types of analysis are carried out. First, the annual publishing trend. Second, the source journals. Third, research institutions. Fourth, keyword co-occurrence. Fifth, keyword clustering. Sixth, burst detection.

3. Results

This section reports the findings from our bibliometric analysis.

3.1. Annual publication trends

In 2016, the number of publications was less than 20, and in 2025, there were about 145. It can be seen that the research interest in BIM carbon reduction is growing. The fastest growth is from 2020 to 2023. This period coincided with China's announcement of "double carbon" in December 2020 [7]. After 2023, the growth continued but slowed down. It can be seen that this field has developed to a relatively mature stage.

3.2. Analysis of source journals and research institutions

Among the 500 papers, the top journals by volume were Sustainability, Buildings, and Journal of Cleaner Production. Most of these journals have JCR impact factors above 3.0. This indicates that BIM-carbon research is published in high-quality outlets, as shown in Table 1 [2, 5, 7].

Table 1. Top 10 journals publishing BIM-based carbon emission research in building projects (2016–2026)

Rank	Journal full name	Publisher	Total publications (2016–2026)	2024 JCR impact factor	JCR quartile (core subject)
1	Sustainability	MDPI	210	3.6	Q2 (Environmental Sciences), Q2 (Construction & Building Technology)
2	Journal of Cleaner Production	Elsevier	165	9.807	Q1 (Environmental Sciences), Q1 (Industrial Engineering)
3	Energy and Buildings	Elsevier	103	6.7	Q1 (Construction & Building Technology), Q1 (Energy & Fuels)
4	Building and Environmen	Elsevier	83	7.1	Q1 (Construction & Building Technology), Q1 (Environmental Engineering)
5	Automation in Constructio	Elsevier	76	11.5	Q1 (Construction & Building Technology), Q1 (Automation & Control Systems)

Table 1. (continued)

6	Sustainable Cities and Society	Elsevier	65	10.5	Q1 (Urban Studies), Q1 (Construction & Building Technology)
7	Renewable and Sustainable Energy Reviews	Elsevier	58	15.8	Q1 (Energy & Fuels), Q1 (Renewable Energy)
8	Energies	MDPI	55	3.2	Q2 (Energy & Fuels), Q3 (Construction & Building Technology)
9	Building Research and Information	Taylor & Francis	45	8.2	Q1 (Construction & Building Technology)
10	Buildings	MDPI	41	3.1	Q2 (Construction & Building Technology)

As far as institutions are concerned, Tongji University, Tsinghua University and Chongqing University are the most successful. The inter-agency cooperation network is weak. Most of the research comes from a single organization or small team. Inter-agency cooperation is rare as summarized in Table 2 [8, 9].

Table 2. Top 10 research institutions contributing to BIM-carbon emission research in building projects (2016–2026)

Rank	Institution name	Country/Region	Number of publications	Core research focus
1	Tsinghua University	China	92	BIM-LCA life-cycle carbon emissions, digital twin carbon tracking, low-carbon design optimization
2	Chongqing University	China	78	Building life-cycle carbon emissions, BIM and green building assessment, low-carbon construction technology
3	Hong Kong Polytechnic University	Hong Kong, China	65	BIM low-carbon operation and maintenance, carbon assessment of prefabricated buildings, smart city low-carbon management
4	University College London	UK	59	BIM-LCA integration, building carbon footprint, digital design for low-carbon buildings
5	Tongji University	China	56	BIM low-carbon construction, carbon reduction in prefabricated buildings, building energy simulation and optimization
6	Southeast University	China	51	BIM low-carbon design, building envelope energy saving, carbon accounting of prefabricated components
7	University of CambridgeUK Sustainable Energy Reviews	UK	48	BIM digital twin, real-time carbon monitoring, intelligent decision-making for low-carbon buildings
8	South China University of Technology	China	45	Low-carbon BIM for Lingnan architecture, building energy efficiency in hot and humid regions, green building materials in BIM

Table 2. (continued)

9	Building Research and Information	Netherlands	42	BIM-LCA standardization, building life-cycle carbon emissions, low-carbon building information integration
10	Buildings	USA	39	Building energy and carbon emission simulation, BIM low-carbon decision support systems, net-zero carbon building technologies

3.3. Keyword Co-occurrence analysis

As shown in Figure 1, keywords Co-occurrence network has 251 nodes and 306 connections. The largest node is carbon emission and the second largest node is green building, which shows that these two topics are the main research directions [4, 10]. Other high-frequency words are BIM, life cycle, prefabricated buildings and low-carbon buildings. The network density is low (0.0098), but the clustering quality is good ($Q=0.77$, $S=0.70$).

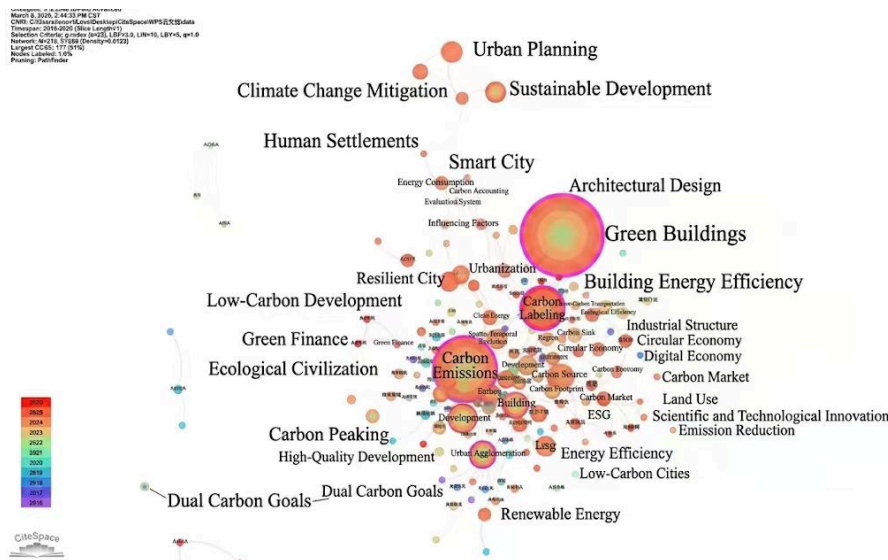


Figure 1. Keyword co-occurrence network of BIM-carbon emission research based on CiteSpace

3.4. Keyword clustering analysis

We found 10 major research clusters. The largest scale is zero carbon emission, others are green building (1), life cycle assessment (2), BIM-LCA integration (3) [6, 10] and prefabricated buildings (4). Cluster is the main research topic. Most research focuses on three aspects, namely, carbon accounting methods, green building design and life cycle assessment.

3.5. Analysis of research frontiers

Burst detection and analysis get many keywords with obvious citation burst characteristics. The earliest outbreak period (2017-2019) centered on "energy simulation" [11]. In 2020-2022, both green buildings and carbon emission reduction are very explosive [2, 5]. Since 2023, new keywords have emerged, namely, digital twin technology, carbon neutrality, machine learning, operation optimization and so on. It shows that the current research frontier is mainly the deep integration of

BIM and emerging digital technologies, and another important direction is the transformation to carbon management in the operational stage.

4. Discussion

This section mainly studies the specific application of BIM in carbon management. It contains the literature and the main challenges in the future.

4.1. BIM applications in carbon emission management of building projects

According to the review articles, BIM has different applications in different stages of the life cycle. BIM can calculate the hidden carbon of materials and compare with low-carbon schemes [6, 10]. During the construction process, BIM is linked with field data to track the emissions of equipment and transportation [11, 12]. For operation, BIM is used to establish an energy model to predict heating, cooling and lighting loads [12]. Other studies use BIM to plan the sorting and recycling of demolition waste [13, 14]. But the application in operation and demolition is much less than that in design and construction [1, 7].

4.2. Main challenges in current research and practice

Several challenges appear repeatedly in the literature.

First, the life cycle coverage is uneven. Most of the research focuses on design and construction. Operation and demolition are rarely taken seriously. According to the research of Liu et al [1], the current research mainly focuses on design and construction (48%). Only 10% pay attention to operation, and 6% pay attention to demolition. The carbon emissions of buildings in the operation stage account for more than 90% in the whole life cycle [7]. However, most of the current BIM applications only do energy simulation. Lack of dynamic connection with real operation data. There is a big gap between the forecast and the actual energy use [12]. It's still early to study demolition. Problems such as carbon accounting and recycling optimization of construction waste have not been solved. Most studies only quantify the demolition of garbage. They are not optimized for recycling emissions [15].

Second, data and technical issues. At present, the database coverage of building carbon emission factors in China is incomplete. It has weak regional specificity. Some new materials have no carbon element. Most of the factors are the national average. Can not reflect the regional differences [16]. In addition, BIM software can't work well with LCA tools or energy simulators. There will be data loss when exchanging. When the Revit model is imported into GTJ2018 for measurement, there will generally be a lack of component information and incorrect attributes [17]. Because of the format mismatch, manual data input is needed to combine BIM model with LCA tool. Increase the workload, there is a risk of human error.

Third, there is a lack of cross-stage data collaboration mechanism. BIM models are generally established independently for each stage. The designed carbon information cannot be completely transmitted to the construction. In the construction process, the field carbon data cannot be synchronized with the operation model. This produced "data islands" [18]. Therefore, carbon information cannot be continuously tracked or updated throughout the life cycle.

Finally, there is a lack of professional personnel. Few people in the field of architecture have both strong BIM skills and a deep understanding of carbon accounting, LCA tools and carbon policies [18]. Most practitioners only have skills in a certain field. There is no uniform standard for carbon

accounting based on BIM. Different projects and companies use different boundaries and methods. So the results are difficult to compare. Due to the high upfront cost and late economic returns, small and medium-sized companies generally do not adopt BIM. Therefore, BIM to reduce carbon emissions is mainly used in large-scale demonstration projects. It has not been widely used by the whole industry.

4.3. Future development trends

Based on our analysis, we can identify several future trends.

First, BIM can be combined with digital twins, Internet of Things and artificial intelligence. This will achieve the effect of real-time carbon monitoring and control [9, 12]. Second, the research will shift from new buildings to the transformation of existing buildings. The stock of old buildings is large [4, 18]. Third, carbon management in the operational phase will get more attention. This stage accounts for the largest amount of emissions [7]. Fourthly, develop a BIM carbon accounting framework. Fifth, policy incentives and training programs can alleviate the skill gap [18].

5. Conclusions

Bibliometric analysis was made on 500 CNKI papers on BIM and carbon emissions in construction projects (2016 -2026). CiteSpace was used for analysis [1]. The main results of the study are as follows.

First, "carbon emissions" and "green building" are the main research objects [4, 14]. Second, there are three stages in this field. They are exploration (2016–2019), rapid growth (2020–2023) and deepening (2024–2026). Third, emerging trends include the integration of BIM and digital twins, big data and carbon neutrality [9, 12]. Fourthly, the existing problems include uneven life cycle coverage, weak data collaboration, poor software compatibility and lack of standards [1, 7, 15-18]. We propose a full-life-cycle BIM carbon accounting system, better cross-stage collaboration, deeper tech integration, and focus on existing buildings and operation [4, 7, 18].

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