

Research Article

Mapping Knowledge Domain to Analyze the Building Information Modeling on Building Energy Saving Based on Visualized Analysis Method

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Building information modeling (BIM), as a novel knowledge field of modern engineering management, is bringing different degrees of changes to the construction industry from engineering practice to management concept. In order to analyze the research status of BIM in the field of energy-saving transformation, find its research hotspots, and reveal its future development trend to guide the practice and application of building information model better, the mapping knowledge domain is constructed via the literature visualization analysis method based on the theory of cocitation analysis and the pathfinder algorithm. This is to analyze the hot spots and reveal the frontier of building information modeling on building energy saving. This article lists journal articles and review articles included in the web of science database between 2012 and 2022, using the literature visualization analysis software Citespace to establish the knowledge graph of the collected literature, the scholars' collaboration analysis, the research institutions' collaboration analysis, the national collaboration analysis, the keyword co-occurrence analysis, the keyword cluster analysis, the time zone analysis, the keywords timeline analysis, and the literature cocitation analysis have been carried out and discussed. According to the analysis results, the research hotspots and future development trends are interpreted and discussed.

1. Introduction

BIM is a technology that visualizes the physical structure and functional characteristics of the whole life cycle of the construction engineering process and equipment and manages it according to its design, implementation, and operation. It is a technology and a means to realize data sharing, optimization, coordination, and control in the process of construction projects planning, design, implementation, and operation and maintenance [1].

BIM has been widely used in education, medical system, economic system, electrical and electronics system, traffic control, image processing and feature extraction, manufacturing and system modeling, forecasting and predictions, BIM enhancements, and social science [2]. The

application of BIM in the construction field is mainly in building site analysis, planning, program demonstration, visual design, performance analysis, engineering statistics, pipeline synthesis, construction schedule simulation, construction organization simulation, digital construction, completion model delivery, maintenance planning, asset management, space management, building system analysis, disaster emergency simulation, and other aspects [3]. BIM, as a new knowledge field of modern engineering management, brings different degrees of changes to the construction industry from engineering practice to management concept. Analyzing the research trend and hotspots of building information model in various fields is of great significance to strengthen the research of building information model and better guide the practice and application of building information model.

Scholars have conducted extensive research on the research status, hotspots, and future trends of BIM through literature visualization analysis technology. Xia et al. discussed the integrated application of GIS and BIM based on the keyword analysis, cocountry analysis, and cocitation and coupling analyses of the published papers by using Citespace application [4]. Wang et al. analyzed the collaborative network, co-occurrence network, and cocitation network of the collected articles and explored the body of knowledge on BIM-enabled facility management (BIM-FM) [5]. Wen et al. used cocitation analysis, cword analysis, and cluster analysis to analyze the data and drew the mapping knowledge domains by using literature visualization analysis technology to study the progress and trend of building information modeling based on 1369 relevant literature existing in the core database of “Web of Science” [6]. Zhang and Zhao explored that the development and evolution of building information modeling (BIM) technology by using the Citespace software, the research themes, cocitations, authorship, literature sources, and the development of the discipline over time were discussed, and the visual knowledge domain map was established [7]. Jing et al. used a combination of qualitative and quantitative methods to sort out 1543 BIM-related literature in the Cnki database from 2006 to 2020. The research hotspots and trends of BIM in China were discussed through a multidimensional analysis from literature statistics, research hotspots, and evolution trends by using the Citespace bibliometrics tool [8]. Zhu et al. analyzed mapping knowledge domains on the BIM from three aspects, namely research focus, knowledge base, and evolution trend based on the literature existed in the web of science (WOS) database and China National Knowledge Infrastructure (CNKI) database published from 2008 to 2016 by using the combination of qualitative and quantitative analysis methods and the visualization software Citespace [9]. Wang et al. discussed the evolution path, hotspots, research fronts of BIM research in the world by using the visual software such as SATI and Citespace based on 493 documents published in the core set Web of Science™ from 2005 to 2017 [10]. Wang et al. made a comparative analysis of the research progress and trends in the field of BIM at home and abroad based on the literature retrieved from the web of science database and CNKI database from 2010 to 2020 by using the visual analysis method [11]. Zhao et al. studied the development and evolution of BIM technology by mapping knowledge domains and information visualization based on the 806 articles published between 1998 and 2017 in the Web of Science by using Citespace. The research power distribution, knowledge base, research focus, and discipline impact were discussed by generating the maps of categories, journals cocitation, authors cocitation, literature cocitation, and discipline evolution in BIM research [12].

In order to analyze the research status of BIM in the field of energy-saving transformation, find its research hotspots, and reveal its future development trend, this work searches the journal and review articles included in the web of science database between 2012 and 2022. Then, the visual analysis technology is used to visually analyze the retrieved articles from scholars’ collaboration analysis, research institutions’

collaboration analysis, national collaboration analysis, keyword co-occurrence analysis, keyword cluster analysis, time zone analysis, keywords timeline analysis, literature cocitation analysis, and other dimensions. Finally, according to the results of the visual analysis of literature, this paper discusses the research status and future development trend of building information modeling on the topic of building energy saving and provides a reference for scholars’ research on this theme in the future.

2. Materials and Methods

2.1. Research Method. Scientometrics can measure the knowledge structure and development trend of the research field through quantitative analysis of scientific literature. In recent years, scientometrics has become one of the most common and effective methods to evaluate the research performance of individual researchers, departments, colleges, universities, countries, and journals [13]. Both bibliometrics and scientometrics take written productions as the object of metrology research, and the research methods of bibliometrics can also be used in scientometrics research. Regarding the bibliometric, analysis can be realized by cword analysis and cluster analysis, where cword analysis counts the number of occurrences of a group of words in the same group of literature and measures the affinity between them by counting the number of co-occurrences. Cword analysis can not only effectively reflect the correlation strength between information items in textual data but also directly map relevant literature according to the interaction of keywords. Therefore, keywords used to describe the content of the literature can be used as basic building blocks for the structure of the research domain [14] while cluster analysis in classifying individuals or objects in such a way that the cohesion between objects of the same class is stronger than that between objects of different classes. Cluster analysis calculates the affinity relationship between variables or samples according to the numerical characteristics of things and classifies the variables with strong homogeneity into one category, so the analysis results are intuitive, and the form of the conclusion is concise [15].

2.2. Data Sources. Bibliometrics is an interdisciplinary science that uses mathematical and statistical methods to quantitatively analyze all knowledge carriers, and its most essential feature is “quantity.” Therefore, bibliometrics can be used to analyze data texts related to various publications, such as journal articles, electronic publications, books, policy texts, and other relevant text data. However, high-quality research results in a field are mainly concentrated in professional academic journal databases, and the main text data objects of bibliometrics are journal papers. Therefore, all the data research texts selected in this work are from the Web of Science database.

2.3. Statistics on the Number of Annual Publications. The annual statistics of 1388 BIM literature related to building energy conservation were published, and the results are

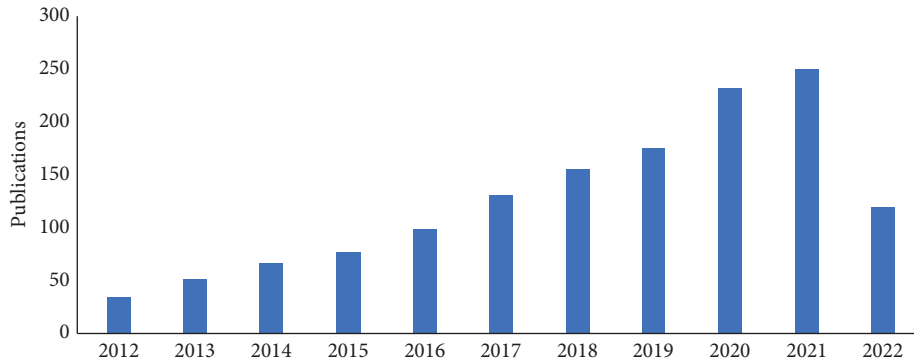


FIGURE 1: Bar chart of the number of annual papers published.

shown in Figure 1. A total of 1,388 related articles were published from 2012 to 2022, showing a steady growth trend overall. The number of publications in 2012 was not high, which was the initial stage of the field. From 2013 to 2021, the number of published articles increased year by year, and especially after 2019, the rising trend of the number of published articles accelerated, indicating that the research in this field has entered its climax. Furthermore, since 2022, there have been 120 articles published, so according to the current growth trend, the number of articles published is expected to grow further, indicating that the research in this field will continue to maintain a hot state.

3. Knowledge Map Visualization Analysis

3.1. Scholars' Collaboration Analysis. Citespace software is used for visual analysis of the collected literature data. The total number of papers published by the author reflects his academic status in this field, and the core author groups and their cooperative relationships reflected by the author's cooperative network were analyzed through the visual analysis of the knowledge graph of the author and the cooperative network. The results of the knowledge graph analysis of the author and cooperative network are shown in Figure 2. The font and node size represents the number of papers published by the authors, the lines between nodes represent the cooperative relationship between different authors, and the thickness of the lines represents the degree of cooperation.

In Figure 2, there are 1177 nodes and 1257 lines in the knowledge graph of author cooperation network, and the overall network density is 0.0018. From the analysis, it appears that there is no significant cooperation relationship between authors and the maximum number of articles published by the author is 5. Huanxin Chen, Jiayu Chen, and Burcin Becerikgerber are the top three authors with the most number of published articles.

3.2. Research Institutions' Collaboration Analysis. Citespace software is also used to analyze the research institutions' cooperation network on the collected literature data, mining the network relationship between research institutions in this research field, intuitively reflecting the

cooperation between institutions, and interpreting the spatial distribution of research forces in this field. The distribution network map of research institutions is shown in Figure 3. The node size represents the number of papers published by the research institution, the connection between nodes represents the cooperation intensity between different institutions, and the color of the connection represents the cooperation relationship in different time periods.

A total of 568 nodes and 556 links were included in the research sample of knowledge graph analysis of institutional and cooperative networks, and the network density was 0.0035. The main organizations in the picture have a tight cooperation network, and the ones with the most papers are successively Hong Kong Polytech Univ, Tsinghua Univ, and Tongji Univ. In terms of cooperation degree, Hong Kong Polytech Univ, Tsinghua Univ, and Natl Univ Singapore have high cooperation density, and the cooperation between foreign language research institutions is obviously relatively close. In order to deeply analyze the research institutions' achievements and cooperation relationship, further data mining was carried out in Figure 3, and the top ten research institutions with the number of publications are obtained as shown in Table 1.

3.3. National Collaboration Analysis. The distribution of study countries is analyzed to reveal the cooperation relationship between different countries. The visual view spectrum of intercountry cooperation network knowledge is shown in Figure 4. The size of nodes represents the number of academic articles published in the country, the connection between nodes represents the cooperative relationship between different countries, and the thickness of the connection represents the degree of cooperation. In Figure 4, there are 84 nodes and 105 connections, and the overall network density is 0.0301, with China as the largest research country, followed by the United States and Spain. The top ten high-yield countries can be seen in Table 2 through the statistics of the number of publications in different countries. China and the US are far ahead of other countries in terms of publication volume. From the perspective of centrality, there is a positive correlation between the number of publications and centrality in most countries, indicating that the international research in this field is relatively mature.



FIGURE 2: Author collaboration network.

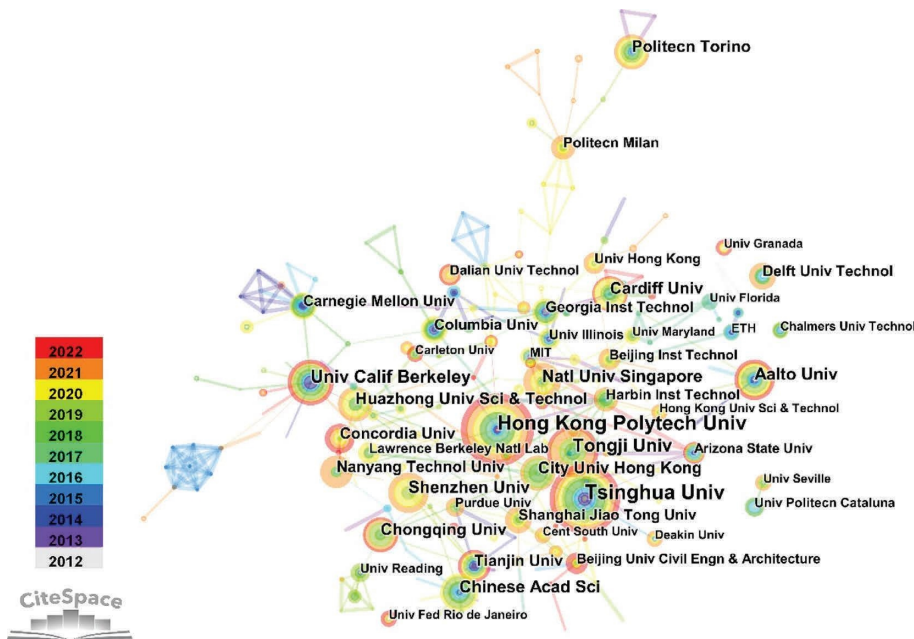


FIGURE 3: Organization collaboration network.

TABLE 1: The top 10 institutions with high production.

Ranking	Institutions	Year	Publications	Cooperation degree
1	Hong Kong Polytech Univ	2013	27	15
2	Tsinghua Univ	2013	26	18
3	Tongji Univ	2012	19	8
4	Univ Calif Berkeley	2012	17	12
5	Aalto Univ	2014	15	6
6	Shenzhen Univ	2019	15	9
7	Natl Univ Singapore	2017	14	13
8	Chinese Acad Sci	2013	14	10
9	Chongqing Univ	2016	13	6
10	Politecn Torino	2013	13	4

3.4. *Keyword Co-Occurrence Analysis.* Via Keyword Co-Occurrence Analysis, a total of 303 high-frequency keywords were found, forming 333 lines. The co-occurrence map of hot keywords in the literature is shown in Figure 5. In Figure 5, the size of nodes and fonts represents the frequency

of keywords; the lines between nodes represent the connections established in different periods; the thickness and density of lines represent the intensity of keyword co-occurrence; it can be seen that “energy conservation” is the largest node, followed by “BIM” and “energy

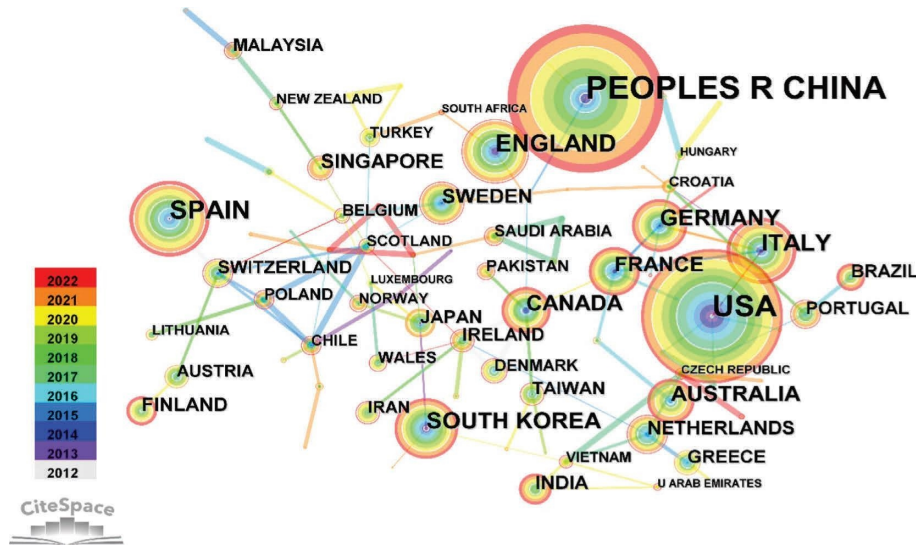


FIGURE 4: Spectrum of intercountry cooperation network knowledge.

TABLE 2: The top 10 states with high production.

Order	States	Papers	Cooperation degree	Starting year
1	Peoples R China	373	0.37	2012
2	USA	275	0.32	2012
3	Spain	111	0.1	2012
4	Italy	88	0.08	2012
5	England	83	0.09	2012
6	Germany	70	0.27	2012
7	South Korea	67	0.04	2012
8	Australia	58	0.05	2012
9	Canada	50	0.06	2012
10	France	42	0.19	2012

consumption.” In terms of time span, energy conservation, BIM, energy consumption, building, and building energy efficiency appeared earlier while recently, there have been indoor environmental quality, facility management, task analysis, HVAC system, urban building energy modeling, and other keywords. Those are likely to be hot spots for future research.

The mediating centrality of keywords is an important index to judge the research hotspots in this field, as well as an important basis to judge the focus of scholars. From the perspective of the intermediate centrality index (see Table 3), which represents the promoting effect of nodes, keywords such as “energy conservation,” “BIM,” and “building” communicate strongly with other hot keywords, indicating that they are often in the communication path with other keywords. This has a positive effect on the mutual citation relationship between literature.

3.5. Keyword Cluster Analysis. As an important part of academic papers, keywords are often used to study hot issues in a certain field. Citespace software and LLR (log-likelihood rate) algorithm were used for cluster analysis of keyword co-

occurrence to intuitively reflect the research hot topics. The keyword clustering view is shown in Figure 6 with the color block representing the clustering area while containing clustering keywords. The analysis resulted in the following values: node $N = 303$, connection number $E = 425$, and network density = 0.0093. The size of module Q is related to the density of nodes, the larger the value of Q is, the better the clustering effect will be, which can be used for scientific cluster analysis. The size of the average contour value S can be used to measure the homogeneity of the cluster. The larger the value of S , the higher the homogeneity of the network, indicating that the cluster has high credibility. As can be seen from Figure 6, $Q = 0.6018$, indicating that the network structure has a good clustering effect. With $S = 0.8677$, the homogeneity is high, and the different clusters are well divided. The figure shows ten clusters, led by “energy conservation,” “energy consumption,” and “machine learning.” The average years of the top five clusters are around 2014–2018, indicating that relevant studies were mature in this period. Among them, the largest cluster is “energy conservation,” in “2014,” which contains 31 keywords. The main keywords are energy efficiency, wireless sensor networks, office buildings, ontology, sustainability, etc.

3.6. Time Zone Analysis. In order to explore the development and evolution process of the research from the time dimension, this paper uses the time zone diagram of Citespace tool to analyze it. From the perspective of space and time, the time zone diagram clearly displays the update of literature keywords and the relationship between literature in the two-dimensional coordinate with time as the horizontal axis, as shown in Figure 7. In the time zone diagram, the size of the node represents the frequency of the keyword, the year of the node represents the time of the first appearance of the keyword, and the line between nodes indicates that different keywords appear in the same article at the same time, indicating the inheritance relationship and evolution process between different periods. Combined with

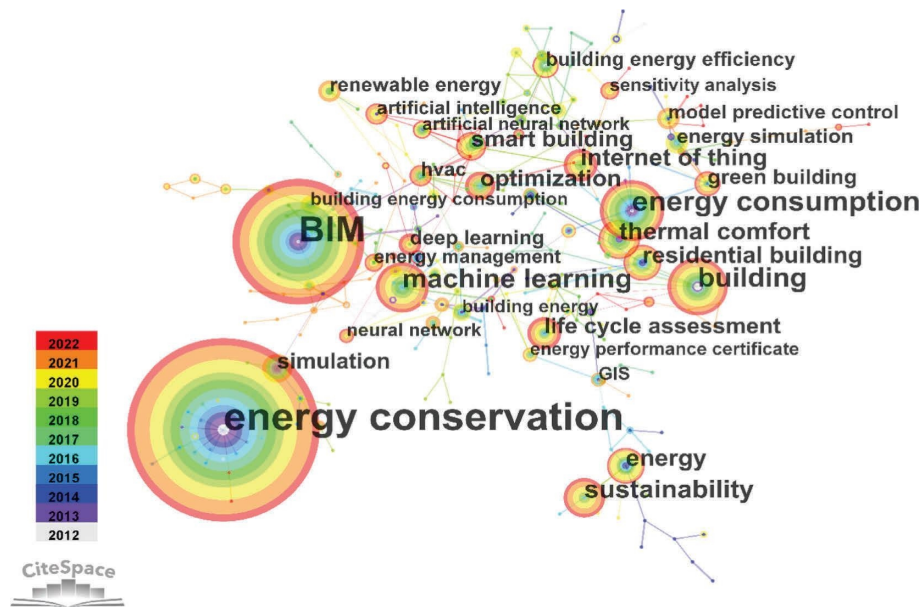


FIGURE 5: Keyword co-occurrence network.

TABLE 3: The top 10 mediating centralities.

Ranking	Keywords	Frequency	Mediating centrality
1	Energy conservation	304	0.72
2	BIM	164	0.39
3	Building	46	0.13
4	Energy consumption	52	0.08
5	Machine learning	42	0.07
6	Energy	25	0.05
7	Internet of thing	26	0.03
8	Sustainability	34	0.03
9	Optimization	24	0.03
10	Artificial neural network	10	0.03

the number of articles published over the years, it can especially explore the main focus of the hot period of research, but also can explain the period or stage of the field. As can be seen from Figure 7, the most prominent and largest node in the relevant literature is “energy conservation” proposed in 2012, and the high-frequency keywords in the early research include BIM, building, and energy consumption. The related concepts of the research span a long period and influence a wide range, while the early research laid the foundation for the related research concepts. Also, recent concepts are proposed such as facility management, urban building energy modeling, and other new keywords.

3.7. Keywords’ Time Line Analysis. Frontier trend analysis mainly relies on cocitation clustering and citations to describe the transition situation and research nature of a certain type of research field. As one of the main views of Citespace, the Timeline graph tiles the literature keywords clustering on a two-dimensional timeline, providing a reference for researchers to explore the evolution process and frontier trends of a topic clustering, as well as the relationship between hot topics. As can be seen from Figure 8,

the largest cluster of relevant literature is “energy conservation,” which contains 31 keywords, and the average year is 2014. The keywords included energy conservation, algorithm, and agent based on simulation proposed around 2012. Over time, keywords included themes such as “building envelope” and “ontology.” This cluster mainly focuses on the research evolution of energy conservation. In this cluster, the literature that fits most with clustering keywords is Kim et al. [16]. It has rich connections with BIM, residential building, and other clusters, indicating that multitheme co-occurrence occurs in it to a certain extent.

3.8. Literature Cocitation Analysis. The literature cocitation analysis is shown in Figure 9. The results show that there are a total of nodes $N=405$, the number of connections $E=1220$, and the network density = 0.0149, forming several significant cocitation relationships. Among them, the largest are Pérez-Lombard et al. [17], Swan and Ugursal [18], and Zhao and Magoulés [19], which are cited with high frequency, indicating that they have an important influence in this field. In addition, according to the centrality of literature cocitation, it can be found that Zhao and Magoulés [19], Pérez-Lombard et al. [17], and Basbagill et al. [20] have high centrality, indicating that they are often cited as classical references in the same literature, which is of great significance for the analysis of their cohesive effect.

4. Basic Analysis of Energy-Saving Transformation in Old Residential Areas in Southern Shaanxi

The renovation of old urban communities is a major livelihood project that China attaches great importance to. It is of great significance to meet the needs of the people for a better life, promote the well-being of the people and

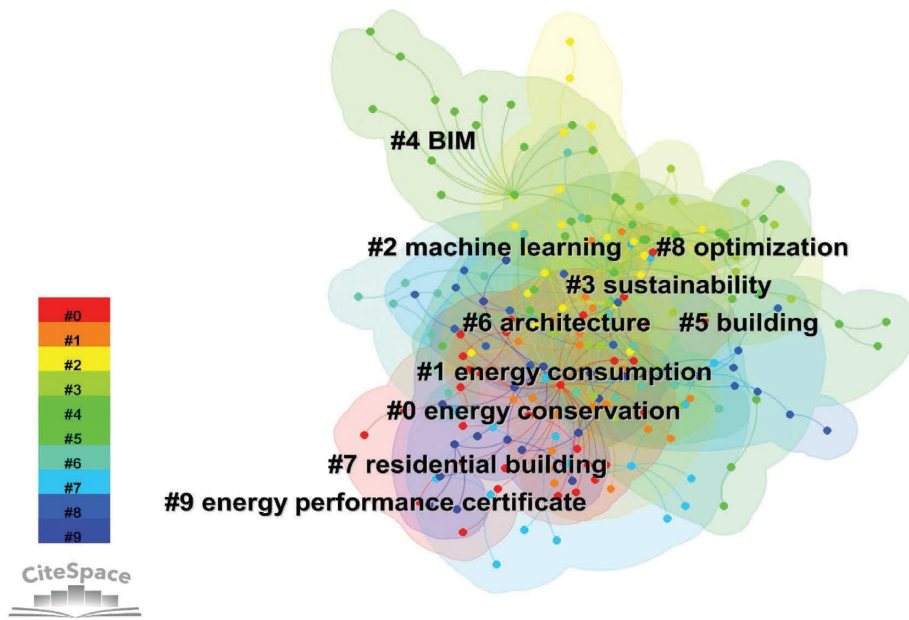


FIGURE 6: Keyword clustering map.

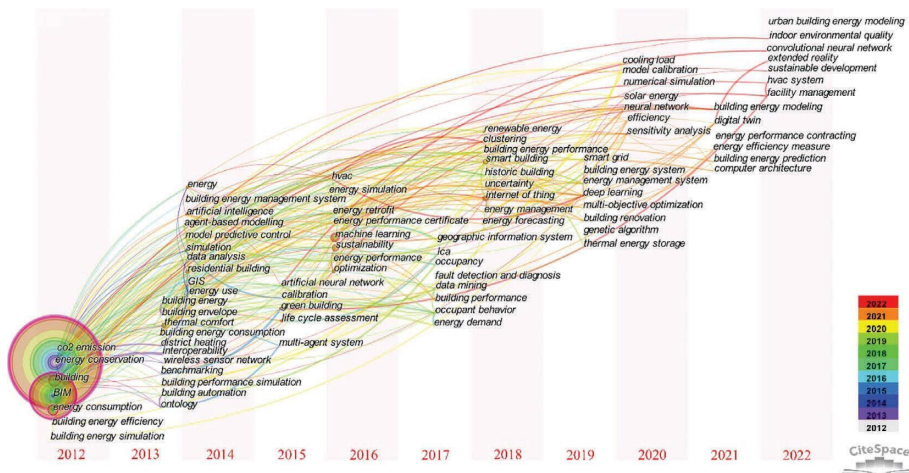


FIGURE 7: Keywords occurrence time slice diagram.

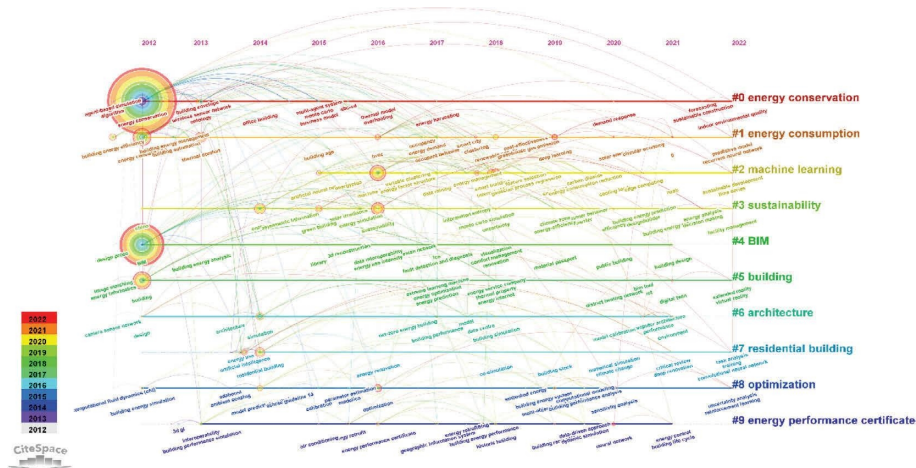


FIGURE 8: Keywords timelines diagram.

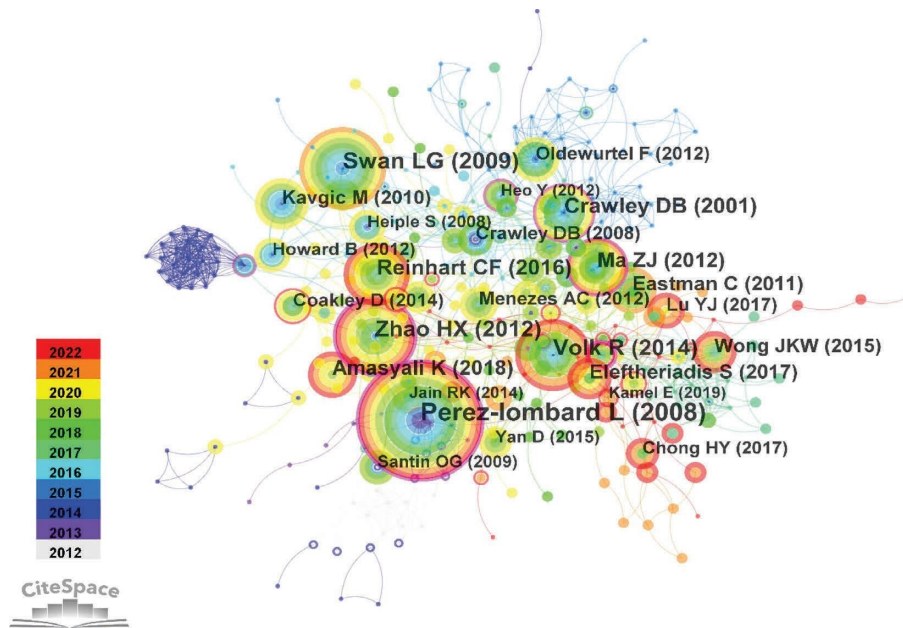


FIGURE 9: Literature cocitation network.

expand domestic demand, promote the transformation of the mode of urban renewal and development and construction, and promote high-quality economic development. Dahekan Town, Nanzheng County, Hanzhong City, through the basic investigation and survey to analyze the current situation of the old residential area renovation project and focus on building appearance renovation, roof renovation, external renovation, windows and doors renewal, and other aspects, at the same time will be using BIM technology to optimize all aspects of the planned transformation.

4.1. Energy-Saving Transformation Object. The old residential area of the ICBC family building is located in Dahe Kan Town, Nanzheng District, Hanzhong City, 800 m to the north of Hanzhong Stadium, Tianhan Avenue. The compound was completed in 2000, with a total of 2 buildings, involving 60 households, and a total area of about 70,300 square meters.

4.2. Site Visit and Demand Survey. The current situation of the ICBC family building is shown in Figure 10. Through the field survey of the community, we found that the houses are in disrepair, the supporting facilities are defective, and the environment is dirty and disorderly. And the final report was shared with the community and property management to clarify the main problems of the community which are as follows:

(1) The outer wall layer of the building falls off, and the energy-saving effect is not up to the standard; (2) the wall in the stairwell falls off, the bright line is disorderly, and the railing handrail is seriously corroded; (3) the phenomenon of “running, leaking and blocking” is serious; (4) flat roof leakage and waterproof aging.

5. Preliminary Study on Transformation Scheme

5.1. Comprehensive Treatment. Illegal construction parts are removed, such as self-built houses built on the first floor, self-built houses built on the terrace, and self-built bay Windows.

5.2. Preliminary Analysis of Comprehensive Reconstruction Measures

- (1) Remove all the guardrails outside the Windows: all the guardrails outside the windows should be removed at the time of energy-saving transformation, and the construction closure of the external thermal insulation board should be completed. The guardrails that do not project out of the walls should be installed in the outer windows of the first-floor households in accordance with the “Construction Quality Acceptance Code for Building Energy Conservation Engineering” (GB 50411).
- (2) Roof renovation: new roof insulation, waterproof, replace the slope roof tile, solve the roof leakage; repair the lightning protection and grounding facilities on the roof to prevent the building from being struck by lightning.
- (3) External wall renovation: new external wall insulation, reduce indoor and outdoor heat conduction, reduce unit thermal energy consumption, and in order to achieve the expected 65% energy-saving standard, energy conservation renovation needs to closely combine the current situation and the specific problems of each building to deal with.



FIGURE 10: Current situation of the old residential area of industrial and commercial Bank of China.



FIGURE 11: Schematic diagram of building style transformation of ICBC.

- (4) Door and window transformation: the outer window of the household should be replaced with a plastic steel energy-saving casement window, and the outer window of the staircase replaced with a plastic steel energy-saving push-pull window to improve the thermal insulation and shading performance of the outer window; replace the unit door with steel insulation antitheft unit door and install access control system.

The schematic diagram after transformation is shown in Figure 11.

Dahe Kan Town buildings as a typical representative of the reconstruction of old residential areas, the goal of the reconstruction of Dahe Kan Town buildings is to optimize the environment quality and achieve energy conservation and emission reduction. This paper analyses the research status and future trend of BIM in building energy conservation and provides a reference for the subsequent transformation of Dahe Kan Town buildings by using BIM technology. At present, the preliminary scheme design of the transformation of the ICBC family building located in Dahe Kan Town has been completed based on the above analysis. In the future, more attention should be paid to the building energy saving, the design of the whole life cycle of the building, and the experimental simulation and verification [1, 21]. BIM should be further adopted to establish building information model to design and improve energy-saving renovation. At the same time, BIM should be further adopted to establish its building information model to design and improve energy saving so as to better achieve the building energy-saving and emission reduction-transformation targets.

6. Conclusions

In order to analyze the research status of BIM in the field of energy-saving transformation, find its research hotspots and reveal its future development trend to better guide the practice and application of building information model. The Mapping Knowledge Domain is constructed via the literature visualization analysis method based on 1,388 related articles published from 2012 to 2022 existing ed in the WOS database. With the type of article and review. Scholars' Collaboration Analysis, Research Institutions Collaboration Analysis, National Collaboration Analysis, Keyword Co-Occurrence Analysis, Keyword Cluster Analysis, Time zone analysis, Keywords timeline analysis, and Literature Cocitation Analysis are discussed via the comprehensive analysis of building information modeling on building energy-saving literature data by Citespace with the following conclusions.

- (1) There are three main stages, 2012 was the initial stage of the field. From 2013 to 2021, the number of published articles increased year by year, and especially after 2019, the rising trend of the number of published articles accelerated, indicating that the research in this field has entered its climax.
- (2) The overall network density of knowledge graph of author cooperation network of 0.0018 indicated no significant cooperation relationship among authors. Looking at the cooperation between research institutions, Hong Kong Polytech Univ, Tsinghua Univ, and Natl Univ Singapore have high cooperation density, and the cooperation between foreign language research institutions is obviously relatively close.

- (3) China and the US are far ahead of other countries in terms of publication volume. From the perspective of centrality, there is a positive correlation between the number of publications and centrality in most countries.
- (4) The keywords are as follows: energy conservation, BIM, energy consumption, building, and building energy efficiency appeared earlier. While recently, new ones such as “indoor environmental quality,” “facility management,” “task analysis,” “HVAC system,” “urban building energy modeling,” and other keywords have been introduced showing that may be a new direction for future research. Zhao (2012), Perez-lombard (2008), and Basbagill (2013) exhibit high centrality, indicating that they are often cited as classical references in the same literature, which is of great significance for the analysis of their cohesive effect.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of financial interest.

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