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EXPLORING THE DRIVING MECHANISM AND PATH OF BIM FOR GREEN BUILDINGS

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Abstract. Despite green building and BIM technology being hot spots in the construction industry, most research remains at the technical level. Leading to exploring the fundamental driving reason and mechanism of BIM for green buildings is still lacking. This paper explored BIM's impact mechanism and driving path on green buildings from the management's perspective to fill this gap. Based on a literature review, 18 expert interviews, and three case studies of green buildings, the influence mechanism was analysed via a qualitative method (ISM). Then, the importance of driving factors was evaluated via quantitative analysis (ANP). Specifically, this study probed the driving path by combining qualitative and quantitative analysis (ISM-ANP). The research findings show that the driving force of BIM for green buildings comes from the fundamental factor layer and is transferred to the intermediate and direct factors layer. The critical driving path of BIM for green building is to promote the visualization of building information, collaborative management, and expand real estate investment through the guidance of policies and standards. Based on research results, this paper puts forward five suggestions: 1) Improving the policy and standard system; 2) Striving to research native software; 3) Adopting an informatization project management mode; 4) Accelerating the construction and improvement of the green building industry chain; 5) Promoting government enterprise cooperation. These results may benefit not only the coupling and coordination of the two but also the construction industry's green transformation and high-quality development.

Keywords: green building, BIM, driving mechanism, driving path, ISM, ANP.

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1. Introduction

Industrial civilization promoted the development of human society while simultaneously caused massive damage to the natural environment. Among them, the production activities of the construction industry consumed a large number of natural resources. The construction industry accounts for 36% of global energy consumption (Khalil et al., 2022). In recent decades, concepts such as "green building" and "ecological city" have become widely known. Green building is also called sustainable building and energy-saving building. Green buildings can save resources, protect the environment, reduce pollution, provide humans with healthy, comfortable, and efficient use of space, and maximize the harmonious coexistence between humans and nature (Zuo & Zhao, 2014). Creating a comfortable, healthy, low-energy-consumption, and pollution-free living environment through scientific design, which have become mainstream trends in the construction industry (Gou & Xie, 2017). The implementation of smart city, low-carbon eco-city and green building projects can alleviate urban heat island effect (He et al., 2019). The smart city spatial architectural layout planning can be optimized under the background of ecological environment (Chen, 2021). Green roofs and green walls are conducive to energy conservation, noise reduction, gray water treatment, and increase the longevity of enclosure (Manso et al., 2021).

However, green buildings have exposed many problems in engineering practice. For example, systematic information management is lacking in the whole life cycle of green buildings, restricting the effectiveness of project management (Chan et al., 2018). High technology, materials, and consulting costs lead to an expensive green building project budget (Hwang & Tan, 2012). The inapplicability of evaluation methods and lack of data support lead to unreliable evaluation results of green buildings (Zhang et al., 2019). Fortunately, the emergence of BIM technology provides an excellent way to solve these problems in engineering practice. BIM has various powerful functions, such as visualization, collaboration, and simulation, which make it develop rapidly and has a high coupling with green buildings (Zhang et al., 2017).

BIM is an efficient information-integrated management tool that can significantly improve the quality and efficiency of green building life cycle management, as shown in Figure 1. In the early planning and design stage of green buildings, BIM can provide a reliable decision-making basis for site layout and traffic flow organization design (Deng et al., 2016). BIM can also realize pipeline collision detection, indoor lighting and ventilation conditions, and energy consumption simulation analysis (Lu et al., 2017). In the construction stage of green buildings, BIM is mainly used for testing design standards and a series of construction management, such as construction progress, cost, quality, and safety hazard investigation based on BIM 3D models (Zhao, 2017). In the operation and maintenance stage of green buildings, the combination of BIM, the IOT, cloud computing, and other technologies can realize carbon emission calculation and real-time analysis of operation energy consumption, providing an optimization plan for building operation management (Tang et al., 2019; Li et al., 2022). In the demolition stage, the application of BIM helps managers formulate reasonable demolition plans and efficiently recover reusable resources (Cheng & Ma, 2013).

Both BIM and green buildings optimize design, construction, operation and maintenance based on the information in the whole life cycle of the building. The combination of green building and BIM (Green-BIM) provides a standardized framework for project decision-making processes and methods to improve the green performance of buildings (Liu & Wang, 2022). Green building provides a platform for BIM to showcase its advantages, and BIM provides data and technical support for green building. The two have shown a coupling trend in their respective development process, but existing research focuses on the field of technology application. This paper aims to explore the driving effect of BIM on green buildings from the perspective of management. Explore the adaptability of BIM technology throughout the entire lifecycle of green buildings, reveal the value driving points of BIM throughout the entire lifecycle of green building projects, and analyze its driving forces. Enrich the theoretical research on applying BIM in green building projects, provide a decision-making basis for project managers, and improve the management performance of green building projects.

2. Literature review

Nowadays, more and more attention has been paid to applying BIM in green buildings. Marzouk et al. (2022) indicated that an effective BIM-based decision-making framework could help achieve sustainability targets and mitigate the negative impacts of the construction industry. AlSaggaf and Jrade (2023) created a 3D model to conduct the selection of architectural orientation, site layout, and traffic streamline organization design. Navisworks was used to conduct collision detection on the pipeline (Sun et al., 2021). Liu et al. (2019) proposed a safety detection method that combined UAV with dynamic BIM and verified the feasibility of this method in safety assessment by a real diversion project case. Zhao and Gao (2022) proposed a BIM-based energy-saving design method for green buildings, and the research results show that the method has good feasibility and effectiveness. During the construction phase, a BIM-progress model was established to monitor and control the construction progress (Li et al., 2017), and a BIM-cost model was used to monitor construction costs dynamically (Vigneault et al., 2020). Chen and Luo (2014) identified that BIM-based green building construction quality management is more reliable and effective. BIM-WMS plugin is verified in the effectiveness of the building materials comparison and selection; the tool can be used as a decision support tool for supply chain management (Chen & Nguyen, 2019). In the operation phase, building operations' real-time energy consumption was calculated via a cloud computing platform (Desogus et al., 2021). During the demolition phase, a BIM-based system is used to estimate and plan for the demolition and renovation of the building (Cheng & Ma, 2013).

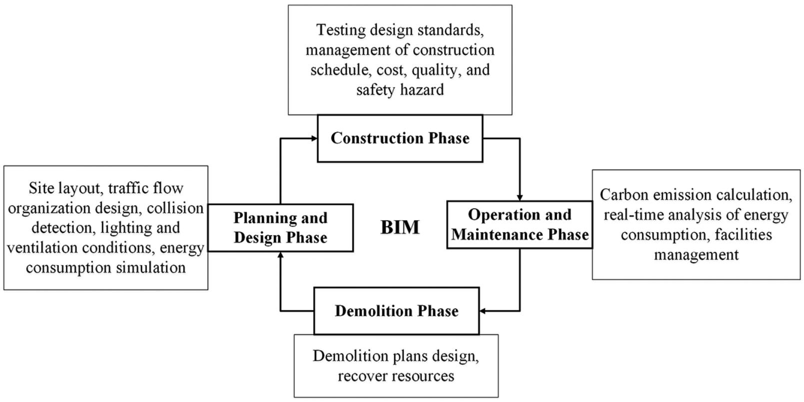

Figure 1. Potential intervention of BIM in the life cycle of green building

According to the Table 1, it is found that the application of BIM in green buildings involves the whole life cycle of the project. At the same time, the existing research focuses on putting forward some conceptual framework or solutions from the technical perspective to solve the practical problems in the construction process, including design optimization, schedule, quality, and cost management in the construction stage, facility management, energy consumption monitoring in the operation and maintenance stage, and material recycling in the demolition stage.

Moreover, many scholars have explored the evaluation of green buildings. Shukra and Zhou (2021) demonstrated that BIM integrated with assessment tools for design optimization could improve environmental sustainability and thus fulfill green requirements. The "Green BIM Triangle" taxonomy confirmed the applicability of BIM in green building assessments (Lu et al., 2017). BIM can be combined with other tools to improve the performance of green building evaluation (Solla et al., 2016), such as blockchain, IoT, and BDA can improve BIM-GBCS integration (Olanrewaju et al., 2022). Liu et al. (2020) developed a cloud-based BIM platform for calculating the Envelope Thermal Transfer Value (ETTV) and verified that the platform could enhance productivity and accuracy as far as ETTV calculation. Kreiner et al. (2015) identified that integrating LCA into BIM is a way to improve the sustainability performance of buildings. In addition, BIM tools combined with value engineering can significantly optimize the design and meets the requirements of green building evaluation and owner (Wei & Chen, 2020). Another intelligent approach based on domain ontology and BIM was confirmed, which greatly improved the efficiency and accuracy of green building evaluation via automatic reasoning (Jiang et al., 2018). In addition, there is a high level of maturity and interoperability between BIM and BIM-related tools (Zou et al., 2017). Through the API plug-in interface, the 3D model can smoothly transfer the required project information between various BIM tools, realizing effective data integration at all phases of the green building's life cycle (Oti et al., 2016). Based on the 3D model and the extracted project information, the performance analysis and evaluation of green buildings can be carried out. Moreover, through effective data interoperability and accurate energy analysis, the integration of LEED and BIM has been proven to simplify the certification process for green buildings (Azhar et al., 2011). Guo et al. (2021) proposed a green building evaluation system by integrating BIM and BIM-related tools, and the results proved that natural ventilation and occupant activity control strategies play a crucial role in the energy efficiency of green buildings. Rehman et al. (2023) demonstrated that BIM is beneficial for energy analysis of green buildings through parametric building models to avoid potential data exchange and interoperability issues and cross-verified the authenticity of the obtained results using three different platforms.

Other existing studies have analyzed the effectiveness of BIM in project management. Based on the parameter values and economic indicators provided by BIM technology, it can realize factual decision-making and improve the process efficiency of all project stages (Doumbouya et al., 2016). According to the statistical test, Mesaros et al. (2022) has verified that using BIM can increase the productivity of construction projects and thus improve project management performance. A study from Lai et al. (2019) shows that collaborative design based on the BIM platform can improve the convenience of communication between disciplines and improve project management performance. Bryde et al. (2013) has analyzed 35 construction projects managed by BIM, and the results show that cost

Table 1. Literature review of BIM application in green buildings

Authors	Stages	Applications
Marzouk et al. (2022)	Full Life Cycle	A BIM-based decision-making framework for sustainable development
AlSaggaf and Jrade (2023)	Planning and design	SLP model for rule-based dynamic conflicts detection in 2D and 3D, route planning and hauling, and spatiotemporal analysis all in one environment
Sun et al. (2021)	Design	A simulation system for material collision detection of buildings
Liu et al. (2019)	Operation and maintenance	An overall workflow for dynamic BIM-augmented UAV safety inspection
Zhao and Gao (2022)	Design	The method for energy-saving effect evaluation
Li et al. (2017)	Construction	A radio frequency identification device (RFID)-enabled BIM platform can supervise the construction statuses and progresses in real-time
Vigneault et al. (2020)	Construction	A framework of 5D BIM solutions for construction cost management
Chen and Luo (2014)	Construction	4D BIM application for quality control during the construction phase
Chen and Nguyen (2019)	Construction	A BIM-WMS integrated decision support tool for selecting sustainable construction material sources and calculates location-related credits in some green building standards, such as LEED
Desogus et al. (2021)	Operation and maintenance	A common data platform for visualization of indoor building conditions and energy consumption simulation
Cheng and Ma (2013)	Demolition and renovation	A system can extract material and volume information through the BIM model and integrate the information for detailed waste estimation and planning, waste recycling, and reuse

reduction and control is the most significant advantage of using BIM. Tserng et al. (2014) verified that the progress management system based on BIM could improve the control and management efficiency of the general contractor on the project. Chen and Luo (2014) built a construction quality management model based on BIM and confirmed that BIM technology is suitable and helpful in improving project quality compliance management through a case operation. In addition, some studies demonstrated that BIM has significant management benefits in terms of facility management (Leygonie et al., 2022) and energy simulation analysis (Gerrish et al., 2017; Li et al., 2020) during the operational phase.

At the same time, other studies illustrated the obstacles to applying BIM in green buildings. Wu and Issa (2015) proposed a BIM project execution planning guide for green buildings, but it needs more quantitative verification and addresses the use of open standards such as IFC. The application value of BIM is fully achieved in the design stage but has declined in the construction and operation stages, and BIM is suffering challenges from its diffusion and popularization among the public (Wen et al., 2020). Wong and Zhou (2015) figured out that most green-BIM research focuses on environmental performance at the building lifecycle's design and construction stages. Technology, management, economy, and social environment are the most urgent macroscopic barriers to applying BIM in green buildings. From the micro perspective, the barrier includes BIM standards, information interaction, BIM technical training for employees, etc. (Huang et al., 2021). Volk et al. (2014) noticed that architects, engineers, and contractors played a major role as early adopters of BIM technology. Nevertheless, owners, facility managers, and related consultants are hardly involved in the BIM functionality development.

Most previous studies focused on technical application instead of macroscopic management. The effectiveness of BIM in project management has been confirmed. However, in what ways can BIM have a positive impact on green buildings? How does BIM play a positive role? How can BIM be used to improve project performance in green buildings? These studies are of great help to managers in making project decisions. Nevertheless, the impact mechanism of BIM for green buildings is still unclear, which will restrict their development. Meanwhile, management research in construction has widely applied the ISM model and ANP method (Chang et al., 2013; Digalwar et al., 2020; Kumar et al., 2020). Existing research has shown that the combination of these two methods has high applicability in analyzing the mechanism of action and quantitatively evaluating indicators. However, applying these two methods in this research direction is insufficient. Therefore, this study deeply analyzed the driving mechanism and driving path of BIM for green building via the fuzzy interpretation structure model (ISM) and the analytic network hierarchy process (ANP) from the management perspective, which is of great significance to the sustainable development of the construction industry.

3. Methodology

This study mainly includes the identification of driving factors, analysis of driving mechanism, weight calculation of driving factors, and analysis of driving path. Firstly, text mining and grounded theory are used to identify the driving factors of BIM for green buildings. Secondly, the driving mechanism of BIM to green buildings is discussed through the fuzzy ISM model. Thirdly, the weights of driving factors are calculated by the ANP method. Finally, the driving path of BIM to green buildings is analyzed through ISM-ANP. The main process is shown in the Figure 2.

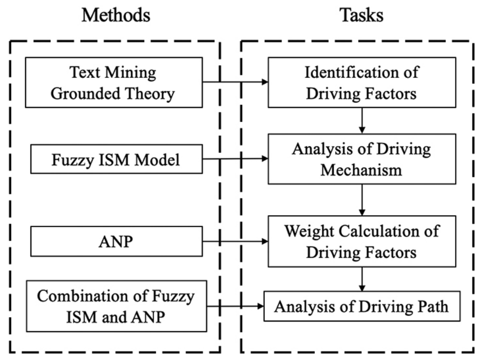

Figure 2. Research process

3.1. Identification of driving factors

ROST CM software has the functions of text segmentation, word frequency analysis, and text semantic analysis. It can mine high-frequency words and analyze the meaning of words in the context, which is beneficial for researchers to extract core information from a large number of texts (Zhang & Yang, 2021). In this study, as shown in Figure 3, ROST CM software analyzed the text data collected from literature, construction companies, and official websites of relevant national departments in China. The factors affecting the development of green building is explored based on text mining. Then, the grounded theory (Wolfswinkel et al., 2013) was used from the perspective of BIM technology, 2/3 of the collected qualitative texts were randomly selected, and further semantic analysis was carried out through NVIVO software to determine the driving factors of BIM for green buildings. NVIVO (Zamawe, 2015) has a powerful coding function to conceptualize and categorize the original statements. The theoretical basis of NVIVO software operation is grounded theory, which coincides with the method in this study.

The research content of this study is based on the application of BIM technology in green buildings, which has a specific purpose. Thus, the procedural grounded theory is adopted, which mainly includes three steps: open coding, axial coding, and theoretical saturation test. Open coding is the operation process of breaking up the original text data, giving concepts respectively, and then combining them in a new way. The primary purpose is to develop concepts and refine categories (Leahy, 2008). As shown in schematic Table 2, the table's contents show how to summarize the core themes in the original sentences into conceptualized words and the process of cognitive categorizations. Each category obtained through open coding still has problems, such as logic ambiguity and lack of primary and secondary correlation. Therefore, it is necessary to build a core skeleton through axial coding, connect each independent category, and explore the correlation between each category (Kendall, 1999). The schematic of axial coding is shown in Table 3. Selective coding is to determine the critical core concept categories with strong correlation ability by analyzing many concept categories and their internal relations. Selective coding can be more closely related to other conceptual categories to express the internal logic of the relations more effectively and finally complete the interpretation of the whole theory (Strauss, 1987). Selective coding is mainly used to construct theories and describe the mechanism of action among the main categories (Pitney, 2002; LaRossa, 2005).

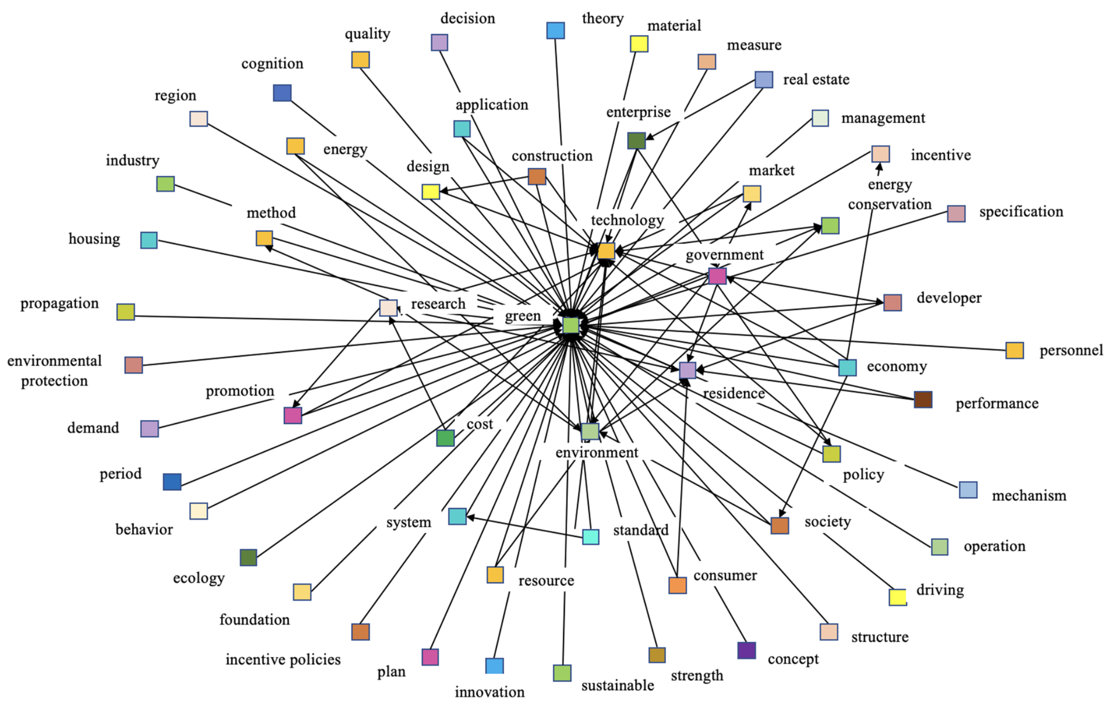

Figure 3. Social and semantic network analysis diagram

Table 2. Open coding of driving factors based on grounded theory (part)

Categorizations	Original statement
N1 Design level	R01···Based on the visualization BIM information platform, relevant parameters are debugged to optimize the shape design of buildings, thereby improving the quality and efficiency of architectural design and making building products more aligned with user needs.
	R02···In the design of architectural schemes, BIM technology can also be used to carry out a detailed analysis of the whole and part of the building, improve the design scheme and enhance the efficiency of the design work.
	......
N2 Construction level	R03···The computer simulation and analysis software based on BIM technology is used to monitor the construction progress of the building structure and simulate the construction progress and construction site layout to quickly adjust the construction scheme, reduce the difficulty of project managers to carry out construction site organization and management, and improve construction quality and efficiency.
	R04···The analysis and collision inspection of electromechanical pipelines based on BIM technology can reasonably arrange the electromechanical pipelines of buildings, formulate scientific construction plans, and monitor them in real-time during construction to build green buildings with high quality and efficiency.
	......
N3 Operational level	R05···The 3D building information model based on BIM technology can quickly locate the corresponding position in the building, extract component information, and complete rapid maintenance; BIM technology can also be used to monitor the operation of construction equipment in real-time to improve the level of building operation and maintenance management.
	R06···BIM model is combined with energy consumption analysis software to analyze building energy consumption and conduct real-time monitoring and analysis of energy consumption during building use, which can significantly improve the energy efficiency of green buildings in the operation and maintenance stage.
	......
......	......

Table 3. Axial coding of driving factors based on grounded theory (part)

Main categories	Initial categories	Connotation of categorical relationships
Technical level factors	Design level	It is conducive to innovating traditional design ideas, improving design efficiency, and optimizing design schemes.
	Construction level	It helps to ensure the quality of green building construction and the organization and management of construction sites.
	Operational level	By utilizing BIM technology, it is helpful to conduct energy consumption analysis, emergency management, and optimization of operation and maintenance management plans during the operation of green buildings.
	......	......
......		

However, there is no need to form a theory in this study. The fuzzy ISM model will have analyzed the mechanism of action in this study, selective coding is not carried out here. The text data is analyzed qualitatively through open coding and axial coding, repeated in-depth induction, and refinement.

Ultimately, a total of 20 driving factors were obtained. Moreover, the remaining 1/3 of the text data was analyzed through the same method, and results show that the categories in the model have developed very richly, and no more new categories and relationships have been found. Therefore, the conceptual model constructed in this paper is theoretically saturated, and the driving factors of BIM for green buildings are shown in Table 4.

3.2. Construction of the Fuzzy ISM model

In the driving factor system of BIM for green building, the relationship between various driving factors is very complex, not just whether there is a correlation. Therefore, the fuzzy matrix in fuzzy mathematics is introduced to improve ISM. When comparing and judging two pairs of driving factors, a fuzzy number replaces the single "0" representing no correlation and "1" representing correlation. The values within [0, 1] are used to more scientifically describe the correlation strength between driving factors and reduce differences in judgment and extreme bias among experts (Yadav et al., 2020). Therefore, the fuzzy ISM model is used in this study to transform the confusing relationship among various driving factors into a straightforward hierarchical relationship.

Step 1: Fuzzy evaluation of driving factors.

Eighteen experts were invited to score the system elements, including six experts from universities related to engineering construction and real estate research; six practitioners from engineering construction, real estate companies, and BIM consulting fields; and six doctors in management. The demographic factors of participants are shown in Table 5. Perform mean arithmetic processing on the scoring results of 18 ISM group members and obtain the fuzzy adjacency matrix of this study (Yadav & Singh, 2021).

Step 2: Construct the correlation strength matrix B.

The essence of the correlation strength matrix is a process of cluster analysis. The correlation strength matrix B is calculated through the membership function b, and the elements with similar functional characteristics are grouped into one class. The calculation formula of b_{ij} in matrix B is:

$$b_{ij} = \frac{f_{ij}}{\left(f_{i\cdot} + f_{\cdot j} - f_{ij}\right)}, \tag{1}$$

where b_{ij} is an element of correlation strength matrix B; f_{ij} is an element of the fuzzy adjacency matrix F; $S_{fi\cdot}$ is the sum of the elements in row i of the fuzzy adjacency matrix F; and $S_{f\cdot i}$ is the sum of the elements in column *j* of the fuzzy adjacency matrix F.

Step 3: Construct the adjacency matrix A.

The element a_{ij} in the adjacency matrix A needs to be determined by setting the threshold λ, which converts the correlation strength matrix B to the adjacency matrix A. It is worth noting that the value of the threshold λ will directly affect the hierarchical division of the driver system. Generally speaking, the number of layers divided by the fuzzy ISM interpretation structure model is 5 to 8, which is more scientific and reasonable (Tavakolan & Etemadinia, 2017).

In this study, through repeated trial and error calculation, it is found that the level division is the most reasonable when λ is in the range of 0.03–0.04. Finally, λ = 0.039 is selected, and the driving factor hierarchy in this study is divided into seven layers. The formula for determining element a_{ij} in the adjacency matrix A is:

$$a_{ij} = \begin{cases} 1, & b_{ij} \geq \lambda \\ 0, & b_{ij} < \lambda \end{cases}. \tag{2}$$

Step 4: Calculate the reachability matrix.

The reachability matrix M describes the reachability of one element to another element in the system. Based on the adjacency matrix A and the identity matrix I, the reachable matrix M can be calculated according to the Boolean operation rules shown in Eqns (3) and (4):

$$\left(I + A\right)^{w} = I + A + A^{2} + \cdots + A^{w}; \tag{3}$$

$$M = \left(I + A\right)^{w-1} = \left(I + A\right)^{w} = \left(I + A\right)^{w+1}. \tag{4}$$

Step 5: The computation of the reachability set and antecedent set.

In order to classify the hierarchy of driving factors, the reachability set, antecedent set, and intersection set should be solved based on the reachability matrix obtained above. Further details can be found in Appendix (Tables A1 and A2).

Table 4. BIM's driving factors for green buildings

System layer	Criterion layer	Indicator layer	Description
BIM's driving factors for green buildings	Technical Level Factors (A1)	Design Quality and Efficiency (F1)	Design quality and efficiency of architecture, structure, mechanical and electrical, HVAC, water supply and drainage.
		Construction Organization Management (F2)	Overall planning and management of machinery mobilization, component hoisting, construction scheme change, etc.
		Construction Quality and Efficiency (F3)	Structural strength, construction accuracy, whether to meet function use, etc.
		Building Performance Analysis and Operations Management (F4)	Analysis of building performance and maintenance of equipment, pipes and components in operation stag.
		Information Visualization (F5)	Representing construction project information in a meaningful, visual way that users can interpret and easily comprehend.
		Information Collaboration (F6)	Collaborative work between project participants.
		Green Technology Research and Application (F7)	Development and application of green technology for energy saving and emission reduction in buildings.
	Economic and Environmental Factors (A2)	Real Estate Development Investment (F8)	The amount of investment in the development of green buildings in the real estate market.
		Construction and Operation Costs (F9)	Cost expenditure of buildings in planning, design, construction, operation and other stages.
	Policy Environment Factors (A3)	Perfection of Policies and Regulations (F10)	The state's macroscopic guidance, supervision, and constraint on the construction industry.
		Perfection of Standards (F11)	Uniform technical requirements within the construction industry.
	Management System Factors (A4)	Project Management Mode (F12)	Project management organization structure, workflow and mechanism, communication and cooperation mode, etc.
		Personnel Expertise Level (F13)	Technical application ability of the practitioner.
		Personnel Management Capability (F14)	Employees' macro management and coordination ability of the project.
	Social Environmental Factors (A5)	Material Supply Management (F15)	Procurement, storage and use of construction materials.
		Resource Consumption and Environmental Protection (F16)	Buildings' resource consumption and benefits in environmental protection in the whole life cycle.
		BIM Software Localization Level (F17)	BIM software language environment, software embedded national standards and norms, etc.
		Development of Prefabricated Buildings (F18)	Fabrication, transportation, site hoisting of prefabricated components, etc.
		Propaganda Method and Strength (F19)	The diversity and intensity of publicity methods aimed at increasing the public's correct understanding of green buildings.
		Maturity of Green Building Industry Chain (F20)	The maturity of the green building industry chain, includes product research and development, consulting design and construction, housing sales, operation and maintenance, building scrapping and demolition, and building material recycling.

Table 5. The demographics of the participants

Demographic factors	Number	Percentage
Gender		
Male	13	72.20%
Female	5	27.80%
Work seniority		
3–5 years	2	11.10%
5–10 years	7	38.90%
10–15 years	5	27.80%
More than 15 years	4	22.20%
Education Background		
Bachelor degree or below	5	27.80%
Master degree	1	5.60%
Doctor degree	12	66.70%

Step 6: System level partition.

According to the antecedent set and reachability set, a directed graph of driving factors is drawn. The calculation of the reachability matrix and the partition of the system hierarchy are realized by MATLAB (Qin et al., 2022; Masood et al., 2023).

3.3. Weight calculation of driving factors

ANP is an improved method based on the AHP analytic hierarchy process (AHP), which is suitable for the decision-making of non-independent feedback system structures. In the ANP network structure model, the internal elements of each level are interdependent and influence each other. In addition, there can also be a mutual influence relationship between the various levels. The network analytic Hierarchy process (ANP) can process quantified and non-quantified data quickly and accurately, simulate the actual situation of the research problem more comprehensively, and fully consider the correlation among indicators to carry out systematic and structured analysis of indicators (Mavi & Standing, 2018).

Therefore, the ANP network structure model was employed to evaluate the important weight of driving factors. The ANP network structure model consists of two parts: the control layer and the network layer (Kheybari et al., 2020). The control layer is only composed of the system goal, and the value of green buildings is mainly reflected in economic and social benefits. Therefore, this study takes the benefit of green building as the system objective. The network layer comprises five-factor groups that affect the benefits of green buildings, and the network structure model is shown in Figure 4.

Based on the ANP network structure model shown in Figure 4, the pairwise comparison judgment matrix on the driving factors of BIM for green buildings is constructed. Eighteen experts were invited to score the judgment matrix, and the relative relationship between each group and each specific factor was evaluated. Then, input each judgment matrix into the Super Decision software for consistency inspection, and all the C.R. values are less than 0.1. That is, they meet the requirements (Ervural et al., 2018).

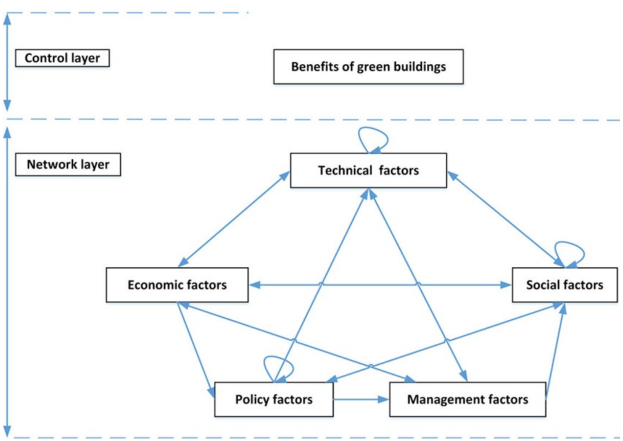

Figure 4. Network structure model of BIM's driving factors for green buildings

After the consistency check is completed, the super-matrix can be solved to obtain the quantitative evaluation results of the driving factors. The computation result can be quickly obtained after the steps of unweighted super-matrix, weighted super-matrix, and limit super-matrix via Super Decision software (Saaty, 2008). The calculation process of the super-matrices is as follows:

Step 1: Calculation of unweighted super-matrix. The unweighted super-matrix represents elements' influence on sub-criterion elements in each element group. According to the correlation between system elements, different elements are taken as sub-criteria, pairwise comparison between elements is carried out, and the judgment results are normalized to obtain the unweighted super-matrix W. The calculation formula is as follows:

$$W = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1N} \\ w_{21} & w_{22} & \cdots & w_{2N} \\ \vdots & \vdots & \vdots & \vdots \\ w_{N1} & w_{N2} & \cdots & w_{NN} \end{bmatrix}. \quad (5)$$

Step 2: Calculation of weighted super-matrix. The weighted super-matrix represents elements' influence degree in different element groups on the elements as sub-criteria. Comparing importance degrees can be carried out in pairs beyond the element groups. The pairwise comparison results between element groups are normalized, and the weighted matrix A is solved. The calculation formula is as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1N} \\ a_{21} & a_{22} & \cdots & a_{2N} \\ \vdots & \vdots & \vdots & \vdots \\ a_{N1} & a_{N2} & \cdots & a_{NN} \end{bmatrix}. \quad (6)$$

By multiplying the unweighted super-matrix W and the weighted matrix A, the weighted super-matrix $\bar{W}$ in the network structure model can be solved:

$$\bar{W} = a_{ij} w_{ij} \quad \left(i, j = 1, 2, \cdots, N\right). \quad (7)$$

Step 3: Calculation of limit super-matrix. Calculate the nth power of the weighted super-matrix to obtain the limit super-matrix:

$$W^{\infty} = \lim_{n \to \infty} \bar{W}^{n}. \quad (8)$$

3.4. Combination of ISM and ANP

There are 20 factors in the evaluation index system, and the average value of the importance weight is 0.05. Therefore, it is advisable to regard the driving factors with higher-than-average importance weights as the key driving factors. Then carry out the combined modeling analysis based on the calculation results of ISM and ANP (Chang et al., 2013; Kumar et al., 2021).

The fuzzy ISM model reflects the hierarchical structure and role relationship among various driving factors, while the ANP importance analysis reflects the relative importance of each driving factor. The ISM-ANP combined modeling method is used from a qualitative and quantitative perspective to analyze BIM's critical driving path for green buildings deeply.

4. Results

4.1. Partition of the fuzzy ISM model

According to the partition results of fuzzy ISM, there are seven system levels. The driving factors in different levels constitute each subsystem of the system, and these driving factors affect each sub-process and sub-environment of the development of green buildings step by step, and the whole fuzzy ISM explanatory structure model shows a strong hierarchy, the partition result is shown in Figure 5 and Table 6.

The results of this level partition can explain the relationship among the factors, but not convenient for further analysis to find the key action points of the driving factors and analyze the drive mechanism of BIM on green buildings. Therefore, sorting out and revising the hierarchical partition results is necessary. According to the original level of driving factors and their driving effect on green building, the results corrected to the direct factor layer, intermediate factor layer, and fundamental factor layer.

The corrected partition results of the fuzzy ISM are shown in Figure 6.

Table 6. Hierarchical classification of driving factors

Hierarchies	Factors	Number of Factors
Layer 1 (top layer)	F5, F8	2
Layer 2	F6	1
Layer 3	F2, F3	2
Layer 4	F9, F12, F14	3
Layer 5	F1, F4, F15	3
Layer 6	F7, F10, F11, F13, F16, F20	6
Layer 7 (ground layer)	F17, F18, F19	3

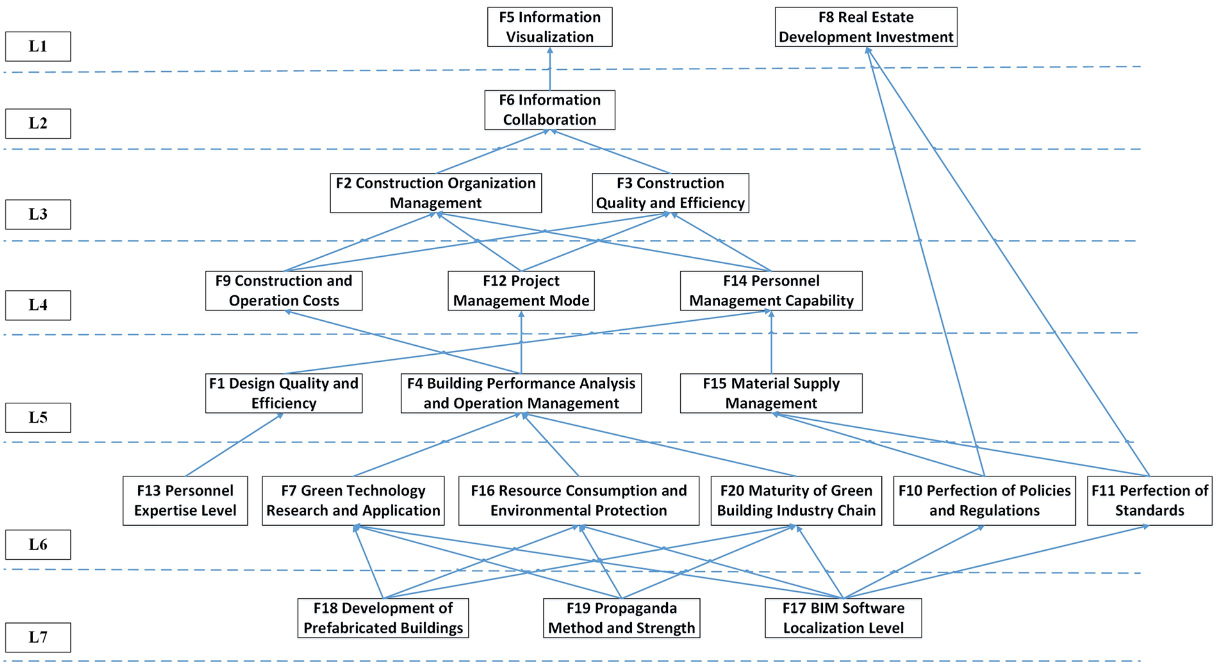

Figure 5. The original partition results of the fuzzy ISM model

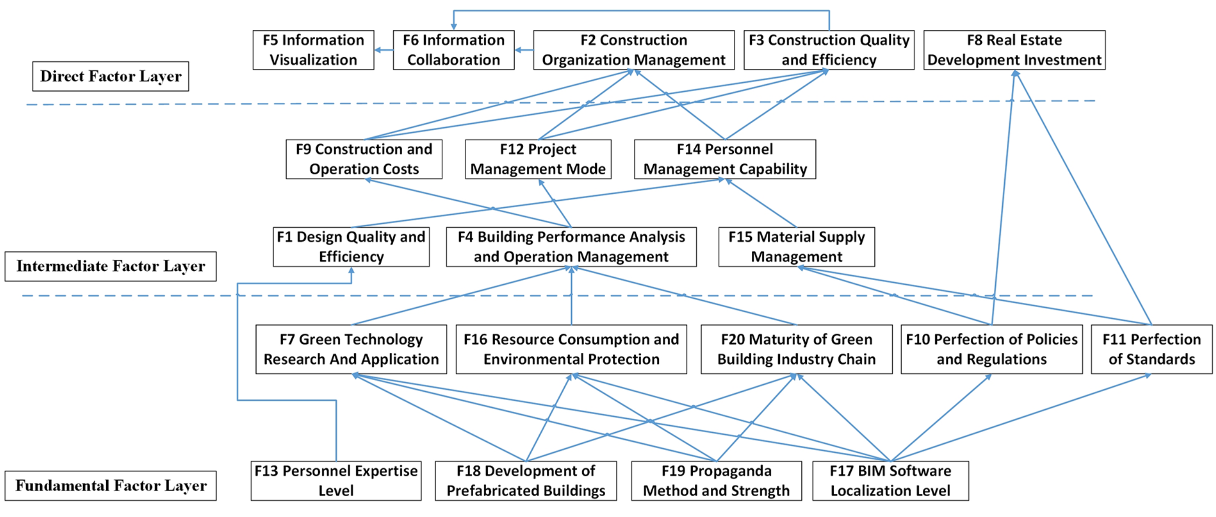

Figure 6. The corrected partition results of the fuzzy ISM model

4.2. Weight of driving factors

The importance ranking results of the driving factors are shown in Table 7. Driving factors were divided into three levels: particularly important, generally important, and second important. The driving factors whose importance degree is above 0.075 are classified as particularly important, including F10, F11, and F17. The driving factors whose importance is in the range of [0.05, 0.075] are divided into important factors, including F1, F2, F5, F6, F7, F8, F13, F14, F16, and F20. The driving factors with importance less than 0.05 were divided into the second important factors, including F3, F4, F9, F12, F15, F18, and F19, as shown in Figure 7.

The particularly important factors are located in the deep level of the fuzzy ISM hierarchy, which indicates that these factors play a decisive role in promoting the development of green buildings. The generally important factors are included in the direct, intermediate, and fundamental layers, mainly from the technical level factor group.

Table 7. The weight of driving factors

Factor group	Factors	Weight
Technical level factor group	Design Quality and Efficiency F1	0.051736
	Construction Organization Management F2	0.05109
	Construction Quality and Efficiency F3	0.018103
	Building Performance Analysis and Operation Management F4	0.005074
	Information Visualization F5	0.051361
	Information Collaboration F6	0.071225
	Green Technology Research and Application F7	0.05049
Economic factor group	Real Estate Development Investment F8	0.053755
	Construction and Operation Costs F9	0.027272
Policy environmental factor group	Perfection of Policies and Regulations F10	0.122691
	Perfection of Standards F11	0.094745
Management system factor group	Project Management Mode F12	0.012158
	Personnel Expertise Level F13	0.057816
	Personnel Management Capability F14	0.062659
Social environmental factor group	Material Supply Management F15	0.013379
	Resource Consumption and Environmental Protection F16	0.066436
	BIM Software Localization Level F17	0.087931
	Development of Prefabricated Buildings F18	0.031692
	Propaganda Method and Strength F19	0.012116
	Maturity of Green Building Industry Chain F20	0.058271

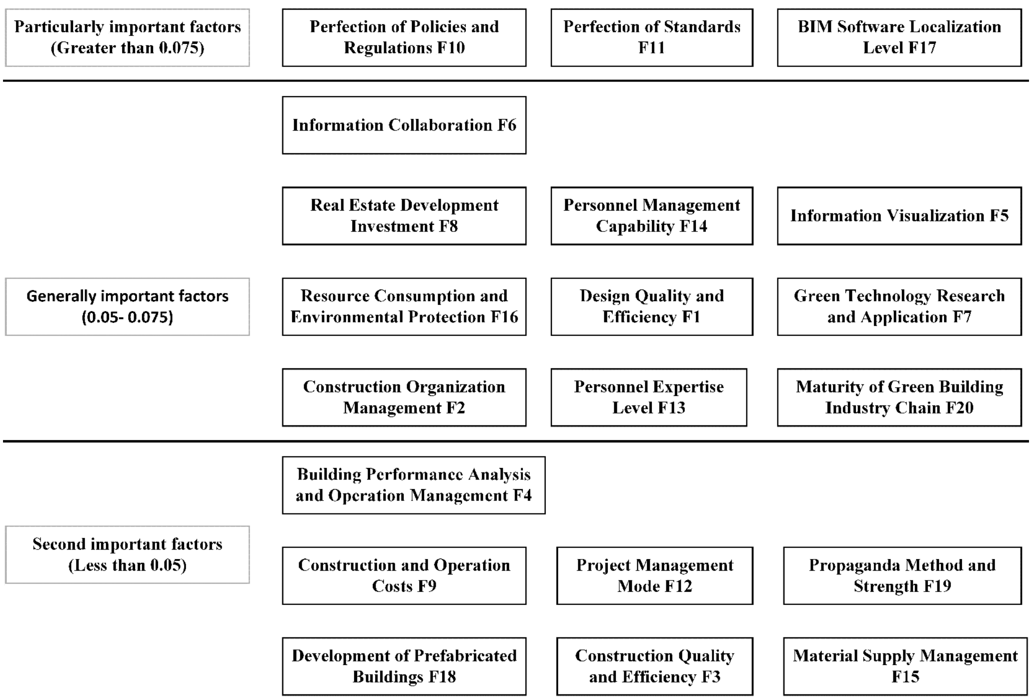

Figure 7. The important degree of driving factors

Indicating that the technical level is an essential factor affecting the development of green building, and also explains why existing researches focus on the technology application. Most of the second important factors belong to the shallow factors in the fuzzy ISM model, which are mainly transmitted and driven by the deep fundamental factors, thus affecting the development of green buildings. Effective management of the particularly important and generally important factors can improve the status of the second important factors.

4.3. ISM-ANP combination model

The ISM-ANP combination model is shown in Figure 8, each element marked with the driving factor's number, name/specific weight value (ranking order of weight). The key driving factors are marked with red outlines and gray fills. The red directional arrows represent one of the key driving factors, the drive path formed among them. The results show that critical drivers run through the model and form the core drive path. The key driving factors of BIM for green buildings formed three core driving paths in the ISM-ANP composite structure model,
path 1: F13→F1→F14→F2→F6→F5; path 2: F17→F10→F8; path 3: F17→F11→F8.

5. Discussion

5.1. The driving mechanism of BIM for green buildings

According to the corrected fuzzy ISM model, driving factors are partitioned into the direct factor layer, intermediate factor layer, and fundamental factor layer. The driving force of BIM on green buildings is transmitted upward from the fundamental factor level and is ultimately visually reflected in the real estate investment amount, construction quality and efficiency, construction organization and management, information visualization, and information collaboration.

Direct factors

According to the calculation and correction of the fuzzy ISM, the direct factor is the top three layers in the original hierarchical structure, which directly impacts the development of green buildings. The driving mechanism of F2, F3, F6 is shown below:

F2: F9, F12, F14→F2→F6→F5.
F3: F9, F12, F14→F3→F6→F5.
F6: F9, F12, F14→F2, F3→F6→F5.

The reachability sets of F5 and F8 only contain themselves, which means that these two driving factors only have an input end and no output end, and they are the most direct influencing factors on the development of green buildings. As an essential part of the national economy, investment in real estate (F8) will significantly impact the development of green buildings. In addition, information visualization (F5) is an essential prerequisite for using BIM for collaborative management (F6). Whether the project managers can effectively carry out collaborative management will further affect the construction organization management (F2), construction quality, and efficiency (F3).

Intermediate factors

The relationship between intermediate factors is complicated. Some factors are both the result of some behavioral factors and the cause of others, and these factors are primarily in the management category. The driving mechanism of F1, F4, F9, F12, F14, F15 is shown below:

F1: F13→F1→F14→F2, F3.
F4: F17, F18, F19→F7, F16, F20→F4→F9, F12→F2, F3.
F9: F17, F18, F19→F7, F16, F20→F4→F9→F2, F3.
F12: F17, F18→F7, F16, F20→F4→F12→F2, F3.
F14: F13→F1→F14→F2, F3; F17→F10, F11→F15→F14→F2, F3.
F15: F17→F10, F11→F15→F14→F2, F3.

After the driving force relationship is transmitted from the intermediate factor layer to the direct factor layer, the driving transmission mechanism of each factor has been

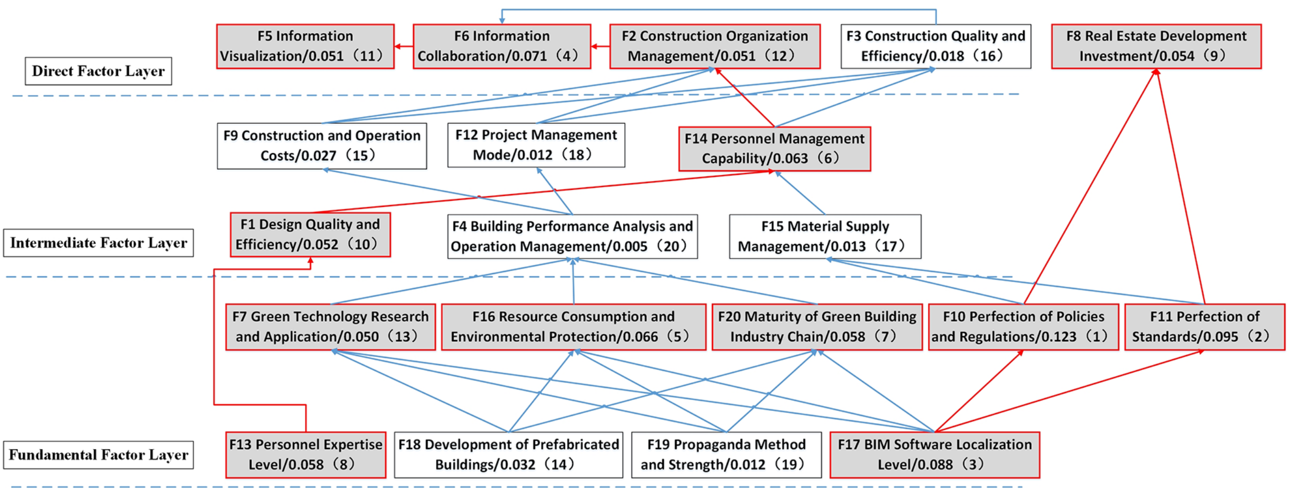

Figure 8. ISM-ANP combined model

analyzed above and is not repeated here. The intermediate factors have a slightly direct impact on the development of green buildings. However, the driving force relationship will be transmitted from the intermediate to direct factor layer, indirectly affecting the development of green buildings through information visualization, construction quality and efficiency, information collaboration, and other factors.

Fundamental factors

The driving mechanism of F7, F10, F11, F13, F16, F17, F18, F19, F20 is shown below:

F7: F17, F18, F19→F7→F4→F9, F12→F2, F3.

F10: F17→F10→F15→F14→F2, F3; F17→F10→F8.

F11: F17→F11→F15→F14→F2, F3; F17→F11→F8.

F13: F13→F1→F14→F2, F3.

F16: F17, F18, F19→F16→F4→F9, F12→F2, F3.

F17: F17→F7, F16, F20→F4→F9, F12→F2, F3; F17→F10, F11→F15→F14→F2, F3.

F18: F18→F7, F16, F20→F4→F9, F12→F2, F3.

F19: F19→F7, F16, F20→F4→F9, F12→F2, F3.

F20: F17, F18, F19→F20→F4→F9, F12→F2, F3.

F10 and F11 affect the intermediate factor layer and the direct factor layer simultaneously, which means that they can directly affect the development of the construction industry and the market environment. In addition, the research and application of critical technologies (F7) can help green buildings to achieve environmental protection, energy saving, and emission reduction (F16) in the whole life cycle, then help to improve the maturity of the entire green building industry chain (F20) consequently. It is worth noting that the antecedent set of F13, F17, F18, and F19 is only itself, which can be summarized as the four core fundamental factors that profoundly impact the development of green buildings.

5.2. The key driving path of BIM for green buildings

According to the ISM-ANP model, three key driving paths are obtained, path 1: F13→F1→F14→F2→F6→F5; path 2: F17→F10→F8; path 3: F17→F11→F8. In order to make the analysis more reasonable and concise, the three paths are summarized and shown in Figure 9.

Building information visualization, collaborative management, and expanding investment in real estate will directly promote the development of green buildings.

Visualization and collaboration of BIM is the inevitable path to develop green building design. The key reason why the traditional design process can not meet the development needs of green buildings is that the whole design process lacks coordination among various majors and links guided by green goals. Integrated design concepts and collaborative design are the main characteristics and advantages of BIM technology. It is conducive to optimizing building structure design, reducing construction risks, ensuring construction quality, and improving building maintenance management levels based on the information visualization and collaboration of BIM. In addition, the application of BIM in green buildings will reduce the incremental cost, highlight the economic and social benefits, and consequently attract real estate developers or related social capital. It is an extraordinary way to provide economic support for the development of green buildings.

Popularization of related technologies, improvement of management mode, and talent training can promote the visualization and collaborative management of building information.

Green building has excellent health, comfort, resource conservation, and environmental protection advantages. From the cost perspective, various advantages of green buildings cannot be separated from the innovation of advanced technology. The integration of BIM and digital twins, intelligent construction, the Internet of Things, big data, and other technologies has attracted wide attention from scholars. The application of these technologies can realize the real-time calculation of construction progress, carbon emissions, and energy consumption, thus reducing the economic and resource consumption of green buildings during the whole life cycle. It has no economic benefits and applicability until the technology is genuinely mature. Furthermore, BIM is an advanced computer technology that requires users to have sufficient professional knowledge and project management ability. Therefore, the cultivation of BIM talents is essential. When BIM is fully

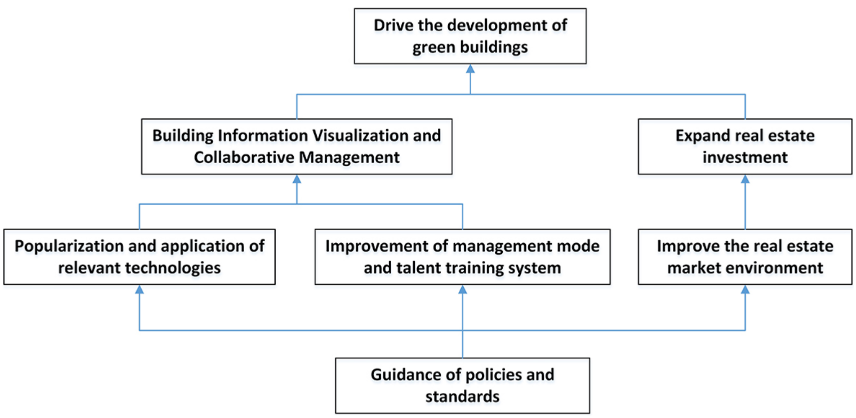

Figure 9. The key driving path of BIM for green buildings

used, it can optimize the traditional project management mode and realize intelligent and digital management, thus promoting the development of green buildings.

Improving real estate market environment can expand investment in green buildings.

In the high-level real estate development area, the market environment is more mature and flexible, and the income from real estate investment is relatively more stable. BIM can fundamentally change the traditional production and construction mode, reduce the incremental cost of green building, and maximize the realization of low-cost and high-income. Thereby, the economic return of real estate developers investing in green buildings can be ensured. It is a fantastic way to increase real estate developers' willingness in green buildings, thus increasing the effective supply of green buildings. Consequently, the increase in the number of green buildings is conducive to promoting healthy competition in the market and stimulating developers to improve the quality of their products. Based on maintaining balance, both supply and demand sides work together to promote green buildings' rapid and steady growth. Of course, this process is inseparable from the central and local macro-control.

Guidance of policies and standards can improve the development of related technologies, project management models, talent training systems, and real estate market environment.

As the manager and top designer of the construction industry, the government should guide and regulate green buildings based on the development strategy of the entire construction industry. Relevant government departments should guarantee the external economic incentives of green buildings. In addition, the government should pay more attention to solving the root causes of the problems and guide the construction industry to resolve the internal obstacles to the development of green buildings. In other words, the government should take market supply and demand as the core driving force, promote technological progress through management mode optimization and talent training, reduce the production cost of green buildings by technological progress, expand the investment in the real estate market by lower incremental cost and considerable investment income, thus promote the high-quality development of green buildings.

5.3. Recommendations

Firstly, *Improving the policy and standard system*. The rapid and healthy development of any new thing cannot be separated from the macro-control and guidance of the state, and BIM and green building are no exception. Therefore, it is an urgent matter to improve policies, including mandatory policies, preferential tax policies, and guiding policies. In this way, the rights, responsibilities, obligations, and other issues of the participants are clarified, thereby restraining the behaviors of all parties and ensuring that BIM technology and green building have laws to follow in the development process. More importantly, relevant departments should formulate targeted policies according to regional climatic conditions, building types, and other factors. At the same time, attention should be paid to the implementation of policies by construction enterprises and individuals, and a reward and punishment mechanism should be established to ensure the implementation of policies. In addition, to evaluate whether green buildings can save resources and protect the environment, many evaluation criteria came into being. However, these criteria need more consensus, and it is necessary to integrate and optimize the existing green building evaluation standards.

Secondly, *Striving to research native software*. The lack of local software has severely hindered the application of BIM in the construction field in China. It is necessary to research and develop native products, reduce the difficulty of BIM software operation, and embed relevant specifications and standards of China's construction industry. Moreover, government departments should play a leading role. In the government-related bidding and purchase, the procurement requirements of green building technology should be clarified, and the enterprises adopting green building technology should be given priority, thus promoting the transformation of green building technology into practical application. Furthermore, the evaluation of green building involves many sustainable environmental considerations, and the existing BIM software has advantages and disadvantages in dealing with different professional problems. Therefore, it is necessary to conduct integrated development and design of BIM software to improve the quality and efficiency of green building certification.

Thirdly, *Adopting an informatization project management mode*. Based on the visualization and collaboration functions of BIM, the information-based project management mode is adopted to integrate the key indicator information at all stages and majors of the project. The entire process of information management based on BIM can improve the industrialization level of the construction industry, which is a crucial path to improve the maturity of the green building industry chain and promote the construction industry to create a sustainable construction mode. On the premise of clarifying the ownership of the information of different participants, the entire project team shares the information database, which can greatly break the information boundary and achieve the integrated management of engineering quality, safety, progress, and cost at all stages of the building life cycle, it is conducive to improving project management performance. Furthermore, the informatization management mode can not avoid the risk of information leakage. Therefore, the access rights of project participants to information should be legally restricted.

Fourthly, *Accelerating the construction and improvement of the green building industry chain*. The core concept of the green building industry chain is the circular economy, which mainly includes research and development of green technology and building materials, green construction consulting and design, green construction, sales, green property management, demolition, waste treatment, recycling, and other links. For a complete and closed green building industry chain, economic activities are constantly circulating in the industry chain, and good economic benefits are the core driving force of the industry chain. The upstream and downstream of the industry chain can maintain the circulation of material flow and energy flow to promote the optimal state of economic benefits, environmental benefits, and resource benefits.

Finally, *Promoting government enterprise cooperation*. Regarding real estate enterprises, they should follow the national development path and deeply understand regional planning and industrial development policies in various places, and pay more attention to social and ecological benefits in the preliminary planning of green building projects, sequentially obtaining strong support from the government and realize cooperation between government and enterprise. Regarding government departments, they should establish and improve the supervision and management system of BIM and green buildings as soon as possible. To improve the service level and work efficiency, give full play to the role of government macro guidance and regulation, and dynamically monitor the market environment of the real estate industry, thus ensuring a healthy economic environment for the development of BIM and green buildings.

6. Conclusions

This paper explored BIM's driving mechanism and path for green buildings from the management perspective. Firstly, text mining and grounded theory are used to identify the driving factors. It is a comprehensive exploration of the research field of this paper from the perspective of experience, which ensures the scientific rationality of the factors' selection. Secondly, the fuzzy ISM model is used to solve the driving mechanism of BIM for green buildings, and the confusing relationship between various driving factors is transformed into a straightforward hierarchical structure relationship. Thirdly, the weights of driving factors are calculated by the ANP method. Fourthly, through ISM-ANP modeling, the driving path of BIM for green buildings is analyzed by combining qualitative and quantitative analysis. In this research direction, the method of ISM-ANP is innovative. Finally, based on the research results, five suggestions are given to improve the driving force of BIM for green buildings.

According to the partition results of fuzzy ISM, all factors are classified into seven levels, which are summarized as the direct factor level, intermediate factor level, and fundamental factor level. The driving force of BIM for green buildings comes from the fundamental factor layer, and the driving force is transferred from the fundamental factor layer to the intermediate factor layer and the direct factor layer. The driving factors were divided into three levels: particularly important, generally important, and second important. Effective management of the particularly important and generally important factors can improve the status of the second important factors.

Another finding of this study discovered the key driving path of BIM to green buildings is reflected in two aspects. First, the guidance of policies can promote technology progress, management model innovation, and improve personnel training systems, thus realizing the visualization and collaborative management of building information, accordingly promoting the development of green buildings. Second, Policy guidance of policies can improve the real estate market environment, expanding the investment in real estate development, thus driving the development of green buildings.

In addition, five recommendations are conducted to enhance the driving force of BIM for green building, including (1) improving the policy and standard system; (2) striving to research native software; (3) adopting informatization project management mode; (4) accelerating the construction and improvement of the green building industry chain; (5) promoting government enterprise cooperation.

In theory, this paper explored the adaptability of BIM technology in the whole life cycle of green buildings, discussed the value driving points of BIM in the whole life cycle of green building projects, analyzed its driving forces, and enriched the theoretical basic research on the application of BIM in green building projects from the perspective of management. In practice, the analysis of driving factors helps to promote the coupling and coordinated development of BIM and industrial construction of green buildings to improve the level of intelligent management of the building industry. In addition, through the analysis of the importance of each driving factor, it is helpful for relevant practitioners in the construction industry to clarify the correlation and mechanism between the benefits generated by the application of BIM technology and the performance of green building projects, and promote relevant practitioners to play a more excellent value in the application of BIM. More importantly, the coupling and coordinated development of BIM and green building will promote the transformation of the construction industry toward the industrial production mode and then encourage all participants in the green building industry chain to actively explore green technology research and development, scientific and technological innovation, and new cooperation models. It will help alleviate the complex problems currently faced by the construction industry, such as insufficient innovation, serious homogenization competition, and low efficiency, promote the green and sustainable development of the construction industry, and point out the direction for the modernization of the construction industry.

Obviously, this study still has two main limitations that should not be overlooked. First, BIM and green buildings in China show unbalanced regional development, and this paper does not consider the differences among regions when analyzing the driving factors. Second, this paper adopts the method of expert interview and questionnaire survey, which inevitably has some subjectivity. Therefore, it is suggested that future research could be combined with other more objective analysis methods.

Author contributions

BZ and YY conceived the study and were responsible for the design and development of the data analysis. YY was responsible for data collection, analysis, and interpretation. YY wrote the first draft of the article, revised by YY and QL, supervised by BZ.

Disclosure statement

There are no competing financial, professional, or personal interests from other parties.

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APPENDIX

Table A1. The reachability matrix

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
F1	1	1	1	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
F2	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F3	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F4	0	1	1	1	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0
F5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F6	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F7	0	1	1	1	1	1	1	0	1	0	0	1	0	0	0	1	0	0	0	1
F8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
F9	0	1	1	0	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0
F10	0	1	1	0	1	1	0	1	0	1	1	0	0	1	1	0	0	0	0	0
F11	0	1	1	0	1	1	0	1	0	1	1	0	0	1	1	0	0	0	0	0
F12	0	1	1	0	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0
F13	1	1	1	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0
F14	0	1	1	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
F15	0	1	1	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0
F16	0	1	1	1	1	1	1	0	1	0	0	1	0	0	0	1	0	0	0	1
F17	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1
F18	0	1	1	1	1	1	1	0	1	0	0	1	0	0	0	1	0	1	0	1
F19	0	1	1	1	1	1	1	0	1	0	0	1	0	0	0	1	0	0	1	1
F20	0	1	1	1	1	1	1	0	1	0	0	1	0	0	0	1	0	0	0	1

Table A2. Reachability set, antecedent set, and intersection set

Factors	Reachability set (P)	Antecedent set (Q)	Intersection set (A = P∩Q)
F1	F1, F2, F3, F5, F6, F14	F1, F13	F1
F2	F2, F3, F5, F6	F1, F2, F3, F4, F7, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F20	F2,F3
F3	F2, F3, F5, F6	F1, F2, F3, F4, F7, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F20	F2,F3
F4	F2, F3, F4, F5, F6, F9, F12	F4, F7, F16, F17, F18, F19, F20	F4
F5	F5	F1, F2, F3, F4, F5, F6, F7, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F20	F5
F6	F5, F6	F1, F2, F3, F4, F6, F7, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F20	F6
F7	F2, F3, F4, F5, F6, F7, F9, F12, F16, F20	F7, F16, F17, F18, F19, F20	F16, F20, F7
F8	F8	F8, F10, F11, F17	F8
F9	F2, F3, F5, F6, F9, F12	F4, F7, F9, F12, F16, F17, F18, F19, F20	F9, F12
F10	F2, F3, F5, F6, F8, F10, F11, F14, F15	F10, F11, F17	F10, F11
F11	F2, F3, F5, F6, F8, F10, F11, F14, F15	F10, F11, F17	F10, F11
F12	F2, F3, F5, F6, F9, F12	F4, F7, F9, F12, F16, F17, F18, F19, F20	F9, F12
F13	F1, F2, F3, F5, F6, F13, F14	F13	F13
F14	F2, F3, F5, F6, F14	F1, F10, F11, F13, F14, F15, F17	F14
F15	F2, F3, F5, F6, F14, F15	F10, F11, F15, F17	F15
F16	F2, F3, F4, F5, F6, F7, F9, F12, F16, F20	F7, F16, F17, F18, F19, F20	F16, F20, F7
F17	F2, F3, F4, F5, F6, F7, F8, F9, F10, F11, F12, F14, F15, F16, F17, F20	F17	F17
F18	F2, F3, F4, F5, F6, F7, F9, F12, F16, F18, F20	F18	F18
F19	F2, F3, F4, F5, F6, F7, F9, F12, F16, F19, F20	F19	F19
F20	F2, F3, F4, F5, F6, F7, F9, F12, F16, F20	F7, F16, F17, F18, F19, F20	F16, F20, F7