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Investigating the Key Hindering Factors and Mechanism of BIM Applications Based on Social Network Analysis

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Abstract: China's construction industry is an important driving force for the development of society. Nevertheless, with the recent new normal of economic development, traditional construction approaches cannot meet the requirements of socialist modernization and sustainable construction. As such, the development of the construction industry needs to match the recent developmental concept of green environmental protection. Therefore, China's construction industry needs to explore innovative development paths of transformation and upgrading. Recently, the Chinese government has been vigorously promoting building information modeling (BIM) applications. However, in the real-world construction process, BIM applications have not achieved their expected impacts. To satisfy the practical demands, this research uses the social network analysis method to analyze the key hindering factors in order to clarify the significance and influencing mechanism of each factor. The current study identified 12 key hindering factors that impede the development of BIM applications in China's construction industry. The results show that a lack of policy guidance and the restriction of relevant laws are the most critical hindering factors. This research contributes to the research of the hindering factors of BIM applications in China and can assist decision makers in formulating appropriate strategies to promote the application and development of information BIM technology in China's construction industry.

Keywords: BIM; construction industry; hindering factors; resilience; social network analysis

Citation: Wu, Z.; Lu, Y.; He, Q.; Hong, Q.; Chen, C.; Antwi-Afari, M.F. Investigating the Key Hindering Factors and Mechanism of BIM Applications Based on Social Network Analysis. *Buildings* **2022**, *12*, 1270. https://doi.org/10.3390/buildings12081270

Academic Editors: Xiao Li, Yue Teng, Chengke Wu, Hengqin Wu and Geoffrey Qiping Shen

Received: 12 July 2022
Accepted: 17 August 2022
Published: 19 August 2022

1. Introduction

With the advancement of the Chinese socialist modernization process, the industrialization, digitalization, and intelligentization requirements of the construction industry have been put forward in China in order to promote the high-quality development of the construction industry. Thus, the traditional building model cannot meet the requirements of the sustainable construction of modernization. The concept of construction industry development needs to match the concept of green environmental protection [1–3]. Therefore, the Chinese construction industry needs to explore the development path of innovative transformation and upgrading, and building information modeling (BIM) is an advanced construction information application. The concept of BIM was first proposed by Dr. Chuck Eastman in 1975 [4]. According to the National BIM Standard of the United States, BIM is the digital expression of the functional characteristics of a project and a shared knowledge system, which can provide a scientific and reliable basis for all decisions in the life cycle management [5].

The construction industry is undergoing a gradual transformation toward a productive and collaborative environment, and BIM is one of the information management methods [6]. In China, to improve the information level of the construction industry, the Ministry of Housing and Urban-Rural Development of the People's Republic of China (MHUC) issued the construction application standard of Building Information Modeling in May 2017 [7]. In addition, the MHUC issued the BIM application guide in May 2018 so as to improve the quality and safety management level of construction projects and to promote the application of BIM in urban rail transit engineering projects [8]. Although the Chinese government has issued several policies to promote the development of BIM applications, BIM has not achieved its expected impact in the construction industry. In October 2019, the China Construction Industry Association released a BIM application analysis report of Chinese construction enterprises, and it stated that the level of industrialization and informatization of China's construction industry at present is low and still has great prospects for progressive development [9]. Recently, in April 2021, the MHUC held a launching meeting for the preparation of China's construction industry informatization development report (2021), aiming to promote the transformation and upgrading of China's construction industry and to accelerate the research and development of BIM. In recent years, the continuous introduction of several policies shows China's determination toward an innovative construction industry.

In fact, there are still many problems in the development of BIM applications in China's construction industry. Hochscheid et al. [10] claimed that digital transitions led by the adoption of BIM are risky operations for the industry. Siebelink et al. [11] divided the barriers that hinder the implementation and application of BIM into four categories, namely, management support, people and culture, technology, and the use of defined processes and standards. Qin et al. [12] argued that BIM education and training, and technical personnel are currently the two largest driving forces in China's construction market. Therefore, it is still necessary to analyze the hindering factors of BIM applications. In the past, many scholars used the DEMATEL square method, the structural interpretation model, semi-structured expert interviews, or questionnaires to analyze the influencing factors of BIM applications [13–16]. The social network analysis can better study the mechanism of the factors, so it is also widely used in the field of sustainable construction and engineering management to research the interrelationship between the factors [17]. However, few scholars have used the social network analysis to study the mechanism of BIM obstacles or to analyze the relationship between the hindering factors. Therefore, in order to fill this research gap and to promote the transformation and upgrading of China's construction industry, this study, based on the implementation of BIM applications, aims to explore the hindering factors that impede their adoption and clarify the mechanism of each factor.

The structure of this paper is as follows: Section 2 describes the research methods and elaborates on the process of data collection, data inspection, and a data depth analysis. Section 3 builds the hindering factor network and presents the results and indicator analyses. Section 4 focuses on the discussion of this research. Lastly, the conclusions and limitations are presented in Section 5.

2. Methods

2.1. Data Collection

In a previous study [5], through the reading and sorting of the BIM literature, it was found that BIM articles are mainly published in Chinese and English journals, masters and doctoral theses, and other editorial sources. Research on BIM applications in the Chinese literature focuses on informatization, visualization, secondary development, cost control, green building, collaborative design, construction simulation, project management, and other fields [5]. However, the foreign literature focuses on interoperability, sustainable construction, collaboration, energy efficiency, ontology, and so on. Furthermore, domestic and foreign literature focus on the influencing factors of BIM applications, and many researchers have explored the influencing factors of BIM development and its mechanism based on specific countries or regions. In this study, the literature on the hindering factors of BIM applications is summarized and sorted using the China National Knowledge Infrastructure (CNKI) and the Web of Science databases, and 43 influencing factors are preliminarily identified, as shown in Table 1.

Table 1. List of hindering factors of BIM application.

Hindering Factors of BIM Application	Sources
1. The costs of BIM expert consultation and training are high.	[18,19]
2. The costs of hardware upgrade configuration are high.	[20,21]
3. The costs of BIM software upgrade configuration are high.	[21,22]
4. The application of BIM increases the design cost.	[23,24]
5. The benefits of BIM application are not clearly defined.	[25,26]
6. The economic benefits and application value brought by BIM are not obvious.	[27,28]
7. The cost sharing and benefit distribution mechanism of BIM application by all parties is not perfect.	[29,30]
8. The support of domestic BIM software is insufficient, and the localization degree of foreign software is not high.	[22,31]
9. The function of BIM software is not perfect (such as poor mapping, poor application, poor expansibility, and poor compatibility).	[28,31]
10. There is a lack of unified BIM information and data exchange standards.	[32,33]
11. The accuracy required by each discipline for the model is not uniform, the interaction between disciplines is not perfect, and the data interoperability of BIM software is insufficient.	[34,35]
12. The BIM supporting software is immature.	[35,36]
13. There are insufficient data sources for BIM modeling.	[37,38]
14. The BIM information collaboration platform is not mature.	[39,40]
15. BIM cloud service technology is not perfect.	[41,42]
16. The data protection and security issues of BIM are not perfect.	[12,43]
17. The BIM secondary development is not mature.	[12,44]
18. BIM technology has a single application point and is not closely combined with other advanced technologies.	[21,45]
19. There is a lack of trust in the accuracy of the BIM model, resulting in the duplication of work.	[15,46]
20. Enterprises do not pay enough attention to BIM and lack external and internal driving forces, and the application rate of BIM is low.	[47,48]
21. The internal BIM capability of the enterprise is insufficient, the enterprise organizational structure matching with BIM is lacking, the overall management is lacking, and the comprehensive application mode of BIM is lacking.	[12,26]
22. The goal of enterprises using BIM is not clear, and there is lack of strategic plans for the use of BIM.	[30,49]
23. The referenced successful cases and BIM application experiences are insufficient.	[40,50]
24. All stakeholders have insufficient awareness of sharing BIM achievements.	[51,52]
25. Stakeholders have insufficient understanding of the essence of BIM technology, and there are deviations in their cognition of BIM value and application.	[53,54]
26. The communication and cooperation among the stakeholders of the projects are insufficient.	[15,55]
27. The project participants have different proficiencies in BIM applications.	[22,56]
28. There is a lack of BIM talents (e.g., lack of mature BIM management teams, BIM experts, and BIM software proficiency).	[34,57]
29. The society has low recognition of middle and senior BIM management staff.	[58,59]
30. There is a lack of systematic BIM education systems and institutions.	[60,61]
31. The BIM-related materials and learning opportunities are insufficient.	[30,45]
32. It is difficult to transform the working mode from independent to collaborative, and it is difficult to accept the new BIM technology.	[54,62]
33. There is insufficient research on BIM.	[36,63]
34. The lack of a BIM application policy has led to the lack of BIM application.	[14,36]
35. There is a lack of unified BIM standards, guidelines, and contract model texts from industry-competent departments.	[39,64]
36. The legal liability boundary of BIM is not clear and lacks relevant laws (such as BIM intellectual property protection law and BIM insurance law).	[12,42]
37. There is a lack of a BIM database conforming to domestic building codes and standardization.	[28,65]
38. The definition of BIM deliverables is unclear.	[40,66]
39. There is a lack of incentive mechanisms for BIM application.	[67,68]
40. The dispute resolution mechanism of the BIM project is not mature.	[21,58]
41. There is a mismatch between responsibilities and risks of parties involved in BIM application.	[30,35]
42. There is a lack of long-term application plans and schemes of BIM.	[41,69]
43. There is a lack of project management mode based on BIM and workflow throughout the whole industry chain.	[26,43]

After interviewing experts and scholars with knowledge domain in building informatization, unnecessary hindering factors were removed, and, finally, 25 hindering factors of BIM applications were determined. The next step was to classify the determined factors. Ni [66] divided BIM adoption intention into technology, organizational, environmental, and internal motivation by establishing a technology acceptance model. Based on the structural equation model, Li and Tang [30] divided the influencing factors of BIM applications into economic, technical, policy, legal, organizational, and personnel factors. Ozorhon et al. [57] divided the hindering factors of BIM applications into personnel, industry, project, policy, and resource factors. Through the classification of these hindering factors by previous researchers in the literature, this study divided the 25 hindering factors of BIM applications into four categories: (1) economic, (2) technical, (3) social environment, and (4) institutional factors. The classification of the hindering factors of BIM applications is shown in Table 2.

Table 2. Classification of hindering factors of BIM applications.

Classification	Hindering Factors of BIM Applications
Economic	A1. The costs of BIM expert consultation and training are high. A2. The costs of hardware upgrade configuration are high. A3. The costs of BIM software upgrade configuration are high. A4. The application of BIM increases the design cost. A5. The benefits of BIM applications are not clearly defined. A6. The cost sharing and benefit distribution mechanism of BIM applications by all parties is not perfect.
Technology	B1. The support of domestic BIM software is insufficient, and the localization degree of foreign software is not high. B2. The function of BIM software is not perfect (such as poor mapping, poor application, poor expansibility, and poor compatibility). B3. The accuracy required by each discipline for the model is not uniform, the interaction between disciplines is not perfect, and the data interoperability of BIM software is insufficient. B4. The secondary development based on BIM is not mature. B5. BIM's cloud service technology is not perfect. B6. BIM's data protection and security issues are not perfect.
Social environment	C1. Enterprises do not pay enough attention to BIM, and the application rate of BIM is low. C2. All stakeholders have insufficient awareness of sharing BIM achievements. C3. The stakeholders' different perceptions of BIM value and application are biased. C4. Stakeholders have different proficiencies in BIM applications. C5. There is a lack of BIM talents (e.g., lack of mature BIM management teams, BIM experts, and BIM software proficiency). C6. There is a lack of systematic BIM education systems, and insufficient BIM-related materials and learning opportunities. C7. It is difficult to transform the working mode from independent to collaborative, and it is difficult to accept the new BIM technology.
Institution	D1. There is a lack of policies to promote BIM application (such as incentive mechanism for BIM applications), resulting in insufficient BIM market demand. D2. There is a lack of unified BIM standards and contract model texts from industry-competent departments. D3. The legal liability boundary of BIM is not clear and lacks relevant laws (such as BIM intellectual property protection law and BIM insurance law). D4. There is a lack of a BIM database conforming to domestic building codes and standardization. D5. There is a mismatch between responsibilities and risks of parties involved in BIM applications. D6. There is a lack of BIM project management mode and workflow throughout the whole industry chain.

2.2. Data Inspection

After identifying 25 hindering factors of BIM applications, this study conducted a questionnaire survey to explore the mechanisms of the key hindering factors of BIM applications. The respondents were invited to fill in the questionnaire via e-mail, on-site conversations with relevant practitioners in the construction industry, and online academic conferences. Finally, 285 questionnaires were collected, of which 283 had valid responses. The collected data were checked using the following statistical analyses:

(1) Reliability Analysis

A reliability test is used to test the reliability of questionnaire results. The higher the reliability value, the more reliable the results. The Cronbach alpha reliability coefficient was adopted in this study, and it reflects whether there is good internal consistency among the indicators of a questionnaire. The reliability coefficient ranges from 0 to 1. If the reliability coefficient is greater than 0.9, it indicates a very good reliability scale [70]. This study used the statistical package of social sciences (SPSS) to analyze the reliability of the 283 valid questionnaires. The results are shown in Table 3.

Table 3. Reliability analysis of hindering factors.

Classification	Number	Standardized Alpha	Standardized Total Alpha
Economic	6	0.910	0.970
Technology	6	0.904	
Social environment	7	0.912	
Institution	6	0.899	

(2) Validity test

A validity test is used to verify the rationality and effectiveness of a questionnaire. This study tested the questionnaire by using factor analysis in SPSS. The coefficient of the Kaiser–Meyer–Olkin (KMO) test ranges from 0 to 1, and the closer the KMO coefficient is to 1, the better the validity [70]. The results show that the KMO test coefficient is 0.982, indicating good validity. According to the Bartlett Test, the significance is infinitely close to 0 (three decimal places are reserved). Therefore, it can be stated that this questionnaire has good validity.

(3) Evaluation of influence degree of hindering factors

The survey responses were imported into SPSS to test the normal distribution of each evaluation index in the collected questionnaire data. The results are shown in Table 4. According to the analysis, the average, median, and mode of the hindering factors of BIM applications are evenly distributed, and the data conformed to normal distribution without polarization. Through the ranking of the mean values, the top eight factors determined as the key hindering factors are as follows: C4, D3, B6, B2, C2, C6, D5, and D1.

(4) Correlation test

To verify the correlation between the hindering factors of BIM applications, this study used SPSS to test the Spearman correlation of the collected questionnaire data. The results are shown in Table 5. The test results show that there is a significant positive correlation between all hindering factors at a confidence level of 0.01. Based on the results of the correlation analysis, the hindering factors with more correlation distribution and larger correlation coefficient were identified as the key hindering factors in this study, and the ranking of the results is as follows: C4, B5, D5, D3, A4, B6, A1, and B3.

Based on the influence degree ranking and correlation analysis results of BIM applications' hindering factors, and preserving their union factor, 12 key hindering factors of BIM applications were finally determined and reordered, as shown in the Table 6.

Table 4. BIM applications' hindering factors impact assessment form.

	Average	Median	Mode	Standard Deviation	Mean Sorting
A1	3.95	4	4	1.034	20
A2	3.94	4	4	1.078	22
A3	4.19	4	4	0.942	9
A4	4.16	4	4	0.935	11
A5	3.90	4	4	1.082	25
A6	4.12	4	4	0.895	12
B1	3.95	4	4	1.098	21
B2	4.23	4	4	0.862	4
B3	3.98	4	4	1.047	15
B4	4.19	4	4	0.883	10
B5	3.97	4	5	1.053	17
B6	4.24	4	5	0.925	3
C1	3.92	4	4	1.024	23
C2	4.22	4	4	0.934	5
C3	4.06	4	5	1.044	13
C4	4.28	4	5	0.877	1
C5	3.98	4	4	1.038	16
C6	4.22	4	4	0.871	6
C7	3.96	4	4	1.038	18
D1	4.21	4	4	0.886	8
D2	3.96	4	4	1.044	19
D3	4.26	4	5	0.934	2
D4	4.05	4	5	1.032	14
D5	4.22	4	4	0.926	7
D6	3.92	4	4	1.033	24

2.3. Data Depth Analysis

A social network is a collection of actors and relationships between nodes, which can be any social unit or entity, such as individuals, institutions, cities, and countries.

The social network analysis is a common research method in the field of sustainable construction and engineering management [17]. It can quantitatively analyze the influence mechanism of a system network through visual charts and quantitative indicators so as to determine the specific relationship of different key influencing factors. In this study, the social network analysis method was used to construct and analyze a social network model of the key hindering factors of BIM applications. The specific operation steps are as follows [71]:

(1) Identify system network nodes. In this study, the 12 identified key hindering factors of BIM applications were taken as the system network nodes, so there were 12 nodes in total.

(2) Determine the detection index of the relational network. In this study, three indicators of the system network of key hindering factors were analyzed, namely, degree centrality, closeness centrality, and between centrality.

(3) Visualize the relationship network. This step uses UCINET software to visualize the relationship between the key hindering factors of BIM applications and the system network.

(4) Analyze and explain the detection results of the social network analysis.

Table 5. Correlation analysis.

	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	C7	D1	D2	D3	D4	D5	D6
A1	1.000																								
A2	0.315 **	1.000																							
A3	0.357 **	0.415 **	1.000																						
A4	0.377 **	0.398 **	0.382 **	1.000																					
A5	0.415 **	0.382 **	0.331 **	0.427 **	1.000																				
A6	0.338 **	0.427 **	0.342 **	0.414 **	0.324 **	1.000																			
B1	0.348 **	0.304 **	0.378 **	0.291 **	0.392 **	0.278 **	1.000																		
B2	0.379 **	0.402 **	0.343 **	0.378 **	0.371 **	0.427 **	0.334 **	1.000																	
B3	0.369 **	0.285 **	0.414 **	0.363 **	0.425 **	0.364 **	0.400 **	0.363 **	1.000																
B4	0.248 **	0.416 **	0.316 **	0.375 **	0.249 **	0.393 **	0.404 **	0.441 **	0.344 **	1.000															
B5	0.362 **	0.376 **	0.370 **	0.350 **	0.382 **	0.334 **	0.466 **	0.342 **	0.345 **	0.405 **	1.000														
B6	0.324 **	0.421 **	0.279 **	0.411 **	0.391 **	0.437 **	0.373 **	0.393 **	0.290 **	0.435 **	0.475 **	1.000													
C1	0.396 **	0.352 **	0.372 **	0.379 **	0.468 **	0.350 **	0.327 **	0.351 **	0.372 **	0.299 **	0.443 **	0.302 **	1.000												
C2	0.434 **	0.401 **	0.382 **	0.351 **	0.382 **	0.426 **	0.309 **	0.375 **	0.344 **	0.382 **	0.331 **	0.344 **	0.383 **	1.000											
C3	0.393 **	0.386 **	0.342 **	0.317 **	0.403 **	0.295 **	0.362 **	0.284 **	0.429 **	0.265 **	0.370 **	0.282 **	0.390 **	0.288 **	1.000										
C4	0.388 **	0.359 **	0.331 **	0.425 **	0.391 **	0.371 **	0.430 **	0.370 **	0.376 **	0.429 **	0.478 **	0.402 **	0.317 **	0.374 **	0.339 **	1.000									
C5	0.375 **	0.311 **	0.372 **	0.305 **	0.265 **	0.319 **	0.375 **	0.338 **	0.381 **	0.281 **	0.307 **	0.333 **	0.359 **	0.353 **	0.419 **	0.358 **	1.000								
C6	0.391 **	0.319 **	0.356 **	0.392 **	0.360 **	0.292 **	0.369 **	0.325 **	0.355 **	0.322 **	0.371 **	0.351 **	0.383 **	0.366 **	0.398 **	0.433 **	0.354 **	1.000							
C7	0.323 **	0.315 **	0.384 **	0.314 **	0.370 **	0.242 **	0.276 **	0.341 **	0.378 **	0.299 **	0.323 **	0.309 **	0.377 **	0.330 **	0.273 **	0.313 **	0.342 **	0.300 **	1.000						
D1	0.386 **	0.428 **	0.368 **	0.370 **	0.300 **	0.359 **	0.312 **	0.402 **	0.380 **	0.339 **	0.319 **	0.356 **	0.381 **	0.341 **	0.421 **	0.437 **	0.339 **	0.391 **	0.348 **	1.000					
D2	0.314 **	0.350 **	0.290 **	0.362 **	0.342 **	0.349 **	0.339 **	0.305 **	0.391 **	0.336 **	0.419 **	0.403 **	0.347 **	0.287 **	0.398 **	0.373 **	0.372 **	0.326 **	0.354 **	0.348 **	1.000				
D3	0.354 **	0.374 **	0.343 **	0.345 **	0.344 **	0.407 **	0.291 **	0.438 **	0.367 **	0.360 **	0.404 **	0.470 **	0.353 **	0.374 **	0.310 **	0.427 **	0.317 **	0.373 **	0.422 **	0.402 **	0.350 **	1.000			
D4	0.385 **	0.325 **	0.411 **	0.403 **	0.307 **	0.322 **	0.296 **	0.304 **	0.382 **	0.331 **	0.375 **	0.366 **	0.309 **	0.285 **	0.273 **	0.375 **	0.403 **	0.413 **	0.328 **	0.318 **	0.413 **	0.358 **	1.000		
D5	0.448 **	0.384 **	0.386 **	0.416 **	0.326 **	0.320 **	0.361 **	0.391 **	0.333 **	0.367 **	0.433 **	0.340 **	0.338 **	0.375 **	0.328 **	0.416 **	0.381 **	0.389 **	0.342 **	0.336 **	0.393 **	0.433 **	0.389 **	1.000	
D6	0.358 **	0.338 **	0.405 **	0.276 **	0.333 **	0.315 **	0.335 **	0.255 **	0.324 **	0.290 **	0.331 **	0.305 **	0.357 **	0.292 **	0.344 **	0.296 **	0.304 **	0.359 **	0.331 **	0.329 **	0.335 **	0.299 **	0.384 **	0.307 **	1.000

** At the 0.01 level (two-tailed), the correlation is significant.

Table 6. The key hindering factors of BIM applications.

Number	Key Hindering Factors
K1	The costs of BIM expert consultation and training are high.
K2	The application of BIM increases the design cost.
K3	The function of BIM software is not perfect (such as poor mapping, poor application, poor expansibility, and poor compatibility).
K4	There is a lack of unified BIM information data exchange standards and insufficient data interoperability.
K5	BIM's cloud service technology is not perfect.
K6	BIM's data protection and security issues are not perfect.
K7	All stakeholders have insufficient awareness of sharing BIM achievements.
K8	Stakeholders have different proficiencies in BIM applications.
K9	There is a lack of systematic BIM education systems, and insufficient BIM-related materials and learning opportunities.
K10	There is a lack of policies to promote BIM applications (such as incentive mechanism for BIM applications), resulting in insufficient BIM market demand.
K11	The legal liability boundary of BIM is not clear and lacks relevant laws (such as BIM intellectual property protection law and BIM insurance law).
K12	There is a mismatch between responsibilities and risks of parties involved in BIM applications.

3. Results

3.1. Building the Influencing Factor Network

In a social network analysis, the social relationship of nodes can be presented in the form of a matrix, among which the simplest and most common form is the binary matrix. After sorting the 12 key hindering factors that impede the application of BIM, an adjacency matrix for the network system was established. If the element in the row has an impact on the element in the column, the cell is marked as 1, and vice versa. In this study, the 12 key hindering factors of BIM applications were taken for each node in the system network. According to the interview with BIM experts, the final obtained adjacency matrix is shown in Table 7.

According to the adjacency matrix, the value of the in-degree of an element is the sum of the values of the corresponding columns of the element, and the value of the out-degree is the sum of the values of the corresponding rows of the element. Therefore, we can calculate the in-degree and out-degree of each node, and the calculation results are shown in Table 8. Figure 1 illustrates the visualized network relationship between the key hindering factors of BIM applications by using UCINET. In Figure 1, the direction of the arrow represents the direct effect from K(i) to K(j). According to the results, the network density of the relationship network is 0.3864, while the maximum network density that can be found in the actual research process is 0.5 [72], indicating that the density among the 12 hindering factors in the system network is large and that the compactness is high.

Table 7. The adjacency matrix of key hindering factors of BIM applications.

Code	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12
K1	0	1	0	0	0	0	0	1	0	0	0	0
K2	1	0	0	0	0	0	0	0	0	0	0	0
K3	0	1	0	1	1	1	0	1	0	0	0	0
K4	0	0	1	0	1	1	1	0	0	0	0	0
K5	0	0	1	0	0	1	1	0	0	0	0	0
K6	0	0	1	1	1	0	1	0	0	0	0	1
K7	0	1	1	1	0	1	0	0	0	0	0	1
K8	1	1	0	0	0	0	0	0	0	0	0	0
K9	1	1	0	0	0	0	1	1	0	0	0	0
K10	1	1	1	1	1	1	1	1	1	0	1	1
K11	0	0	0	1	1	1	1	0	0	1	0	1
K12	0	0	0	0	1	1	1	0	0	0	0	0

Table 8. Centrality analysis of key hindering factors of BIM applications.

	Degree Centrality			Closeness Centrality		
Number	Out-Degree	In-Degree	Difference	In-Closeness Centrality	Out-Closeness Centrality	Between Centrality
K1	2	4	−2	50.000	10.000	1.000
K2	1	6	−5	68.750	9.910	4.500
K3	5	5	0	23.404	23.404	9.333
K4	4	5	−1	23.404	22.449	1.033
K5	3	6	−3	23.404	22.000	1.200
K6	5	7	−2	24.444	22.917	4.533
K7	5	7	−2	24.444	23.404	12.700
K8	2	4	−2	57.895	10.000	1.500
K9	4	1	3	9.910	28.205	0.000
K10	11	1	10	9.091	100.000	3.700
K11	6	1	5	9.091	68.750	0.000
K12	3	4	−1	22.917	21.569	0.500
Mean Value	4.250	4.917	1	28.896	30.217	3.333

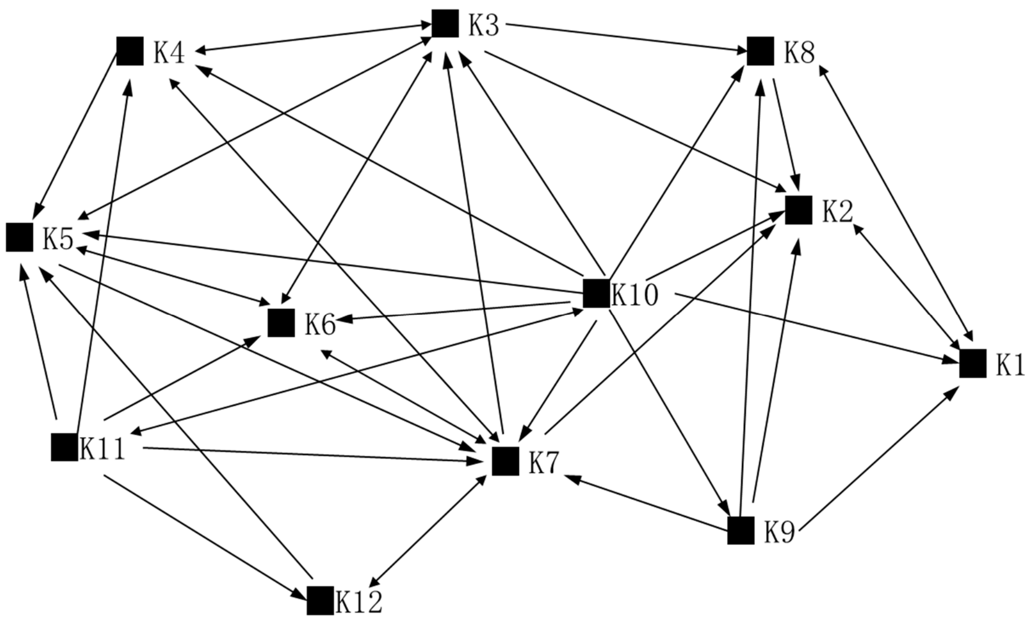

Figure 1. Network relationship of key hindering factors of BIM applications.

3.2. Results of Network Analysis

(1) Degree Centrality

Degree centrality means that a node may occupy a more favorable position if it has more connections than the other nodes. Degree is a very simple and effective measurement of node centrality, and it is divided into in-degree and out-degree. In-degree refers to the number of connections received by the node, indicating the number and association of the node affected by the other nodes. Out-degree refers to the number and association of the other nodes affected by this node. A high out-degree usually indicates that the node has more influence [71].

Using UCINET, the analysis results are shown in Table 8. It is found that the out-degree of factors K10 and K11 is large and that the in-degree is small, so it can be considered that these two key hindering factors have a great impact on the other factors in the network, but they are not easily affected by the other factors. They are the source and belong to spontaneous factors. K1, K2, K5, K8, and K12 have a small out-degree and a large in-degree. It can be considered that these five key hindering factors are easily affected by the other factors in the system network, but they do not easily affect the other factors. They are the result factors affected by other obstacles. K3, K4, K6, K7, and K9 have relatively middle values of out-degree and in-degree, which can be regarded as the general relevance and influence of these five factors on the other factors in the system network.

(2) Closeness Centrality

Closeness centrality reflects the distance between nodes. If a node is close to other nodes, it indicates a higher proximity centrality and, thus, the easier it is to transfer and obtain information. Then, this node can be considered an important node factor in the relationship network. Closeness centrality is divided into in-closeness centrality and out-closeness centrality. In-closeness centrality indicates how easy it is for the other nodes to reach this node. The higher the value, the easier it is for the other nodes to reach this node. The out-closeness centrality indicates the ease of a node to other nodes. The higher the value, the easier it is to connect this node to other nodes. In-closeness centrality indicates the degree to which the node is subject to other nodes, and out-closeness centrality indicates the degree to which the node restricts other nodes [73].

In the closeness centrality system network relationship, K10 and K11 have a high out-degree and a low in-degree, and they are located in the center of the system network, indicating that the restriction ability of these two hindering factors is strong. K1, K2, and K8 have a high in-degree and a low out-degree, indicating that the restriction ability of these three hindering factors is weak and needs to be transmitted by the resources of the other nodes, which is a passive factor. The out-degree and in-degree of K3, K4, K5, K6, K7, K9, and K12 nodes, which are general influencing factors in the system network, are not high.

(3) Between Centrality

Between centrality measures the ability of a node to control resources in the system network. It indicates the number of times a node acts as the shortest path bridge between two other nodes. The more the number of times, the more obvious the intermediary effect of the node.

According to the analysis results, the average between centrality of these 12 nodes is 3.333. Amongst them, the between centrality of K7, K3, K6, K2, and K10 is higher than the average, indicating that these five nodes have strong control over resources in the system network and have an obvious intermediary effect in the system network. The between centrality of K11 and K9 is 0, indicating that these two hindering factors basically do not play a role in the transmission process of the system network relationship. The other nodes have less between centrality, and the corresponding hindering factors have a lower conduction effect in the system network.

4. Discussion

This paper adopts the social network analysis method to explore the obstacles to BIM adoption, analyzes 12 key hindering factors of BIM applications, and draws the following conclusions:

(1) There is a lack of policies to promote BIM applications resulting in insufficient BIM market demand (K10), and the legal liability boundary of BIM is not clear and lacks relevant laws (K11). These two key hindering factors are self-developed reasons in the system network and are a source of influence. That is, the lack of policy and relevant laws is one of the most important barriers to BIM application in China. In China, the research power is mainly concentrated in the universities or institutes of the Academy of Sciences, which means that the research power of BIM and the standard of BIM mainly come from national policies [29]. Therefore, to promote the healthy development of BIM, the government needs to provide strong policy and legal support.

(2) The application of BIM increases the design cost (K2), the function of BIM software is not perfect (K3), BIM's data protection and security issues are not perfect (K6), and all stakeholders have insufficient awareness of sharing BIM achievements (K7). These four key hindering factors have an obvious intermediary effect. They occupy the center of the system network, and they play a strong controlling role in the application and development of BIM. Qin [12] believed that owners, designers, general contractors, and subcontractors do not have the willingness and motivation to use BIM in the Chinese construction market because the use of BIM does not bring obvious benefits and advantages, and, instead, it creates additional expenses (e.g., early software purchase, hardware installation, and personnel training costs). Qi [28] pointed out that building construction companies that use BIM are mostly influenced by technical aspects, such as software functions. As a result, to solve the hindering factors of BIM applications, the above four aspects should be examined, and their strong control characteristics should be used to promote the development of BIM applications.

(3) The costs of BIM expert consultation and training are high (K1); BIM's cloud service technology is not perfect (K5); stakeholders have different proficiencies in BIM applications (K8); there is a lack of systematic BIM education systems, and insufficient BIM-related materials and learning (K9); and there is a mismatch between responsibilities and risks of parties involved in BIM applications (K12). The out-degree of these five key hindering factors is small, and the in-degree is large, so, in the system network, they are passive factors and result factors, which are greatly affected. These five key hindering factors control ability is weak, and need to be transmitted by the resources of other nodes. According to the results, it can be seen that these five hindering factors are caused by BIM itself; therefore, it is necessary to pay attention to these factors in order to better promote the development of BIM applications. Li [46] pointed out that an imperfection in BIM software led to the difficulty of information exchange and sharing among various project participants, and it affected the popularity and promotion of BIM applications. Therefore, understanding the mechanisms of the BIM hindering factors can help to better solve the difficulties of BIM development.

5. Conclusions

Based on the CNKI and Web of Science databases, a total of 43 hindering factors that impede BIM applications in the Chinese construction industry were identified by using the methods of literature analyses, screening, and preliminarily interviews with experts. The 25 selected hindering factors were further classified into four categories: (1) economy, (2) technology, (3) social environment, and (4) system. Accordingly, a questionnaire survey was conducted, and the collected data were statistically analyzed using SPSS. The results found 12 key hindering factors of BIM applications. UCINET software was used to further analyze the social network of the 12 key hindering factors of BIM applications, and it reported the position and action mechanism of the 12 key hindering factors in the system network.

According to the research results, this paper draws the following conclusions: (1) there is a lack of policies to promote BIM applications resulting in insufficient BIM market demand, and the legal liability boundary of BIM is not clear and lacks relevant laws. These two factors are self-developed reasons in the system network and are a source of influence. (2) The application of BIM increases the design cost, the function of BIM software is not perfect, BIM's data protection and security issues are not perfect, and all stakeholders have insufficient awareness of sharing BIM achievements. These four key hindering factors have an obvious intermediary effect. (3) The costs of BIM expert consultation and training are high; BIM's cloud service technology is not perfect; stakeholders have different proficiencies in BIM applications; there is a lack of systematic BIM education systems, and insufficient BIM-related materials and learning; and there is a mismatch between responsibilities and risks of parties involved in BIM applications. These five key hindering factors are passive factors and result factors in the system network.

Despite the current findings, there are still some limitations to this study. First, this study identified the hindering factors of BIM applications through expert interviews and a questionnaire survey. Due to the subjective survey method, the identified factors would be affected by the respondents' experiences, subjective understanding, and other factors. Second, in clarifying the relationship between the key hindering factors of BIM, only one method, the social network analysis, is used in this research, and the results may be one-sided. Future studies should use other research data collection methods (e.g., a case study analysis) for specific practical cases, and they should use multiple methods for a data relationship analysis.

Author Contributions: Conceptualization, Z.W.; methodology, Y.L. and C.C.; software, C.C.; writing—original draft preparation, Y.L. and Z.W.; investigation, Q.H. (Qiufeng He) and Q.H. (Qing Hong); data curation, Q.H. (Qiufeng He) and Q.H. (Qing Hong); writing—review and editing, Q.H. (Qiufeng He) and M.F.A.-A.; visualization, C.C.; supervision, Z.W. and M.F.A.-A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Guangdong Basic and Applied Basic Research Foundation, grant number 2019A1515110247; the National Natural Science Foundation of China, grant number 72001148; and Research Start-up Funding in Shenzhen, grant number 000376.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The authors thank the editors and anonymous reviewers for their valuable and constructive suggestions for improving this paper.

Conflicts of Interest: The authors declare no conflict of interest.

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