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Investigating the Constraints to Buidling Information Modeling (BIM) Applications for Sustainable Building Projects: A Case of China

Lei Zhang [1], Zhenwei Chu [2,*], Qing He [1] and Peipei Zhai [3]

[1] School of Management Engineering, Shandong Jianzhu University, Jinan 250101, China; zhlei06@sdjzu.edu.cn (L.Z.); heqingzdsl@163.com (Q.H.)

[2] School of Business, Shandong Jianzhu University, Jinan 250101, China

[3] Department of Business Administration, Wonkwang University, Jeonbuk 54538, Korea; zhaipeipei.jju@hotmail.com

* Correspondence: leochu1929@163.com

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Abstract: China's construction industry is facing significant challenges in achieving sustainable development and digital operations. Integrating building information modeling (BIM) and sustainable construction is a good method for achieving these goals. However, barriers impact the applications of BIM technology to sustainable buildings, resulting in significant cost loss and time. As such, it is important to identify the constraints, hindering the application of BIM technology in sustainable buildings. This study used the factor analysis method, exploratory factor analysis (EFA), and structural equation modeling (SEM) to investigate the key constraints and conducted a questionnaire survey with 389 respondents to investigate the applications of BIM technology in sustainable building projects. The results showed that there were four main constraining factors: "Public participation", "technology application", "economic cost", and "application management"; "public participation" was particularly important. The study offers practical and managerial implications based on the findings for local government and the private sector and thus can improve the implementation of BIM technology in sustainable buildings and contribute to the accomplishment of China's sustainable development goals.

Keywords: building information modeling; sustainable building projects; structural equation; exploratory factor analysis

1. Introduction

Large resource consumption and contaminant outputs are of vital worldwide concern and are also a focus of attention in construction projects. Using innovative technologies and applying them to the theory of sustainability in the construction industry has been regarded to be effective in balancing environment protection and construction schedules [1]. By implementing green innovations, sustainable development is valuable in every aspect of a construction project. This involves conducting sustainable strategies and using advanced technologies [2]. Sustainable building projects, as an advanced building type, is attracting worldwide attention. It was initially proposed by researchers at Osaka University in Japan, who designed "sustainable architecture" in their research center. The buildings are decorated with green plants and are naturally cool. Therefore, constructors, architects, and designers are shifting their goals to design buildings in an environmental and natural way. These buildings have proven to be viable in real life. Due to their reductions in carbon dioxide (CO_2), advanced technology, environmental methods, and cost savings [3], sustainable buildings can create enormous profits. It has been widely cited as a useful approach, contributing to the reduction of resource waste and human health risks during construction [4]. For example, to improve high-efficiency of construction and achieve the goals of cost-saving in construction industry, the United Kingdom (UK), has applied technology of information modeling and visualization to strengthen the applications of sustainable buildings in the last decade [5]. Moreover, the economic benefits of sustainability on buildings have gradually emerged. A 2% increase in upfront building costs, for example, saves nearly 20% of building costs [6]. In a word, sustainable buildings are having positive impacts on environmental protection and on the development of green construction.

To achieve energy saving targets, methods and technologies have been presented with sustainable design, optimized management structure, and efficient energy use. Furthermore, monitoring building operations and sharing precise data are good ways to save energy in the process of construction. Building information modeling (BIM), is an acknowledged technology widely used in sustainable buildings, especially for energy usage, thermal flows, lighting patterns, and other sustainability measures [7]. It builds an information-sharing platform through application software and visualizes the building project to achieve a more efficient management of the project life cycle [8].

BIM technology is gradually becoming a hot point in the construction industry because of its model visualization characteristics and coordinated management of building information. The deepening of relevant research is bringing deeper changes to the construction industry [9]. Barlish (2012) noted that BIM has the advantages of improving design information quality, reducing construction costs, integrating management of project participants' information, contributing to the sustainable development of engineering projects, and speeding up the construction project [10]. In terms of practical use, the usage rate of actual BIM technology projects in Western countries is generally high [11]. There is significant evidence that the popularity of BIM adoption and innovation has brought improvement in the United States (U.S) and Europe [12]. A 2015 report from the U.S National BIM Standard found that BIM awareness and use dramatically increased from 13% to 48% from 2010 to 2014 [13]. In Europe, several countries, such as Sweden, Norway, and Finland have widely applied BIM tools in nearly 70% of their construction industry, which is higher than in other developed countries [14].

Building information modeling is also a representative method to help smoothly operate sustainability systems and develop the potential of sustainable buildings, described as a set of applications and process. BIM brings many benefits in sustainable building for project stakeholders [15]. It can generate and manage project information about energy consumption and provide accurate work flow data in the project operation process. BIM includes information and communication technology (ICT) framework and technology, which prompts collaboration among stakeholders over the life cycle of sustainable projects; this makes it easy to input, extract, exchange, or transform information in the BIM platform. Furthermore, BIM adoption in sustainable building projects has significantly improved and is used widely around the United Kingdom [16] and in North America [17]. However, the largest difficulty for sustainable buildings is the inability to achieve life-cycle data collection and project monitoring and conducting real-time data analysis to share with project participants. The visual characteristics of BIM technology can mitigate these shortcomings and help sustainable building projects achieve energy-saving goal. Therefore, ensuring the effective use of BIM technology in sustainable buildings is of great significance for promoting sustainable development in the world.

In the last several decades, China has witnessed unparalleled development in the architecture, engineering, and construction (AEC) industry. However, with mass projects being constructed, managing construction projects is becoming increasingly complicated and time-consuming, especially for very large projects. Meanwhile, energy waste and construction pollution are key problems for government and the public that hinder the development of society and economy. To address this issue, the integration of BIM and sustainable building projects is gradually being applied in China. For example, Pearl River Tower, as a landmark sustainable building project in China, has reduced energy cost by 30% and achieved optimized management structure under BIM usage. Therefore, given environmental characteristics, popularizing the combination of BIM technology and sustainable buildings is a good method to improve the development of the architecture industry and achieve environmental goals.

Based on the discussion above, it is critical to study the integration between the BIM and sustainable buildings in China. However, there are a number of constraints in applying BIM in sustainable buildings. Previous studies have not addressed these constraints totally, however, these constraints need to be carefully considered to develop and undertake effective measures for improving BIM technology use in sustainable buildings. This study determined these constraints and analyzed their impact on sustainable buildings in China. Once the key constraints were identified, recommendations were made for developing BIM technology in sustainable building projects and will provide the basis for future research on the integration of BIM and sustainable buildings.

2. Research Background

2.1. BIM in Sustainable Building Project

The key impact of sustainable buildings occurs when highly effective building performance helps address issues among stakeholders, including owners, users, and consumers, despite the barriers of time limitations and construction costs. Because of the silos and fragmentation associated with delivering several buildings, it is difficult to provide useful sustainable buildings' value to users. BIM provides an online platform for users, allowing them to work on an integrated online platform across the life cycle of the building delivery process. BIM allows for the solving of practical issues using environmental and highly-effective information strategies, mostly during the design stage.

For example, designers usually receive feedback on their design about the analysis of energy consumption. This includes how much energy the building will use, the anticipated CO_2 emissions, and if the building will pass performance criteria. The intelligent information created by the BIM model can conduct a whole-building energy analysis, simulate performance, and visualize appearance [18]. This provides building designers with direct feedback to test the design, allowing them to improve building performance throughout the building's life cycle. Applying BIM during the design stage can assess a wide range of construction options and their related environmental influences. Martin created a BIM conceptual model to assess the diversity of material compositions in sustainable buildings and the underlying factors affecting the total embodied impact of the building design [19]. The method integrating the BIM concept can identify specific hot spots at the design stage, which can be visualized through the building model, and facilitate communication between visual design guidance and LCA results.

The main benefit of adopting BIM technology in sustainable buildings is that it provides data for sustainability assessments and energy performance evaluations. This increases the value of the design of a sustainable building project. Previous studies have highlighted that applying BIM technology plays a vital role in waste reduction, which is an important aspect of a sustainable project [20]. For example, the highest building in China, the Shanghai Center, is a landmark for BIM use. This project has achieved massive profits from applying a new data management approach based in BIM technology. Applying BIM technology has led to significant project improvements in waste reduction, with a material rate of 4%, compared with China's average level of 10% [21]. In another case, a system-based BIM technology was applied to provide a risk evaluation of construction waste for contractors [22]. In the construction process, a lack of coordination and poor integration of building subsystems are the main factors limiting the normal operation of BIM technology, leading to mass construction waste. A real-time BIM and System Dynamics-based methods have been proposed to minimize construction waste generated throughout the building process [23].

It is critical to supervise the normal performance of sustainable building across life cycle processes to ensure real performance. BIM technology, with its visualization features, provides an online platform that confirms the normal supply, integration, and data exchange across the construction life cycle [24]. Therefore, it has been widely noted that BIM technology plays a critical role in monitoring sustainability performance throughout the operation phase of sustainable building [25]. For example, BIM technology can be integrated with a cloud-based system during the operations stage to support data storage and transmission in sustainable buildings [26].

2.2. Constraints in Application of Building Information Modeling

BIM technology is usually used for very large projects and involves investing large amounts of money into construction management. BIM technology is widely popular in management of construction projects and is helping construction teams save construction cost and energy consumption. However, there remain many constraints and risk factors in developing and managing construction projects. Therefore, it is critical to effectively identify and control key constraints and factors impacted by using BIM on construction projects, compared to projects that do not use the BIM technology. Previous research has emphasized underlying constraints in the process of BIM implementation. For example, to improve the interoperability performance in BIM, Arayici proposed a specific approach to help develop BIM execution in construction projects [27]. In order to establish a review analysis on critical success factors, Antwi-Afari (2018) conducted a comprehensive review on study of CSFs for BIM implementation and provided valuable reference for future research [28]. Also, Tan (2019) highlighted the barriers to BIM implementation in China's prefabricated construction and offered technological and managerial solutions to improve BIM implementation in China's prefabricated construction [29].

Construction projects often face diverse constraints that hinder normal project operations. To ensure revenue maximization in construction projects using BIM technology, the underlying constraints must be identified in the preparation stage.

2.3. Researches on BIM Applications in Sustainable Building Project

From a macro-perspective, BIM technology is an application that enhances overall planning and coordinated management, helping sustainable buildings achieve revenue goals. From a micro-perspective, BIM technology is a dynamic decision-making tool for sustainable buildings. The information in the software system is used throughout the project's life cycle. In recent years, with the rapid development of BIM technology and the increasing number of sustainable construction projects, many scholars have focused on combining BIM technology and sustainable architecture.

For example, taking an economic perspective, B. Soust (2017) focused on a life-cycle cost assessment and proposed the integration of BIM and LCA [26]. This approach can simplify data acquisition for the building and provides feedback into both tools. Bynum (2013) investigated perceptions associated with applying BIM in sustainable buildings, mainly based on the perspective of sustainable design among designers and constructors [30]. The research results indicate that most interviews noted that sustainable design and construction practices matter. However, many respondents noted that applying BIM was not a key tool in sustainable building for designers and managers.

Conducting a simulation analysis between BIM and sustainable building projects, Sandeep (2014) concentrated on applying BIM with a day-lighting simulation and analysis in sustainable buildings and discussed the application of BIM technology for simulating building performance [31]. The researchers also addressed how to integrate a daylight analysis with a BIM environment. Fh. Abanda (2016) investigated the impact of energy consumption in small-scale sustainable construction, assessing how BIM can be used to facilitate this process. With the analysis of the energy consumption relating to the different orientations, the final result showed that well-oriented sustainable buildings can save significant energy throughout the life cycle [32]. Looking at the constraints on the stage of construction, Timothy (2018) investigated the barriers to integrating BIM in sustainable construction projects and used descriptive and inferential tests for data analysis to identify critical constraints [33].

With the increase of BIM applications in sustainable buildings, new questions have emerged for BIM practitioners: What are the major constraints in applying BIM with sustainable projects? What can we do to identify the key constraints? How will we overcome these constraints?

The literature review above provides useful information for identifying the constraints impacting BIM application in sustainable buildings. However, there are few studies that address the constraints of applying BIM in sustainable buildings in China. Consequently, this type of research will benefit the construction industry, cultivating BIM technology to play a key role in sustainable buildings.

3. Research Methodologies

The following methods were used in this article to identify the critical constraints affecting the applications of BIM in sustainable buildings. Figure 1 presents the research framework.

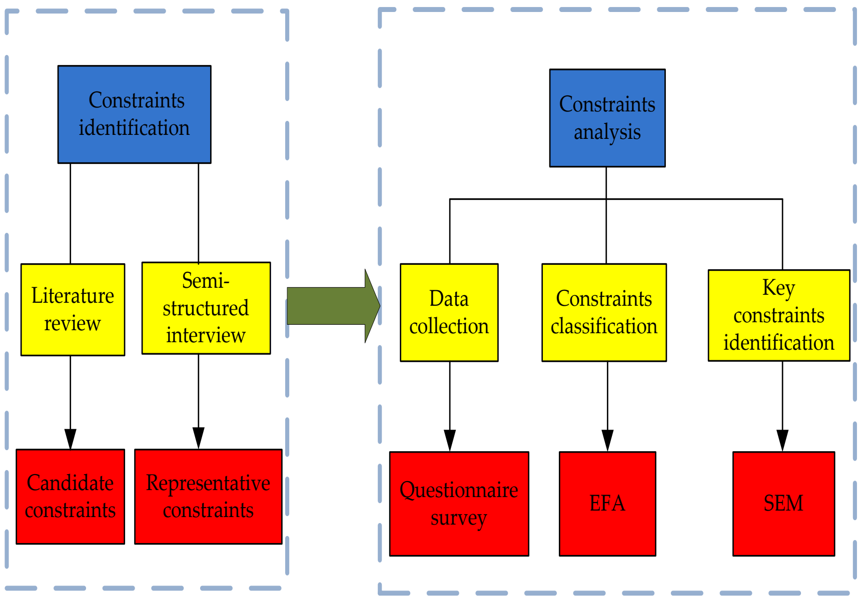

Figure 1. Research framework.

3.1. Methods for Identification of Representative Constraints

In this study, professional books, published authoritative literature, and influential websites were used to find almost 31 candidate constraints related to applying BIM in sustainable buildings. Table 1 presents this list of constraints.

Semi-structured interview is a broadly used way to select and identify representative constraints, because it can provide a direct link with the researchers. This approach uses face-to-face discussion to decrease the error associated with the process of constructing a project and ensures the authenticity of collected data among interviewed participants. Moreover, it tends to provide information about effective approaches to stimulate inspiration and address problems that actually exist in the factual situation [34].

The interviewees for this study had diverse backgrounds. Ten practitioners from different industries were selected as interviewees to offer representative constraints. Among the ten practitioners, two practitioners worked at a university in the field of construction management, with almost 20 years of experience in researching BIM applications. Two practitioners worked in construction administration departments and have abundant supervising knowledge about BIM application in sustainable buildings. Two practitioners were senior project-management counselors from two different BIM consultancy companies. Two were top managers of a construction firm. Two practitioners were senior designers at design firm. Table 2 shows the backgrounds of the interviewees.

Table 1. Candidate constraints to the application of building information modeling (BIM) technology in sustainable buildings.

Code	Constraints	Reference
1	Lack of detailed processes for applying BIM technology in sustainable buildings	[35]
2	Lack of clear BIM application standards in sustainable buildings	[36]
3	Shortage of cross-disciplinary experts in BIM and sustainability	[37]
4	Low level of involvement of BIM users in sustainable building	[36]
5	Lack of appropriate BIM software procurement policies and contractual agreements	[38]
6	Lack of legal framework for BIM application	[39]
7	Difficult to obtain accurate BIM application data results in sustainable buildings	[38]
8	Lack of understanding of the process and workflow required for BIM and sustainability	[40]
9	Little research on BIM technology in sustainable buildings	[41]
10	Lack of clear BIM technology application standards in sustainable buildings	[42]
11	Incompatibility issues between different software packages	[43]
12	Lack of supporting sustainability analysis tools	[44]
13	Lack of a clear definition of operational management data exchange	[40]
14	Unreliable estimates of energy analysis using BIM in sustainable buildings	[40]
15	Incompatibilities between BIM data and sustainable building application requirements	[43]
16	Lack of BIM data definitions for sustainable buildings	[42]
17	Non-implementation of open source principles for software development	[37]
18	Lack of clarity about purpose and concern about future expenditures	[39]
19	Unpredictable technical training fees	[39]
20	High BIM software and application expenditures	[43]
21	Recurring need for additional and associated resources and high economic expenses	[45]
22	High-cost expenditures for specific information systems that integrate BIM technology with sustainable buildings	[43]
23	Lack of senior management support and attention	[46]
24	Psychological resistance of practitioners to new technologies	[46]
25	Longer time required to adapt to new technologies	[44]
26	Uncontrolled application risk of BIM technology in sustainable buildings	[47]
27	Increased liability	[47]
28	Non-uniformity of sustainability evaluation criteria and measures	[35]
29	Difficulty in allocating and sharing BIM-related risks	[47]
30	Inadequacy of BIM data schemas to semantically represent sustainability-based knowledge	[48]
31	Lack of a comprehensive framework and implementation plan	[49]

Table 2. Interviewee backgrounds.

Interviewers	Work Place	Job Position	Working Years	Interview Type
A	University	Professor	≥20 years	Teleconferencing
B	University	Professor	≥20 years	Face-to-face
C	Government	Department director	10–15 years	Face-to-face
D	Government	Department director	10–15 years	Teleconferencing
E	Construction firm	BIM engineer	10–15 years	Face-to-face
F	Construction firm	Senior manager	≥20 years	Face-to-face
G	Consultancy firm	Senior counselor	10–15 years	Face-to-face
H	Consultancy firm	Senior counselor	≥20 years	Face-to-face
I	Design firm	Senior designer	10–15 years	Face-to-face
J	Design firm	Senior designer	≥20 years	Face-to-face

As the research background indicated, few studies have been published that support this research of BIM applications in sustainable buildings. Thus, there was concern that the 31 candidate constraints in Table 1 may not be representative and effective. To address this concern, semi-structured interviews were conducted to ensure that the representative constraints were adequately identified. Experts participated in two rounds of interviews. First, experts were asked to share their views about the feasibility of the candidate constraints. Practitioners were then asked to suggest ways to improve BIM applications in sustainable buildings. These discussions focused on the following questions: Are the expressions of the constraints suitable? If not, how should they be revised? Are any of the constraints similar? If so, how should they be integrated? Are there any key constraints? If so, how should they be selected? After sorting the suggestions, a new list of candidate constraints was developed. Next, experts were asked to select and judge representative constraints, based on the principle that “the minority subjects to the majority". In this study, representative constraints considered to be a better fit by more than 5 practitioners were selected into a final list. Table 3 shows the new list of 22 constraints.

Table 3. Representative constraints list.

Code	Constraints
1	Lack of detailed application processes for BIM technology in sustainable buildings
2	Shortage of cross-disciplinary experts in BIM and sustainability
3	Lack of appropriate BIM software procurement policies and contractual agreements
4	Lack of application legal framework
5	Lack of clear BIM application standards in sustainable buildings
6	Lack of understanding of the process and workflow required for BIM and sustainability
7	Little research on BIM technology in sustainable buildings
8	Difficult to obtain accurate BIM application data results in sustainable buildings
9	Lack of a clear definition of operational management data exchange
10	Unreliable energy analysis estimates using BIM in sustainable buildings
11	Incompatibilities between BIM data and sustainable building application requirements
12	Lack of BIM data definitions for sustainable buildings
13	Non-implementation of open source principles for software development
14	Lack of clarity about purpose and concern about future expenditures
15	Unpredictable technical training fees
16	High BIM software and application expenditures
17	Recurring need for additional and associated resources and high economic expenses
18	High-cost expenditures for specific information systems that integrate BIM technology with sustainable buildings
19	Lack of attention from senior managers
20	Psychological resistance of practitioners to new technologies
21	Longer time needed to adapt to new technologies
22	Lack of a comprehensive framework and implementation plan

3.2. Method for Identifying Key Constraints

3.2.1. Data Collection

A questionnaire survey was used to collect recommendations about the significance of the representative constraints developed through the interviews. The questionnaire was based on the literature reviews and semi-structured interviews and was based on the ten experts' comments. A total of 389 candidates were selected to respond to the survey. The survey was conducted from June to November 2018. Candidates came from cities around China, including Beijing, Shanghai, Guangzhou, Shenzhen, Qingdao, Zhengzhou, Jinan, Tianjin, and Taiyuan. The respondents were mainly from universities, research institutes, construction companies, government departments, and consultancy firms. Fundamental respondent qualifications included having sufficient professional knowledge and advanced working experience with sustainable construction projects related to the application of BIM technology. The Likert scale was used to rate respondent views on the relative significance of the different factors; 5 meant very valuable and 1 meant very low value.

Questionnaire surveys were distributed by hand (135), email (147), and posting via the internet (107). Table 4 provides a profile of the respondents. A review of the questionnaire information indicated that the selected options on 11 questionnaires were all the same and 23 questionnaires had missing options. The questionnaires were determined to be randomly completed and were thus deemed invalid. The final statistics indicated there were 355 valid questionnaires, resulting in an effective questionnaire recovery rate of 91%. The selected samples meet the model analysis requirements.

Table 4. Distribution of respondents.

	Category	Frequency	Percentage
Gender	Male	180	46%
	Female	209	54%
Age	20–30	80	21%
	31–40	100	26%
	41–50	101	26%
	Above 50	108	27%

Table 4. *Cont.*

	Category	Frequency	Percentage
Education	Specialists and below	30	8%
	Bachelor	120	31%
	Master	169	43%
	PhD	80	21%
Position	Executive manger	40	10%
	Designer	35	9%
	Project/site manager	30	8%
	University professor	53	14%
	BIM engineer	66	17%
	Other	165	42%
Parties	Developer	63	16%
	Consultancy company	95	24%
	Construction company	37	10%
	University	107	8%
	Research institute	38	10%
	Government department	69	69%
BIM experience	0–3 years	159	41%
	3–5 years	102	26%
	Above 5 years	128	33%

3.2.2. Identifying Key Constraints

Representative constraints were roughly selected based on previous research. However, it is not easy to identify the key constraints affecting the process of applying of BIM technology in sustainable buildings. Exploratory factor analysis (EFA) is an effective method to identify key constraints. After classifying the representative constraints, EFA can clearly illustrate the relationship among the interrelated variables [50]. Further, EFA offers a combination of interrelated variables into a smaller extracted set of new common dimension factors or constructs. From the perspective of research applications, EFA has been widely applied and plays an important role in classifying loads of factors or indicators into different kinds of groups. For example, Shen et al. (2016) used EFA to identify the potential constraints in achieving infrastructure sustainability of mountainous townships in China [51].

After collecting representative constraints using EPA, the determination of key constraints is crucial. Structural equation modeling (SEM) is a good statistical way to test and analyze causal relationships between observed variables and latent variables [52]. SEM is an important branch in applied statistics, and is widely used in different research areas, including sociology, management science, and behavioral science [53]. Thus, SEM is mostly used to get EPA results and then confirm the key constraints. The software AMOS is widely adopted to apply SEM. Version 22.0 was used for this study.

4. Analysis of the Representative Constraints

This section classifies the representative constraints and identifies the key constraints. The questionnaire survey provided the data that was analyzed.

4.1. Data Analysis

4.1.1. Convergent Validity

Reliability is determined by testing the degree of consistency within the measurement results. This study used SPSS 22.0 to verify data reliability, generating a Cronbach's alpha coefficient value as the measure. When the alpha coefficient approaches 1, the item is more related to the corresponding variable. When Cronbach's alpha coefficient is between 0.6 and 0.8, it exhibits effective reliability;

a value greater than 0.8 is the best effective reliability [54]. The research and analysis for this study generated a reliability coefficient value of 0.914, which is a very high data reliability level.

4.1.2. Discriminant Validity

Validity refers to the extent to which the data are reflected in the expected measurement using a variety of measurement methods. Validity verifies data validity using KMO values, commonality, cumulative variance interpretation rate, and other indicators. This study analysis shows that the common value of all research items exceeded 0.4, indicating that the research item information can be effectively used. The KMO value was 0.819, which exceeds 0.6. This indicates the data were valid, with a cumulative variance interpretation rate of 72.005%. Because this is greater than 50%, research data can be effectively extracted.

4.2. Classification of the Constraints

The SPSS software analysis found that the 22 constraint variables were strongly correlated and can be classified into four common factors, covering public participation (F1), technology application (F2), economic cost (F3), and application management (F4). The PCA method was to be applied to identify four common factors from the 22 constraints variables. In the PCA analysis, the cumulative contribution of variance reached 83.67%. This indicated that the four factors selected can accurately represent 22 variables, listed in Table 5 (the numbers correspond to the constraints listed in Table 3). Orthogonal rotation was used for the original factor-loading matrix [47]. After orthogonal rotation with Kaiser normalization converged to 7 iterations, the coefficients in the rotated factor loading matrix were more correlated and the relationship among the four factors were restructured.

Table 5. Rotated factor loading matrix.

Constraints	F1	F2	F3	F4
V1	0.824			
V2	0.811			
V3	0.732			
V4	0.965			
V5	0.936			
V6	0.715			
V7		0.746		
V8		0.786		
V9		0.891		
V10		0.876		
V11		0.913		
V12		0.698		
V13		0.798		
V14			0.843	
V15			0.823	
V16			0.816	
V17			0.765	
V18			0.789	
V19				0.836
V20				0.814
V21				0.754
V22				0.887

4.3. Identification of Key Constraints

There are differences in the degree of significance of each constraint to the applications of BIM in sustainable buildings. Identifying the key constraints is critical for adopting the most effective measures to improve BIM performance in sustainable buildings. SEM was therefore applied to analyze the EPA results and identify the key constraints.

4.3.1. Hypotheses and Assessment Model

According to the EFA results in Table 5, the following hypotheses were developed to describe the relationships between the variables.

H1. *The variables classified as "public participation" significantly influence the application of BIM in sustainable buildings (ABSB).*

H2. *The variables classified as "technology application" significantly influence the application of BIM in sustainable buildings (ABSB).*

H3. *The variables classified as "economic cost" significantly influence the application of BIM in sustainable buildings (ABSB).*

H4. *The variables classified as "application management" significantly influence the application of BIM in sustainable buildings (ABSB).*

In this study, the 22 constraints in Table 3 were the observed variables and the four common factors were unobserved latent variables. This led to Figure 2, which presents a conceptual framework for an assessment model to evaluate the degree of constraint significance for sustainable buildings. The ovals represent unobserved latent variables, the rectangles represent observed variables, and the arrows represent the relationships among the variables [48].

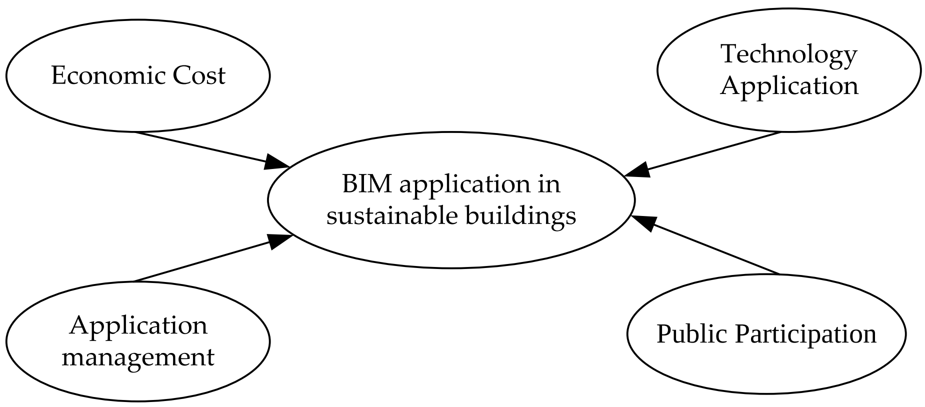

Figure 2. Framework for the assessment model.

4.3.2. Structural Mode

For this study, AMOS 22.0 was used to test the fitness of the model and to perform the fitting analysis. The operation revealed an RMR value of $0.042 < 0.05$, an RMSEA value of $0.063 < 0.08$, a GFI value of $0.953 > 0.9$, an IFI value of $0.964 > 0.9$, and the AGFI value was $0.971 > 0.9$, meeting the adaptation standard value. However, the values of the indicators TLI ($0.077 < 0.9$), CFI ($0.791 < 0.9$), PGFI ($0.466 < 0.5$), and PNFI ($0.452 < 0.5$) deviated from the adaptation standard values. The overall fit of the model was not good.

4.3.3. Refining the Model

Goodness-of-fit (GOF) measures are an effective way to improve the fitness of an initial model [55]. After adding covariance error paths among observed variables or latent variables, the model showed a good fit and all of the GOF measures met recommended levels. Table 6 compares the degree of fit before and after the model correction. With respect to the strong practical significance for all 22 observed variables, the model was refined by releasing variables, but not deleting them. In this study, the GOF measures of the final refined SEM model demonstrated a successful fit between the hypothesized SEM model (Figure 3).

Table 6. Model fit test.

Goodness of Fit Index	Original Model	Modified Model	Model Matching Criteria
GFI	0.953	0.964	GFI > 0.9
IFI	0.964	0.978	IFI > 0.9
AGFI	0.971	0.972	AGFI > 0.9
RMSEA	0.063	0.063	RMSEA < 0.08
RMR	0.042	0.042	RMR < 0.05
CFI	0.791	0.921	CFI > 0.9
TLI	0.077	0.987	TLI > 0.9
PNFI	0.452	0.582	PNFI > 0.5
PGFI	0.466	0.572	PGFI > 0.5
P-value	0.021	0.021	P < 0.05
X2/df	1.116	1.277	X2/df < 2

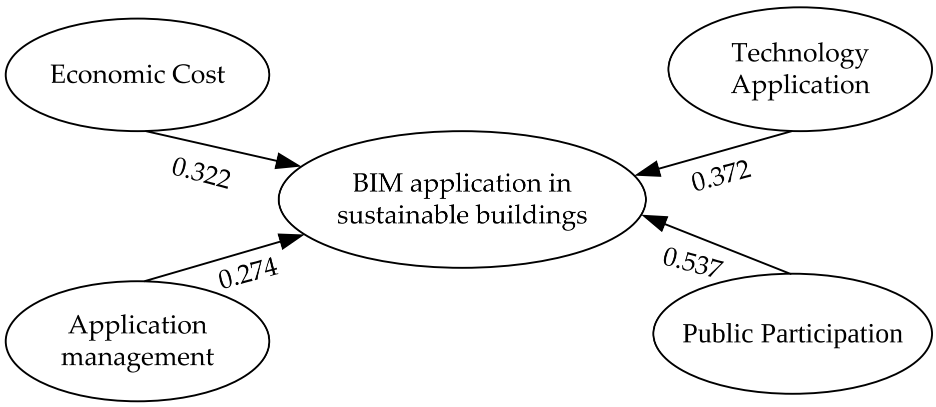

Figure 3. Framework for the assessment model.

4.3.4. Results

Using the SEM model, the research indicated that public participation for applying BIM is the most important factor in the process of applying BIM in sustainable building projects. In the SEM model, the factor loading values were higher and the observed variables (the 22 constraints) were more consistent with the latent variables (namely, the four common factors) [54]. This indicates that the observed variables with the higher factor loading had the largest impacts on the latent variables. In this study, the value of the factor loading showed the degree of significance between the latent variables and observed variables when applying the BIM technology in sustainable buildings, as shown in Table 7. All the standardized path coefficients for regression weights and covariance were highly positive and significant at the 0.01 level. This indicates that all of the regression weights and the covariance were statistically significant.

The path analysis of the structural model revealed the following results: Public participation ($\beta = 0.537$, $P < 0.001$), technology application ($\beta = 0.372$, $P < 0.001$), economic cost ($\beta = 0.322$, $P < 0.001$), and application management ($\beta = 0.274$, $P < 0.05$). The study hypothesis was verified and the four variables were shown to positively affect the application of BIM technology in sustainable buildings. The public participation was the most influential variable, indicating that the effective control of external influencing factors and the application of the standard are important in promoting the application of BIM technology in sustainable buildings. The other three factors also have a positive impact.

Table 7. Model goodness-of-fit index.

Assumed Path	Estimates	T-Value	S.E	P	Test Results
public participation → ABSB	0.537	8.765	0.059	***	Important significance
technology application → ABSB	0.372	7.793	0.049	***	Important significance
economic cost → ABSB	0.322	5.543	0.043	***	Important significance
application management → ABSB	0.274	2.335	0.028	**	Important significance

Note: * represents $p < 0.05$; ** denotes $p < 0.01$; *** indicates $p < 0.001$.

5. Discussion

Verifying the SEM path revealed that the public participation is the largest influencing factor for applying BIM technology in sustainable buildings. Technology application, economic costs, and application management have less of an impact on BIM technology in sustainable buildings. For the public participation dimension, the most critical limiting factors were the lack of clear BIM application standards in sustainable buildings, the lack of understanding of the processes and workflow required for BIM and sustainability, and the shortage of cross-disciplinary experts in BIM and sustainability. Among these factors, a lack of understanding of the process and workflow required for BIM and sustainability had the largest load factor, which is the most critical limiting factor. This shows that in a sustainable building project, strengthening BIM technology training for users and explaining the entire BIM application process is the most critical link.

This study's findings are consistent with a study by Timothy O. Olawumia et al. [1]. During the research process, it was found that a lack of familiarity about BIM technology in the process of sustainable buildings directly led to the failure of most technical users to successfully work with it. This led to a chaotic work system and significant economic losses. Second, the lack of a clear BIM application standard for sustainable buildings also significantly impacted the normal work of users. Sustainable building energy analysis data cannot be effectively displayed in BIM and indirectly leads to sustainable buildings parameters. This evaluation error has caused the entire energy saving model to fail [37]. A shortage of BIM and sustainability cross-disciplinary experts also plays a crucial role in applying BIM technology in sustainable buildings. As mentioned in the literature review, sustainable building project is a new type of building and BIM technology has not been used for a long time around the world. As such, there are few experts who know how to apply the two technologies [55]. This makes the government and construction companies particularly critical in developing cross-disciplinary talent.

For the technology application dimension, the following constraints impacted the application of BIM technology in sustainable buildings: On compatibilities between BIM data and sustainable building application requirements, lack of clear definition of operational management data exchange, and unreliable estimates for energy analysis in using BIM. The survey found that incompatibility with BIM data and sustainable building application requirements was the largest limiting factor. For example, the raw data in BIM must be modified to support green energy efficiency analysis in sustainable buildings. To meet green energy conservation requirements, it is difficult for the sustainability analysis system to adopt the large amount of BIM data.

Data extraction and data exchange are key factors for increasing the compatibility between BIM technology and sustainable system analysis. Some scholars are actively engaged in improving this problem. To ensure specific data are extracted in the BIM, Daniel (2013) designed a new algorithm for sustainable building applications for the entire model, thus ensuring normal model operation [56]. Arno (2017) designed an automatic semantic identification system that ensures automated information exchange between the BIM and other systems in sustainable buildings [57].

Second, a lack of clear definitions with respect to operational data exchange management has an important impact on the application of BIM technology in sustainable buildings. For example, the

BIM system and sustainable buildings information management system need real-time data exchange across operation processes. However, the application modes of the two systems are not uniform with respect to data exchange. This results in chaotic system operation. Furthermore, the results of sustainable analysis are not accurate and have technical limitations. Another constraint with respect to technology application is the problem of unreliable energy analysis estimates when using BIM. For example, in the U.S, Autodesk Ecotect underestimated thermal loads across all field measurements and overestimated illuminance levels in 98% of LEED Gold-certified university buildings [58].

With respect to economic management, economic constraints include: A lack of clarity of purpose and concerns about future expenditures, unpredictable technical training fees, and high BIM software and application expenditures. Of these, the perceived lack of purpose and concern about future expenditures are the biggest limiting factors. As mentioned above, BIM technology is being applied to more and more projects. However, BIM is an emerging technology and the application of the technology to projects is not yet sufficiently stable to effectively control application cost. Sustainable building project is also a new form of construction and the management costs and benefits of the building sustainability system cannot be accurately determined. Therefore, it is difficult to estimate the cost of combining BIM technology with sustainable buildings. This leads to users being worried about the prospects of applying BIM technology in sustainable buildings.

Unpredictable technical training fees also significantly impact the application of BIM technology in sustainable buildings. As noted above, there is a lack of cross-disciplinary experts in the construction industry who understand BIM technology and sustainable buildings. Therefore, BIM technology users cannot gain comprehensive technical training, reducing work efficiency. Furthermore, it is expensive to purchase BIM software and to establish a sustainable building information management system. The subsequent equipment maintenance and software updates are also expensive. High BIM software and application expenditures greatly impact on the application of BIM technology in sustainable buildings [44].

In terms of application management, there is a lack of a comprehensive framework and implementation plan, lack of senior management attention, and practitioners psychologically resist new technologies. The lack of a comprehensive framework and implementation plan is the most critical limiting factor. Because sustainable building is in an initial stage, market awareness in China is not high and there are few application projects combined with BIM technology. Senior managers have certain deviations from the formulation of the implementation plan and cannot be forced. The lack of a comprehensive and integrated framework negatively impacts the long-term development of BIM technology in sustainable building projects.

A lack of senior management attention has an important impact of BIM technology on sustainable buildings. In sustainable building projects, the level of emphasis on BIM technology by senior managers has contributed to the integration of BIM technology and sustainability systems. In contrast, if managers have negative attitudes toward BIM technology, the BIM technology may become ineffective. This result is consistent with research by M. Abubakar [47]. Also, the psychological resistance of practitioners to new technologies is a difficult problem in application management. Technicians often show a certain resistance to the promotion of new technologies and concepts; this is one of the obstacles affecting the effective operation of BIM technology in sustainable buildings.

6. Conclusions and Implications

This study focused on the application of BIM technology in sustainable buildings in China. Using expert semi-structured interviews, the study identified limiting factors and combined EPA and SEM to identify key constraints. The study results show that the public participation has the greatest impact on the application of BIM technology in sustainable buildings. Technology application, economic costs, and application management are the main influencing factors. To better apply BIM technology, this paper concludes with the following recommendations for the government, enterprises, and individuals to promote the application of BIM technology in sustainable buildings.

First, the results of this study offer useful reference for relative authorities and government to formulate relevant legal norms to improve the applications of BIM in sustainable buildings; by formulating relevant regulations, the participating units in projects will clarify the application standards of BIM technology. This would strengthen the synergistic management effect of sustainable buildings and ensure efficient project operations. For example, considering the constraints of the technology application, the authority can make suitable technical policies to effectively implement BIM technology in sustainable buildings, so that BIM technology can be more effectively applied.

Second, at the enterprise level, relevant companies should have an in-depth understanding of the combination of BIM and sustainable buildings, increase technical training for employees, and conduct training lectures and skill development. In addition, a BIM technology application skill competition should be held regularly to enable employees to improve their practical skills.

Third, from the individual perspective, BIM users should understand the value of BIM technology application in sustainable buildings. This awareness would increase the degree of perceived satisfaction and enhance the willingness to use the system. BIM users need to strengthen their psychological commitment and enhance their own technical knowledge by studying excellent individual role models. Moreover, employees would benefit from increasing effective communication with project team members, reducing negative emotions such as change resistance, and promoting an optimistic psychology with respect to achieving the goal.

Like all studies, this research study has some limitations. First, future studies should expand the selection of research projects to be more comprehensive, as insufficient survey questionnaires lead to measurement errors. Second, few BIM technologies have been applied in sustainable buildings and there were deviations in the survey data. In a follow-up study, the sample types for the survey will be further enriched, to make the survey dimension more stereoscopic and the data sources more extensive.

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