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Research on the Adoption Behavior Mechanism of BIM from the Perspective of Owners: An Integrated Model of TPB and TAM

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Abstract: How to expand an owner's market demand for BIM and fundamentally mobilize an owner's application enthusiasm is of great significance to the high-quality development and effective promotion of BIM. Taking the Theory of Planned Behavior (TPB) as the basic framework and integrating the Technology Acceptance Model (TAM), we build a theoretical model of an owner's adoption behavior mechanism for BIM technology. The theoretical model is tested by the partial least squares structural equation model (PLS-SEM). The research results show that the perceived usefulness of BIM technology by an owner is the most significant factor that affects the owner's behavioral intention to apply BIM technology. The influence of attitude on behavioral intention is very weak and not significant. Subjective norms can significantly and positively affect an owner's adoption intention. The perceived ease of use has a positive impact on the adoption intention of BIM technology, but its role is very limited. The adoption intention of an owner can positively affect adoption behavior and has a direct driving effect. The research results can improve the relevant research on BIM, encourage an owner to actively participate in the development process of BIM, and further promote the comprehensive promotion and application of BIM.

Keywords: BIM; PLS-SEM; theory of planned behavior; technology acceptance model

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1. Introduction

Globally, the wide and intensive application of information technology has been considered an important strategic tool to improve the production and management of the construction industry. Building information modeling (BIM) is a dynamic decision-making tool for creating and managing parametric digital models of buildings (or infrastructure projects) [1], which enables the integration and sharing of information throughout the life cycle of buildings [2]. It also helps to fundamentally solve the problem of information disconnects during the life cycle of buildings, which can provide a reliable basis for decisions during the project life cycle, thus assisting in solving traditional project performance problems such as cost overruns, schedule delays, and quality defects [1]. BIM has changed the management mode of architectural design, construction, and operation in many countries, leading to technological progress and innovation in the construction industry.

Although BIM has shown greater advantages in the construction industry and has begun to receive increasingly widespread attention, it is common for many professionals and organizations to be unwilling to adopt BIM. There are still significant obstacles to the adoption of BIM technology [3]. From a global perspective, due to the complexity, ambiguity and resource requirements of BIM technology, the actual application of BIM technology and its huge potential advantages still have a relatively large gap. Additionally, the breadth and depth of BIM adoption in practice are not as satisfactory [4,5]. The study of BIM's application value in Australia and New Zealand found that, compared with design enterprises and construction companies, only a small number of BIM application enterprises believe that they have only experienced a small part of the value that BIM can

create for them. Furthermore, the use of enterprises shows an uneven state [6], and the overall level of BIM adoption and application level are low [7], which has encountered greater challenges in the adoption of BIM technology. The current research on the adoption of BIM technology mainly includes the following two dimensions:

(1) Research on the barriers to BIM adoption. At this stage, scholars in the field of empirical evidence have conducted a multilevel and in-depth analysis of the barriers to the promotion of BIM. Lindblad [8] summarized and analyzed the current barriers to the adoption and promotion of BIM technology, including the slow development of BIM technology software, the limited compatibility and interoperability of the software itself, the lack of unified international standards for the application of BIM technology, and the time and financial cost of training to master BIM technology. Von [9] proposed that the main barriers to the adoption of BIM technology include the huge capital investment required to carry out BIM technology, the lack of successful cases of BIM technology adoption, the difficulty of forming a long-term mutually beneficial cooperative partnership between construction project developers and contractors, and the lack of high-level BIM experts. Oesterreich et al. [10] pointed out that the obstacles to adopting BIM mainly come from the social behavior of actors and social arrangements in the construction industry rather than technical issues. Mehran [11] focused on the influencing factors of BIM technology adoption in the United Arab Emirates, and the research results reveal three main obstacles to implementing BIM: resistance to change, lack of BIM, and lack of BIM awareness. Browne et al. [12] further pointed out that the degree of institutional pressure from the government level plays a key role in the adoption of BIM technology, and the industry barriers among BIM software vendors have become a major barrier to the adoption of BIM technology. Guanpei [13] mentioned that construction project companies adopting BIM technology services need to weigh the advantages and disadvantages of adopting BIM technology in the whole life cycle of construction projects against the high cost of adopting BIM technology. Gu [14] and Monteiro [15] pointed out the factors that hinder the adoption of BIM technology, such as immature implementation policies and standards related to BIM technology, uneven development of BIM in different regions, and a lack of BIM software application combinations that can meet the current needs of the construction industry.

(2) Research on the enhancement path of BIM adoption. Hong et al. [16] evaluated the benefits, costs, and challenges of BIM implementation faced by SMOs in Australia, and confirmed that potential benefits are a major incentive factor for BIM implementation. In addition, the ability of existing employees to use BIM tools ultimately determines the decision to adopt BIM. Ngowtanasawan [17] explored the main factors affecting BIM. The main factors affecting the adoption of technology are BIM characteristics, including product quality, relative advantages, testability, ease of use, and compatibility. Jung [18] quantified the level of BIM technology adoption and implementation by analyzing actual BIM project visualization icons. Chong [19] analyzed BIM technology standards and evaluated BIM technology sustainability to assess the operability of BIM technology adoption from a circular economy perspective. Madusanka [20] believed that changing traditional management models is a strong guarantee for the efficient application of BIM; as under the IPD model, project participants can strengthen collaboration and communication, so it is considered the most suitable management mode to ensure the maximum value of BIM. Kassem [21] constructed a dynamic theoretical model for BIM technology adoption and measured the benchmark path for BIM technology adoption at the national level based on empirical research and analysis results. Gledson [22] concluded that strengthening 4D BIM technology as an innovation is conducive to the adoption and promotion of BIM technology based on Rogers' Diffusion of innovations and through empirical analysis of British construction projects. Mamter [23] used an empirical analysis to investigate the adoption and promotion of BIM technology in Malaysia, which is the value of

BIM technology and the importance of its various dimensions. Mahalingam [24] concluded through an analysis of two actual BIM technology adoption projects in India that design optimization and project refinement management based on BIM technology should be reflected as the main characteristics of BIM technology adoption and promotion.

In summary, these studies are of great significance to the development and promotion of BIM, but there are still some shortcomings: First, the current studies on BIM technology mainly focus on the barriers to the promotion of BIM and improvement strategies, and the research perspectives are mostly from the development environment of BIM itself, while there are relatively few studies analyzing BIM technology based on the perspective of the owner. Second, although some studies have recognized the great influence of the owner on the development of BIM, most of them only elaborate on the causes and phenomena, and few studies systematically and deeply analyze the formation mechanism or mechanism of the owner's behavior on the application of BIM technology. Third, current studies mainly focus on the influence of objective factors such as policy and environment on the application behavior of BIM technology, while there is a gap in the examination of the influence of the owner's subjective factors. Therefore, this study uses the TPB-TAM framework in the field of social psychology to construct a theoretical model of BIM application behavior based on the owner's subjective psychological feelings towards BIM technology, and uses partial least squares structural equation modeling (PLS-SEM) to quantitatively verify the assumptions of the theoretical model, analyze the effects and paths between the variables, and elaborate the owner's application behavior towards BIM technology. The theoretical model is used to analyze the effect of variables and paths, explain the mechanism of the application behavior of owners to BIM technology, and reveal the difference between behavior and willingness, so as to improve the relevant research on BIM technology, promote the active participation of owners in the development process of BIM technology, and further the comprehensive promotion and application of BIM.

2. Theoretical Background

2.1. Theory of Planned Behavior

The Theory of Planned Behavior (TPB) was developed via the Theory of Reasoned Action (TRA) proposed by Fishbein et al. in 1975. As a widely known theoretical model, the Theory of Reasoned Action is better at explaining and predicting individual behavior [25], but has a major limitation [26], i.e., it does not take into account the influence of external factors on individual behavior. To compensate for the shortcomings of TRA, Ajzen [27] continued to add perceived behavioral control (PBC) variables to its foundation to reflect individuals' ability to control behavioral outcomes, making the theory of planned behavior mature. The five behavioral variables of the theory of planned behavior include attitudes, subjective norms, perceived behavioral control, behavioral intention, and behavior. The theory considers behavioral intention as a direct influence on individual behavior, while subjective norms, behavioral attitudes, and perceived behavioral control are common factors that influence individuals' behavioral intention. The advantage of this theory is that it constructs a systematic analysis framework, clearly demonstrates the decision-making process of individuals or organizations on expected behaviors, and fully considers the influence of multiple factors on individual behaviors, including the psychological cognition of the actor, internal and external environmental influences, and reduces metric bias. After extensive practice and behavioral research, the Theory of Planned Behavior has demonstrated more effective explanatory and predictive power than the Theory of Rational Behavior for individuals' decision-making behavior. The theoretical model of the Theory of Planned Behavior is shown in Figure 1.

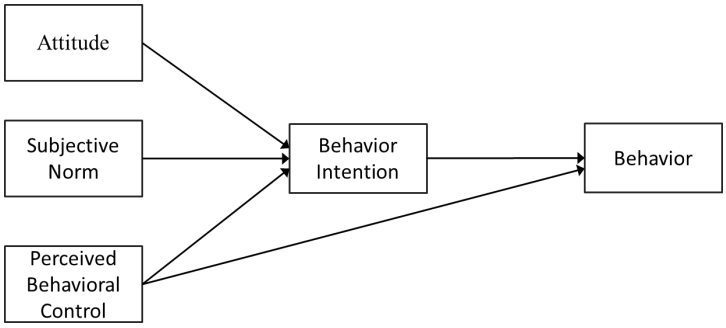


Figure 1. Theory of Planned Behavior, TPB.

2.2. Technology Acceptance Model

The Technology Acceptance Model (TAM) is a behavioral prediction theory model proposed by Davis [28] in 1989 based on the Theory of Rational Behavior and Theory of Planned Behavior to describe and explain the magnitude of an individual's or organization's acceptance of a technology. The TAM model is shown in Figure 2. Like TRA theory, the technology acceptance model assumes that an individual's attitude influences his or her behavior intention and that his or her actual behavior derives from his or her intention. However, in addition to this foundation, the TAM model also incorporates some ideas from self-efficacy theory and expectancy theory, subsequently introduces the concepts of Perceived Usefulness (PU) and Perceived Ease of Use (PEOU), and believes that both individual attitude and intention are influenced by PU. The Technology Acceptance Model (TAM) has been tested and refined by a number of empirical studies [29,30] and has proven to be of great theoretical value and generalizability for the study of individual adoption of a particular thing. Although TAM has been widely used, it has some explanatory limitations. TAM mainly takes into account the perceived attributes of technology, and thus lacks the influence of objective social factors, so it needs to improve its explanatory power. In recent years, with interdisciplinary convergence and development, the application area of TAM has been expanding, and it has become a trend to combine it with other theories and variables. Therefore, this study hopes to further enhance the mechanistic mechanism of explaining an owner's adoption behavior towards BIM technology through the integration of technology acceptance theory, and planned behavior theory.

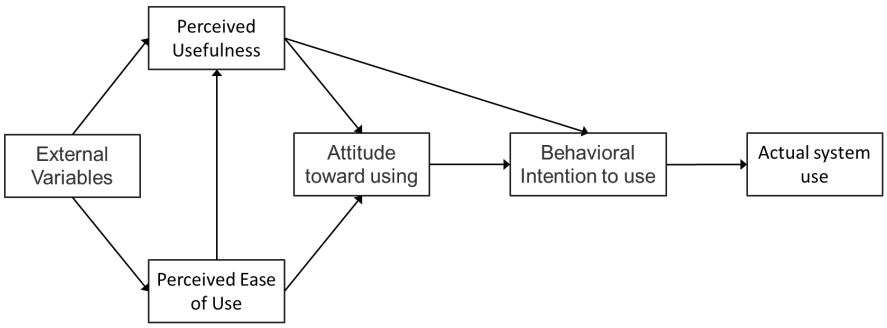


Figure 2. Technology Acceptance Model, TAM.

2.3. An Integrated Model of TPB and TAM

Since both the Theory of Planned Behavior and the Technology Acceptance Model are derived from the Theory of Rational Behavior, the homology between the two models provides a theoretical basis for their articulation and integration. Moreover, considering that both models have some degree of explanatory limitations, the TPB-TAM integrated model demonstrates greater explanatory power than either model alone. Song et al. [31] and Lee et al. [32] have achieved better results by using this integrated model in related research. In addition, this integrated model served as a customer relationship management (CRM) tool to establish effective channels and methods of owner-centered information

management, helping to promote the growth and future development of BIM technology. CRM has proved to be both a highly influential powerful business management technology solution [33]. Based on this, this study takes Theory of Planned Behavior (TPB) as the basic framework of the study and integrates the Technology Acceptance Model (TAM) to construct a conceptual model of the behavior formation mechanism of an owner's adoption of BIM technology. The perceptual behavior control in TPB is reflected by two variables, perceived usefulness (PU) and perceived ease of use (PEOU), to construct an owner's adoption behavior model of BIM technology (Figure 3) and put forward the corresponding research hypotheses.

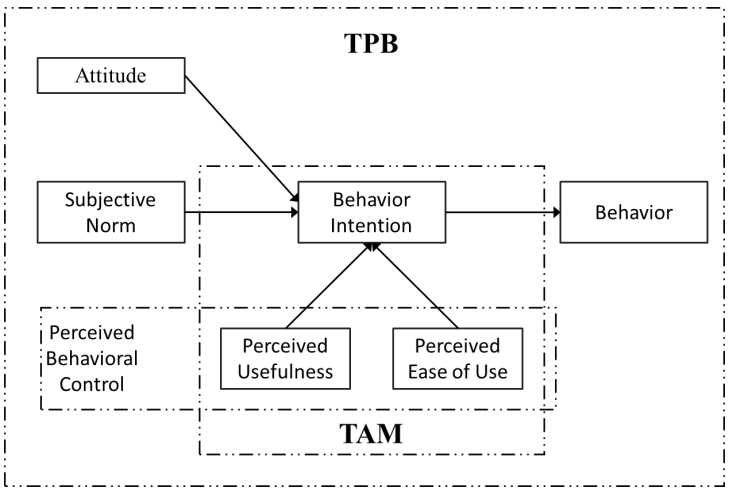


Figure 3. Theoretical Model: An Integrated Model of TPB and TAM.

3. Research Hypotheses

This section proposes five research hypotheses to investigate the relationship between an owner's behavioral attitude, subjective norms, perceived usefulness, perceived ease of use, and behavioral intention, as well as the relationship between behavioral intention and adoption behavior.

3.1. Owner's Behavioral Attitude and Behavioral Intention

Behavioral Attitude (BA) is the relatively stable evaluative response of a subject to an object. Behavioral Intention (BI), the collection of all factors that influence behavior, reflects the degree of effort an individual is willing to put forth in order to perform a behavior [27]. The influence and predictive role of attitude as a relatively persistent and stable psychological construct on behavior have been confirmed in many studies [34]. In this study, behavioral attitudes are characterized as a comprehensive evaluation of both the internality and externality of an owner's behavior toward the adoption of BIM technology. In terms of internal evaluation, when owners are increasingly dissatisfied with traditional project performance issues in the construction industry, such as cost overruns, schedule delays, and quality defects, they increasingly want to improve the situation by applying BIM technology to enhance operational efficiency or investment effectiveness. In terms of external evaluation, an owner's behavior and attitude are mainly expressed by the degree of market demand and policy response. At the same time, the more positive owners perceive the current policy of BIM technology, the more they are willing to respond to industry demand and the more they are willing to apply BIM technology. An owner's attitude towards the adoption of BIM technology is the result of the combined effect of its internal and external evaluation. Therefore, this research proposes Hypothesis 1.

H1: *An owner's attitude towards the adoption behavior of BIM technology is significantly and positively correlated with behavioral intention.*

3.2. Owner's Subjective Norms and Behavioral Intention

Subjective Norms (SN), which refer to the social pressure perceived by an individual when deciding whether to perform a particular behavior, reflect the influence of significant others or groups on the individual's behavioral decisions [27]. In this study, characterized as the social pressure felt by an owner when applying the BIM technology, Cialdini et al. [35] classified subjective norms into directive and exemplary norms. The subjective norms arising from an owner's adoption behavior of BIM technology are subjected to directive norms mainly from national policies and industry development and to exemplary norms mainly from competitors and partners. From the perspective of long-term development goals, the national policies which promote the development of BIM technology are conducive to accelerating the formation of comprehensive, information-based, and integrated technical services, bidding farewell to the barbaric growth of the past, and promoting the healthy development of the entire construction field. The national policies also play an important leading and guiding role for owners and have a profound impact on owner's investment decisions. Competitors and partners are important social resources for owners, and their adoption precedents will become an important reference basis for owners when they decide whether to apply BIM technology, and have a strong demonstration effect. The better the benefits of competitors and partners through BIM technology, the more owners may be willing to apply the BIM technology. Therefore, this research puts forward Hypothesis 2.

H2: *The subjective norms of an owner's behavior towards BIM technology adoption is significantly and positively correlated with behavioral intention.*

3.3. Owner's Perceived Usefulness and Behavioral Intention

Perceived Usefulness (PU) reflects how much someone believes that using a specific system can bring benefits and welfare to oneself [28]. In this study, it is characterized as the utility that an owner expects from the adoption of BIM technology. When applying BIM technology, an owner will prejudge the impact of the adoption of this new service. From the viewpoint of outcome benefits, whether the adoption of BIM technology is conducive to the overall improvement of investment benefits or beneficial to the quality of construction and operational efficiency is the primary consideration of an owner when judging the usefulness of BIM technology and the adoption of this new service technology. From the viewpoint of service quality, whether the adoption of BIM can enjoy high-quality intellectual technology services will be the key factor to be examined by an owner when making decisions. From the viewpoint of technical risk, whether the adoption of BIM can reduce the conflicts between collaborating units in the traditional mode is also an issue that an owner needs to consider. When owners decide that the adoption of BIM can help improve efficiency and service quality and mitigate risk, their perception of the usefulness of the adoption of BIM technology will be relatively higher, and then the willingness to apply will be increasingly strong, and finally the actual adoption behavior will be produced. Thus, the higher the perceived usefulness of the owner, the more favorable the willingness to apply BIM and the actual behavior. Therefore, this research proposes Hypothesis 3.

H3: *The perceived usefulness of an owner's behavior towards BIM technology adoption is significantly and positively correlated with behavioral intention.*

3.4. Owner's Perceived Ease of Use and Behavioral Intention

Perceived Ease of Use (PEOU) reflects an individual's perception of the ease of using a system [28]. Venkatesh et al. [36] showed that the easier an individual perceives the system to be under his or her control, the more positive his or her attitude toward the system will be and the more useful the system will be. When individuals perceive the behavior easy to perform, they also perceive that the outcome of the behavior will be more similar to their expectations. When an owner chooses engineering design services, in order to avoid uncertainty and reduce the risk, he or she tends to choose the technical services that he

or she knows better, so as to prevent his or her rights and interests from being damaged. Therefore, when owners believe that they have more information about BIM technology and know more about the adoption of BIM, their perceived ease of use will be higher, which will promote their perceived usefulness, and their willingness to apply BIM as a service technology will be more positive, increasing the possibility of using BIM. Therefore, this research proposes Hypothesis 4.

H4: *The perceived ease of use of BIM technology adoption behavior by an owner is significantly and positively correlated with behavioral intention.*

3.5. Owner's Behavioral Intention and Adoption Behavior

Behavior is the way in which someone conducts oneself or behaves. Numerous studies have shown that behavioral intentions contribute positively to behavior and that there is a definite link between intention to behavior and the process by which individuals move from decision making to concrete implementation. The theory of planned behavior has also demonstrated that behavioral intention has a significant effect on behavior [27]. Armitage et al. [37] have confirmed that behavioral intention has an effect on behavior in many different research areas, reflecting to some extent the universality of the facilitation effect of behavioral intention on behavior. In the field of engineering and construction, Goncalves et al. [38] showed a significant positive correlation between designers' intentions for architectural heritage preservation and actual design decisions. An owner's intention to apply BIM technology indicates the degree to which he or she wants to apply BIM technology services and the degree of effort he or she is willing to make in order to achieve the behavior, which is one of the best predictors of behavior. Only when an owner recognizes the short-term benefits or long-term value of BIM from the heart, will he or she be more willing to apply BIM and stimulate the implementation of application behavior. Therefore, this research advances Hypothesis 5.

H5: *The behavioral intention of owners to apply BIM technology is significantly and positively correlated with adoption behavior.*

4. Materials and Methods

4.1. Analysis Method

In order to test the theoretical model and related hypotheses, this study used partial least squares structural equation modeling (PLS-SEM) to explore the mechanism of the owner's adoption behavior towards BIM technology by conducting path analysis among variables. The model estimated the hypothesized paths between exogenous and endogenous variables. According to a recent study by Zeng et al. [39], it is known that many empirical studies in the field of construction project management [40,41] have chosen PLS-SEM for two main reasons. First, it has the purpose of exploratory research. Because this study aims to explore the owner's adoption behavior for BIM technology, PLS-SEM is suitable for this exploratory study [39]. Second, the sample size of this study is relatively small, with only 164 valid samples, which is small compared to the sample size required for CB-SEM, and PLS-SEM can show high statistical power when dealing with small sample sizes [42]. In addition, PLS-SEM has proven to be effective in dealing with survey-based engineering management studies and can produce insightful results [39]. Therefore, PLS-SEM is suitable for exploring the behavioral mechanisms of TPB-TAM integration model-based owners' adoption of BIM technology.

4.2. Questionnaire Design

From the above model, it can be seen that the variables involved in this study include owner's behavioral attitudes, subjective norms, perceived usefulness, perceived ease of use, behavioral intention, and adoption behavior, all of which are latent variables that cannot be directly observed and need to be measured by observed variables. In order to

effectively measure the variables in this study, we designed the measurement scales for each latent variable in this study by drawing on the mature scales or related questions from other studies, and finally formed a measurement scale based on the results of the discussion (Table 1). For the measurement of perceived usefulness and ease of use on intention to use, Davis [28] and Venkatesh et al.'s [36] model was used as a reference. For the measurement of subjective norms, refer to Ang et al.'s [43] scale. For the measures of behavioral attitude, behavioral intention, and adoption behavior, refer to Ajzen et al.'s [27] scale. On the basis of the above scale, 20 items were formed for the adoption behavior of BIM technology (Table 1). The questionnaire was designed in the form of a five-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

Table 1. Questionnaire scale.

Latent Variable	Name	Measurement Question Items
Behavioral Attitude (BA)	BA1	1. I support the advancement of BIM technology.
	BA2	2. I support the application of BIM technology in subsequent projects.
	BA3	3. I support the standardization of BIM technology.
Subjective Norm (SN)	SN1	1. The state encourages the promotion of the development of BIM technology.
	SN2	2. Many construction companies have launched BIM technology.
	SN3	3. Many of the company's partners and competitors have chosen BIM technology.
Perceived Usefulness (PU)	PU1	1. BIM technology can provide high-quality intellectual technology services.
	PU2	2. BIM technology is conducive to the overall improvement of investment efficiency.
	PU3	3. BIM technology is beneficial to engineering construction quality and operational efficiency.
	PU4	4. BIM technology can solve traditional project problems such as cost overruns, schedule delays, and quality defects.
Perceived Ease of Use (PEOU)	PEOU1	1. I know the information about BIM technology.
	PEOU2	2. I know the remuneration of BIM technology.
	PEOU3	3. I know the technical standards of BIM.
	PEOU4	4. It is not difficult for me to use BIM technology in construction projects.
Behavioral Intention (BI)	BI1	1. I intend to apply BIM technology in the future.
	BI2	2. I look forward to the benefits of adopting BIM technology.
	BI3	3. I would recommend our company's partners to apply BIM technology.
Adoption Behavior (AB)	AB1	1. I will definitely adopt BIM technology in construction projects.
	AB2	2. I will apply different forms of BIM technology.
	AB3	3. I will use BIM technology to improve efficiency.

4.3. Sample and Data Collection

Since scales will be used to measure the constructs in the research model, a questionnaire was used to collect data for this study. The questionnaire consists of two main parts. The first part asked respondents to provide basic information about their gender, education, and years of work experience. The second part asked respondents to score the question items for each variable measured.

In order to ensure the authenticity, reasonableness, and accuracy of the survey results, the following basic principles were adopted:

- The descriptions of the variables in the questionnaire should be short and easy to understand, so that there will be no ambiguity in the understanding of the questions designed in the questionnaire. The questions should be as easy as possible for the respondents to answer to ensure that most respondents can complete the whole questionnaire more easily.
- After the questionnaire was designed, experienced practitioners were invited to conduct a small sample analysis before the large-scale survey to revise the ambiguous and illogical parts of the questions in order to make the scale questions more relevant to engineering practice.

The official questionnaire was distributed from 15 February to 16 April 2023, about 60 days, and the survey respondents were mainly from various provinces in China. The questionnaires were distributed on paper and online. A total of 232 questionnaires were returned, and before data analysis, the questionnaires were eliminated according to the following criteria: (1) the questionnaire response time was too short; (2) the questionnaire answers were focused on one option or there were too many "neutral" options; and (3) there were inconsistencies in the questionnaire answers. A total of 164 valid questionnaires were finally obtained through screening one by one, which is much larger than the minimum sample size suggested by Barclay et al. [44], and the effective recovery rate of the questionnaires was 70.68%.

5. Results

5.1. Descriptive Results

The results of the statistical analysis of the sample characteristics are shown in Table 2. Among the respondents, there were 112 males, accounting for 68.29% of the total, and 52 females, accounting for 31.75% of the total. Most respondents have received higher education, with 101 having a bachelor's degree, accounting for 61.59%, and 54 having a master's degree or above, accounting for 32.92%. Most respondents were experienced and knowledgeable in the construction industry, as 71.34% had working experience over 5 years, and 72.57% were project managers or department managers. These interviewees can be considered capable of making reliable judgments to ensure the validity of the collected data.

Table 2. Sample characteristics.

Characteristics	Item	Number	Proportion
Gender	Male	112	68.29%
	Female	52	31.71%
Education level	Below Bachelor	9	5.49%
	Bachelor	101	61.59%
	Master and above	54	32.92%
Qualifications	General Engineer	45	27.44%
	Project Manager	102	62.20%
	Department Manager and above	17	10.37%
Work experience	<5 years	47	28.66%
	6–10 years	94	57.32%
	>10 years	23	14.02%

5.2. Measurement Model Evaluation

In this study, SmartPLS 4 statistical software was applied to analyze the data. First, the measurement model was subjected to validation factor analysis. Second, its reliability and validity were tested. Lastly, the measurement model was assessed for internal consistency, convergent validity, and discriminant validity.

1. Factor loadings test. As shown in Table 3, all factor loadings (factor loadings) were greater than 0.7 [45], and the validation factor analysis allowed for subsequent reliability and validity tests.
2. Internal consistency reliability test. Cronbach's alpha coefficient (Cronbach's α) and composite reliability (CR) are common sets of indicators used to examine reliability. One of the most commonly used methods to test the internal consistency reliability of a scale is Cronbach's alpha, and the standard recommended by Nunnally et al. [46] is above 0.7. Hair et al. [47] proposed that a Cronbach's alpha greater than 0.7 indicates that the scale has high reliability, but in exploratory studies Cronbach's alpha can be less than 0.7, but should not be less than 0.6. Since this study is an exploratory study, based on Hair's suggested criteria, Cronbach's α for behavioral attitudes (BA),

subjective norms (SN), perceived usefulness (PU), and perceived ease of use (PEOU) is greater than 0.7 (Table 4). The Cronbach's α for behavioral intention (BI) and adoption behavior (AB) is greater than 0.6 (Table 4), indicating that the scales exhibit good reliability. Unlike Cronbach's alpha coefficient, the combined reliability does not assume that all indicators are equally reliable, which makes it more suitable for the PLS-SEM, which prioritizes indicators based on their reliability during model estimation [48]. The combined reliability should be higher than 0.70 (in exploratory studies, 0.60 to 0.70 is considered feasible), while lower than 0.60 indicates a lack of reliability. The CR values for all factors in this study were greater than 0.7 (Table 4), indicating good internal consistency reliability of the measurement model.

Table 3. Cross-loadings.

	Cross-Loadings					
	BA	**SN**	**PU**	**PEOU**	**BI**	**AB**
AB1	0.045	0.126	0.03	0.155	0.177	0.754
AB2	0.08	0.028	0.244	0.239	0.222	0.844
AB3	0.105	0.087	0.113	0.217	0.163	0.711
BA1	0.79	−0.207	0.34	0.109	0.079	0.108
BA2	0.843	−0.244	0.461	0.189	0.267	0.079
BA3	0.839	−0.118	0.33	0.088	0.268	0.077
BI1	0.125	0.14	0.131	0.179	0.749	0.225
BI2	0.299	−0.098	0.56	0.176	0.799	0.274
BI3	0.193	0.364	0.358	0.167	0.725	0.069
PEOU1	0.163	−0.022	0.116	0.911	0.225	0.323
PEOU2	0.135	−0.082	0.067	0.772	0.156	0.099
PEOU3	0.12	−0.113	0.115	0.918	0.232	0.177
PEOU4	0.135	0.03	0.11	0.778	0.133	0.309
PU1	0.331	−0.13	0.844	0.084	0.327	0.197
PU2	0.285	−0.225	0.826	0.125	0.356	0.155
PU3	0.455	−0.145	0.877	0.125	0.475	0.132
PU4	0.453	−0.049	0.834	0.079	0.521	0.137
SN1	−0.215	0.885	−0.269	−0.121	0.083	0.018
SN2	−0.192	0.929	−0.05	−0.054	0.197	0.15
SN3	−0.181	0.776	−0.2	0.006	0.088	0.009

Table 4. Reliability and Validity.

Latent Variable	**Internal Consistency Reliability**		**Convergent Validity**	**Discriminant Validity**					
	Cronbach's α	CR	AVE	Fornell–Larcker criterion *					
				BA	SN	PU	PEOU	BI	AB
BA	0.786	0.864	0.680	**0.825**					
SN	0.851	0.899	0.750	−0.22	**0.866**				
PU	0.869	0.909	0.715	0.465	−0.153	**0.846**			
PEOU	0.869	0.910	0.715	0.161	−0.062	0.121	**0.848**		
BI	0.644	0.802	0.575	0.291	0.165	0.514	0.228	**0.759**	
AB	0.660	0.814	0.595	0.098	0.098	0.179	0.265	0.246	**0.771**

* Fornell–Larcker criterion: Diagonal is the AVE square root value, below the diagonal is the correlation coefficient.

3. Validity test. Validity analysis includes convergent validity and discriminant validity. Convergent validity is often assessed by the average extracted variance value (AVE), and Hair et al. [48] suggested that an AVE value of 0.50 and above indicates a sufficient degree of convergent validity, i.e., the potential variable explains more than half of its indicator variance. The results of this study showed that the AVE values of all factors exceeded 0.5 (Table 4), indicating that the measurement model had good convergent validity. The statistical methods commonly used for discriminant validity analysis

are the Fornell–Larcker criterion, cross-loadings, and HTMT (heterotrait–monotrait ratio). The Fornell–Larcker criterion means that the average extracted variance value (AVE) of each variable square root should be greater than the standardized correlation coefficient between that construct and the other variables [48,49] (See Table 4). Cross-loadings mean that the loadings of the indicator on the variable of interest should be greater than all its loadings on the other variables [48] (See Table 3). The HTMT value between two variables cannot be greater than 0.85 [50] (See Table 5). All three tests of discriminant validity passed, which indicates a sufficient degree of discriminant validity between the variables.

Table 5. Heterotrait–Monotrait Ratio (HTMT).

	Heterotrait–Monotrait Ratio (HTMT)$_{0.85}$					
	BA	SN	PU	PEOU	BI	AB
BA						
SN	0.279					
PU	0.534	0.243				
PEOU	0.191	0.096	0.14			
BI	0.365	0.373	0.593	0.294		
AB	0.151	0.143	0.247	0.362	0.381	

5.3. Structural Model Evaluation

The main evaluation criteria of the structural model include R^2, path coefficient and its significance, Q2 (Predictive Relevance), and *GOF*. Like the corresponding results in OLS regression, the R^2 results in PLS represent the amount of variance in the variables of interest explained by the model [44]. The results of the analysis showed that the R^2 for behavioral intention (BI) and applied behavior (AB) were 0.364 and 0.060, respectively. The path coefficients of the structural model of this study and their significance by the bootstrapping calculation method and after sampling 3000 times are shown in Table 5. Another assessment of the structural model involves the predictive ability of the model. The main measure of predictive relevance is the Stone–Geisser's Q^2, and the Q^2 values of behavioral intention (BI) and adoption behavior (AB) obtained by using the blindfolding calculation method are 0.169 and 0.024, respectively, which are greater than 0, indicating that the exogenous variables have predictive correlation [48]. Finally, the fit of the model was tested by applying the indicator *GOF*, which was calculated according to the formula (1) proposed by Tenenhaus et al. [51], and it was obtained that *GOF* = 0.372, which is greater than the maximum standard value of 0.36, indicating that the structural model of this study has a very good fit.

$$GOF = \sqrt{\overline{Communality} \times \overline{R^2}} \quad (1)$$

6. Discussion

The purpose of this paper is to investigate the mechanism of the formation of the owner's adoption behavior towards BIM technology. This paper uses the TPB-TAM integrated theoretical model in the field of social psychology as the analytical framework and conducts empirical tests. The empirical results show that all the hypotheses are confirmed except for hypothesis 1 (See Table 6). The specific results and discussion are shown below.

6.1. The Influence of Behavioral Attitude on Behavioral Intention

The data results show that the path coefficient of the owner's attitude toward BIM adoption behavior on its behavioral intention is 0.095, which indicates that behavioral attitude has a positive effect on behavioral intention, but the effect is very weak and insignificant. So, hypothesis H1 is rejected. This is quite different from the conclusion that attitude has a significant positive effect on behavioral intention in the previous study. In this paper, according to the questionnaire survey, it is found that most of the owners' parties are in favor of the implementation and promotion of technology. The reasons for

the insignificant role of attitude on behavioral intention can be explained by the following three dimensions: First, the relevant system policy is not sound, the orderly management of BIM technology in the construction industry is still in the fumbling stage, the relevant system and measures are imperfect, and the owners' may worry about service quality. The second reason is the stunted development of BIM enterprises; the BIM enterprises in the market have weak comprehensive business ability, lack of practical experience, insufficient BIM talents, and many other problems. Therefore, it is difficult for owners to choose BIM enterprises. Third, there is still a lack of demonstration BIM project, and most owners hold a wait-and-see and further investigation mentality in the current situation, resulting in little willingness to use BIM.

Table 6. Path Coefficient.

Hypothesis	Path	Path Coefficient	P [1]	Inference
H1	BA → BI	0.095	-	Not supported
H2	SN → BI	0.272	**	Supported
H3	PU → BI	0.491	***	Supported
H4	PEOU → BI	0.170	***	Supported
H5	BI → AB	0.246	***	Supported

[1] Note: ** Correlation is significant at the 0.05 level. *** Correlation is significant at the 0.01 level.

6.2. The Influence of Subjective Norm on Behavioral Intention

As can be seen from Table 6, social group pressure contributes to some extent to the behavior of the owner in deciding whether or not to apply the BIM. The path coefficient of subjective norms on the behavioral intention of the owner to apply BIM technology is 0.272, which is significant at the 0.05 level, and hypothesis H2 is supported. This reflects that the social group pressure generated by the government's policy promotion, the development demand of the industry, and the cooperation and competition of peers can have a greater impact on the willingness of owners to apply BIM technology. This is mainly because China, as a country with a collectivist culture, exhibits distinctive characteristics of high power distance. Social pressure and group norms will prompt owners to actively follow and respect the government's policy guidance, fully reflecting the dominant role of the government in the process of promoting BIM technology. Moreover, the construction industry is currently seeking a new and effective service technology to improve quality and efficiency and to achieve value-added engineering projects, so as to break the dilemma of the fragmented development of the traditional engineering and construction industries, which also leads to a greater willingness of the owners' to adopt BIM technology behavior. Thus, the government should take the lead in building BIM pilot projects to strengthen the demonstration effect of BIM. Moreover, the government should further promote the development of relevant policies and measures, in order to improve the application willingness of BIM by enhancing the perception of user-directed pressure.

6.3. The Influence of Perceived Usefulness on Behavioral Intention

From the empirical results of this paper, owners perceived usefulness is the most significant factor influencing their behavioral intention to apply BIM technology. The path coefficient of perceived usefulness in the behavioral model on owners' willingness to apply is 0.491, which is significant at the 0.01 level and supports H3. This finding indicates that owners' subjective evaluation of BIM places more emphasis on the practical value that this new service technology can bring. When owners perceive that the adoption of BIM technology can reduce costs and efficiency, reduce risks and better realize the whole life cycle value of the project, their willingness to apply the BIM technology will be strengthened, and the effect is very obvious. Thus, the core driver of the owner's demand for BIM technology is to let the owner feel the outstanding role and impact of BIM technology in enhancing the value of the project and the potential benefits of the adoption.

6.4. The Influence of Perceived Ease of Use on Behavioral Intention

The empirical research data in this paper show that there is a significant positive influence of perceived ease of usefulness of owners on behavioral intention to apply BIM technology, and the path coefficient of perceived ease of use on willingness to act is 0.170, which is significant at the 0.01 level, and hypothesis H4 is supported. When owners face complex and difficult engineering projects, they are more concerned about the reliability and ease of use of BIM technology and the simplification effect of the services. If owners assess that it is more tedious to complete the project when applying BIM technology, they are less likely to use such services, which will also have a negative impact on their willingness to use them. Therefore, on the one hand, relevant government departments should improve the service standard of BIM and at the same time do a good job of improving the simplicity of BIM adoption by owners. Furthermore, the basic process and steps of BIM technology adoption should be kept as concise as possible, and the knowledge of BIM should be popularized through both online and offline lines. On the other hand, upstream and downstream enterprises need to actively negotiate and seek cooperation, establish partnerships, and integrate resources so as to build a complete and smooth cooperation channel and form a better positive cycle of industry ecology. In addition, the industry needs to cultivate more new composite BIM talents with strong comprehensive abilities so as to ensure the accessibility of BIM technology.

6.5. The Influence of Behavioral Intention on Adoption Behavior

The coefficient of the effect of the owner's behavioral intention to apply BIM technology on adoption behavior is 0.246, which is significant at the 0.01 level and supports H5. The results of the study indicate that if the owner's willingness to apply BIM is stronger, the more the owner side is inclined to carry out the adoption of BIM technology services. This is consistent with the findings of many research fields such as sociology and psychology that behavioral willingness has a positive contribution to behavior. In the field of engineering management, Gonalves et al., have also confirmed that behavioral willingness can directly determine behavior and has a direct driving effect [38]. In other words, when the owner affirms from the bottom of his heart that the behavior of applying BIM technology has better benefits and positive effects on himself and wants to really implement the behavior, it can greatly promote the owner's adoption behavior of BIM technology.

7. Conclusions

The emergence of BIM technology has enabled the integration and sharing of information throughout the entire life cycle of construction, solving fundamental issues related to the production characteristics of the construction industry and improving project performance for the owner. To expand the owner's market demand for the BIM technology and fundamentally mobilize its adoption enthusiasm, this study constructs an integrated theoretical model of TPB and TAM from the perspective of the owner's subjective psychological feelings towards BIM technology adoption and proposes corresponding research hypotheses to investigate the interrelationship between the owner's behavioral attitude, subjective norm, perceived usefulness, perceived ease of use, behavioral intention and adoption behavior. The theoretical model is verified quantitatively by partial least squares structural equation modeling (PLS-SEM), the effects and paths between the variables are analyzed, and the mechanism of owners' adoption behavior toward BIM technology is explained.

The empirical research data in this study show that the owner's perceived usefulness of BIM technology is the most significant factor influencing their behavioral intention to apply BIM technology, the influence of attitude on behavioral intention is very weak and insignificant, the subjective norm can significantly and positively influence behavioral intention, the owner's perceived ease of usefulness has a significant positive influence on behavioral intention to apply BIM, but its role is very limited, and the owner's behavioral intention can positively influence adoption behavior and has a direct driving effect. Based

on the above findings, this study explores the reasons for the findings so as to improve the research on BIM, promote the active participation of owners in the development of BIM technology, and further the comprehensive promotion and adoption of BIM technology.

There are still some limitations in this research. First, the research subjects may also be influenced by external objective environments factors such as nationality and policies. Further research will combine the attitude–behavior–context model [52] and other scholars' research to introduce "context factors" into the theoretical model. Second, this study identified the research object as the owner, but the construction projects are all complex components with multiple parties involved. Future research could clarify the roles played by various stakeholders in the decision-making process of BIM technology adoption behavior based on stakeholder theoretical research, and construct a theoretical model of BIM technology adoption behavior from the perspective of stakeholders. Thus, the findings of this paper may have certain stages and limitations, and subsequent studies need to be improved in this regard.

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