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Research Article

Building Information Modeling Application Maturity Model (BIM-AMM) from the Viewpoint of Construction Project

Chengshuang Sun,[1] **Hanting Xu**,[2] **Dongjun Wan**,[1] **and Ying Li**[3]

[1]*School of Urban Economics and Management, Beijing University of Civil Engineering and Architecture, Beijing 100044, China*
[2]*School of Economics and Management, North China Electric Power University, Beijing 102206, China*
[3]*School of Environment and Energy Engineering, Beijing University of Civil Engineering and Architecture, Beijing 100044, China*

Correspondence should be addressed to Dongjun Wan; wandongjun@bucea.edu.cn

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BIM maturity models have become a significant method used to show the development stage of building information modeling (BIM) and to assist in measuring BIM capability. However, most of the existing maturity models focus on the evaluation technology, but the effect of BIM is not only related to technology, and most of them are mostly used for a comprehensive evaluation of BIM capability after the event. In this paper, for the purpose of comprehensive preevaluation of BIM application maturity of the project, considering the temporary characteristics of the project, based on Nolan's growth stage model, from the perspective of technology, social environment, and project participants, a BIM application maturity model (BIM-AMM) including 10 measurement indicators is proposed. The model integrates the Barrel Principle in accordance with the characteristics of a single project. The conditions of BIM implementation are evaluated in advance, and specific deficiencies of BIM implementation are identified; then, BIM decision-making is determined for the project. Finally, an actual project is taken as the application demonstration case of BIM-AMM, and according to the results, the obstacles faced by the project organization in adopting BIM technology and the improvement strategies are put forward. The research results further expand the BIM maturity research to the early stage of the project and provide new ideas for BIM maturity research.

1. Introduction

With the development of science and technology and the innovation of management and knowledge, labor productivity has improved greatly in almost all industries with the exception of the construction industry [1–3]. According to the research conducted by Paul Teicholz [3], labor productivity in the US construction industry—which is measured by constant contract dollars of new construction work per work hour—has experienced an average decrease of -0.6% annually since the early 1960s; meanwhile, all nonfarm industries have increased labor productivity at an average rate of 1.8% annually. Furthermore, more than 72% of projects are completed over budget, 70% run over schedule, and 75% of delayed projects are 50% over the initial contract price. Chapman et al. [1] found that factors affecting construction productivity include (1) life cycle construction processes, (2) technology utilization, (3) skilled labor availability, and (4) offsite fabrication and modularization; they also pointed out that effective collaboration could improve construction productivity.

BIM can provide solutions to these factors to increase productivity. Thirty-two large-scale construction projects were studied by Stanford University Comprehensive Facilities Community Center (CIFE). The results show that the use of BIM can shorten the project budget calculation time by 80% and the total construction period by 7% and reduce the contract cost by 10% [4]. BIM is defined by the US [5] as the development and use of a multifaceted computer software data model to not only document a building design but also simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting building information model is a data-rich, object-based, intelligent, and parametric digital representation of the facility, embedded with detailed information for current and future construction projects [6] from which views appropriate to various users' needs can be extracted and analyzed to generate feedback and improvement of the facility design. BIM provides revolutionary ways of generating, visualizing, exchanging, predicting, and monitoring information [7]; it improves collaboration among different stakeholders such as planners, designers, structural engineers, construction managers, and field workers, and it ultimately improves the performance and quality of construction products [8]. Generally, BIM can be used at every construction project phase for visualization, change management, code reviews, collision detection, fabrication, communication and collaboration, and facility management [9–11]. In recent years, BIM has been applied to and contributed great benefits to many giant and complicated construction projects. For example, in Beijing National Aquatics Center, China, shorter schedules and improved sustainability, building performance, fire protection, and safety were implemented using BIM [10]. In the Hilton Aquarium, Atlanta, Georgia, BIM was applied to design coordination, clash detection, and work sequencing; a $600,000 cost benefit was attributed to the elimination of clashes, and schedule benefits amounted to 1143 saved hours [11].

Due to the technical limitation, the labor productivity of the traditional construction industry is always at a low level. BIM can reduce the cost of construction projects, shorten the construction period, and reduce the workload of personnel, and the introduction of BIM technology provides a solution to the long-term shackles in the construction process and improves production efficiency. However, besides the change of production tools, the change of production process and project organization in BIM adoption cannot be ignored. Blind adoption of BIM will cause more problems, which goes against the original intention of BIM development. With the recognition of BIM advantages and the exposure of BIM problems, the implementation effect and technology development of BIM have been gradually concerned, maturity model focusing on BIM software capability is proposed to measure the capability of BIM, but the function of BIM is not only related to software technology.

This paper proposes a BIM application maturity model (BIM-AMM) from the perspective of the practical application of BIM in the project referring to Nolan's Stages-of-Growth Model in management information system and Capability Maturity Model Integration (CMMI) in software development and management, which provides a prediction tool for the real level of BIM application in different actual projects, carries out a comprehensive preevaluation of the project BIM conditions, provides a basis for improving the BIM shortcomings of different projects, and further extends the research of BIM maturity to the early stage of the project, a stage of the project that can effectively control the risk, which provides a new research idea for the research of BIM maturity.

2. Literature Review

2.1. BIM-Related Maturity Model. For better application of BIM, the BIM Capability Maturity Model (BIM-CMM)—an important part of research promoting BIM use—has been studied significantly.

Based on the CMM, the National Institute of Building Sciences (NIBS) established an interactive BIM-CMM in which 11 areas of interest are included (data richness, life cycle views, change management, roles or disciplines, business process, timeliness/response, delivery method, graphical information, spatial capability, information accuracy, and interoperability/IFC support), and the weight and maturity level of each area is defined [12, 13]. The IU BIM productivity matrix, developed by the University of Indiana, contains 32 metrics and 5 maturity levels [14]. Succar presented a BIM research and delivery framework and its maturity stages—pre-BIM, object-based modeling, model-based collaboration, network-based integration, and integrated project delivery—and pointed out that BIM tools are immature with regard to scalability, interoperability, and support for remote collaboration [15]. BIM QuickScan (BIMQ) is proposed by Rizal Sebastian and van Berlo [16] of the Netherlands Institute of Building Environment and Earth Sciences. It is divided into organization and management, mentality and culture, information structure, and information flow, which are used to evaluate the ability of BIM service institutions to provide BIM. BIM Planning Guide for Facility Owners v2.0 was released in 2013 to guide the project team to complete the BIM implementation planning process which contains six key BIM planning elements. The maturity of each element is divided into six levels, which indicates the advanced process of the maturity of application elements in the organization from not being applied to being fully applied [17]. The authors of [18] developed a framework for building owners in 2013 to assess BIM capabilities to improve the BIM requirements of the owners. BIM Cloud Score was developed in 2014, including 6 main measurement aspects and 19 measurement indicators, to evaluate the maturity level of BIM modeling technology [19]. Liang et al. [20] proposed that the development of BIM is not only about BIM technology but also related to processes and protocols and developed a multifunctional BIM maturity model from the three levels of technology, process, and protocol. Chen et al. [21] summarized and discussed BIMM- (Building Information Modeling Maturity-) related academic achievements from the aspects of information management, process management, and technology management. Siebelink et al. [22] developed a BIM maturity model which focused on the technical and organizational aspects of BIM.

It can be seen that these existing studies mainly focus on the technology capability maturity of BIM itself and not the application maturity of BIM using an actual construction project. In fact, whether BIM is successful is affected by many factors besides BIM itself, such as the owner's attitude to BIM, related laws, and codes. The differences between BIM's application maturity model (BIM-AMM) and BIM-CMM can be seen in Figure 1. In Figure 1, the overlap of BIM and CMM is BIM-CMM, which has been studied by many scholars and organizations [13, 15]; the overlap of BIM and applying environment (which refers to the interior and exterior environment relative to some technology application in practice) is the BIM application model (BIM-AM); the overlap between CMM and applying environment is the CMM application model (CMM-AM).

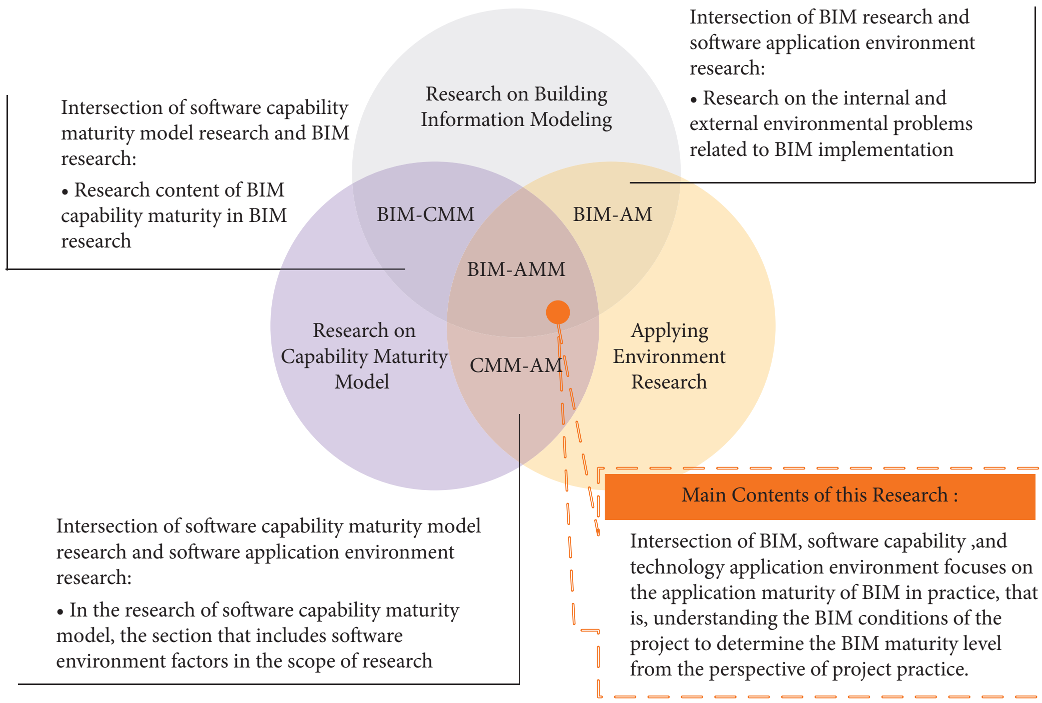

Figure 1: Description of BIM-AMM.

2.2. Stages-of-Growth Model. Among the stages-of-growth models, Nolan's Stages-of-Growth Model is the most representative [23]. It was developed by Richard L. Nolan during the 1970s, and it is a theoretical maturity model that initially included four stages for the growth of information technology in a business or similar organization [24]. It was modified in 1979, and growth progress was divided into six different stages: initiation, contagion, control, integration, data administration, and maturity [25]. Following the thinking from Nolan's Stages-of-Growth Model, several revised models have been proposed to adapt the model to developments in technology evolution, including a new Nolan model with three more stages added [26, 27].

A stages-of-growth model can be used to help organizations construct information systems and implement comprehensive management of information resources; it emphasizes the importance of information resource integration between enterprises and institutions [28]. Gottschalk proposed a model of growth stages with four stages for law firm knowledge management technology; it aims to develop suitable strategies for implementing technology at higher stages in the future [27]. The authors of [29] presented a conceptual stages-of-growth model for managing an organizations' social medial business profile with five stages from a theoretical and practical perspective.

2.3. Capability Maturity Model Integration (CMMI). CMMI was originally developed at Carnegie Mellon University. CMMI is a process improvement approach that provides organizations with the essential elements of effective processes, which will improve their performance [30]. CMMI is a model that combines three source models: a capability maturity model for software, a systems engineering capability model, and an integrated product development capability maturity model. The main objective of the model is to evaluate and improve organizational processes within the development, operation, and maintenance of information systems and software products [31]. CMMI for development includes five maturity levels: initial, managed, defined, quantitatively management, and optimizing [32]. CMMI-based process improvement includes identifying the organization's process strengths and weaknesses and making process changes to turn weaknesses into strengths [30].

This paper studies BIM-AMM from the viewpoint of actual construction projects. The aim of this study is to provide decision supports for project managers about whether to apply BIM in a construction project or not and determines where weaknesses exist which require improvement if applying BIM. Firstly, factors affecting BIM application on construction projects are analyzed and, on the basis of factor analysis, the index system in BIM-AMM is presented. Secondly, using Nolan's Stages-of-Growth Model for information technology as a reference, BIM-AMM is divided into four stages: initiation, discreteness, integration, and maturity. Thirdly, each index evaluation criterion of BIM-AMM is discussed. Finally, to demonstrate the validation of the BIM-AMM, one practical construction project is introduced and evaluated.

3. Research Framework

The framework of this paper is shown in Figure 2. For the feasibility of BIM-AMM application in actual construction projects, three key aspects should be carefully considered:

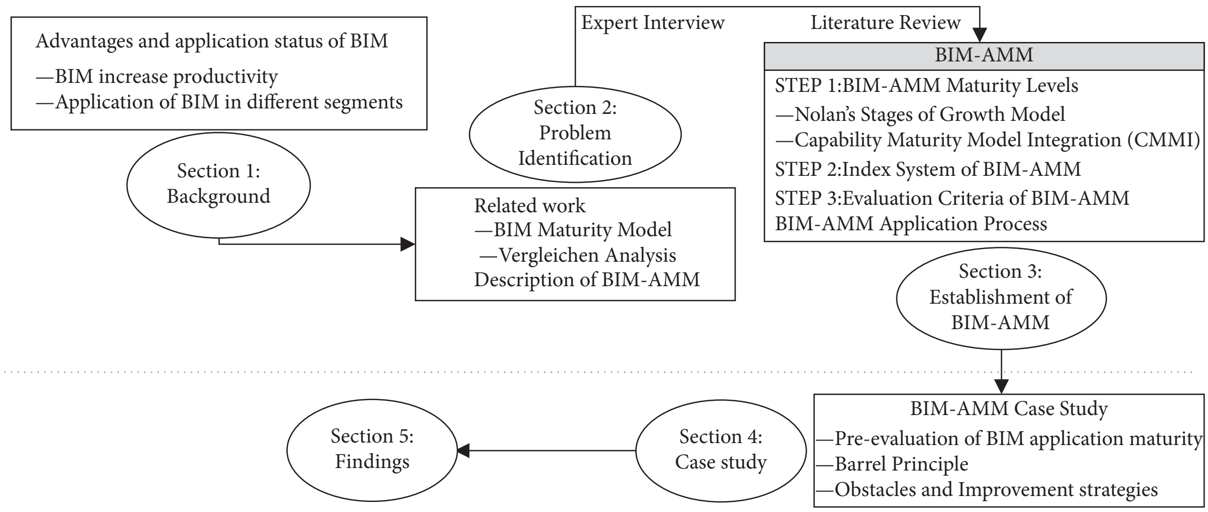

Figure 2: Research framework.

the BIM-AMM maturity levels, the index system of the BIM-AMM, and the evaluation criteria of the BIM-AMM. The BIM-AMM maturity levels define the feasibility, capability, and benefits of a construction project using BIM under the existing limitations of technology, software and hardware, and various exterior environments. The index system of the BIM-AMM defines the factors affecting the maturity levels of the BIM-AMM. The evaluation criteria of the BIM-AMM define the mature condition of each index according to actual construction project information.

Step 1. The first work is to determine levels of BIM-AMM. The methodology employed in setting up an integrated application maturity model of a BIM is based on existing maturity models, such as the stages-of-growth model and CMMI, to establish a BIM-AMM's maturity levels combined with the characteristics of BIM application.

Step 2. This study uses a systematic review of the research results, aiming to select the measurement index of BIM application maturity. The correctness of the selection of measurement direction depends on the perspective of the research problem and the characteristics of the research subject. Through the analysis of the relevant research on BIM maturity, the direction of BIM application should be considered, and considering the shortcomings of existing research and the characteristics of the project application, the influencing factors of BIM are determined. Through interviews with BIM-related experts and practitioners in the industry, the dimensions and measurement indicators of BIM-AMM are finally determined.

Step 3. Combined with the classification of BIM-AMM and the results of expert interviews, the meaning of each measurement index under different levels is described, which is used as the evaluation standard of BIM-AMM. Finally, an actual project case is used to verify the effectiveness of BIM-AMM. According to the results of the BIM-AMM evaluation, suggestions of/for BIM adoption are putting forward.

4. Establishment of BIM-AMM

4.1. BIM-AMM Maturity Levels. Nolan's Stages-of-Growth Model and CMMI describe the evolution stage model of the information system, which has important guiding significance for the construction of the enterprise information system [33, 34]. BIM is the product of the combination of emerging IT technology and the modern construction industry. BIM also follows Nolan's Stages-of-Growth Model of IT maturity in the application and future development of the project life cycle [35]. Therefore, it is reasonable for a BIM application that the BIM-AMM be divided into four maturity levels: unfeasibility, discreteness, integration, and maturity, as shown in Figure 3:

Stage 1: *Unfeasibility*. In this stage, there are many restrictive factors that hinder the application of BIM. For example, participants may have only heard of the concept of BIM, and no one may have ever used BIM tools in actual construction projects. If preevaluation of the project demonstrates that the project is in the first stage, this shows that the project does not have the conditions to apply BIM.

Stage 2: *Discreteness*. In this stage, BIM project participants use BIM tools alone, and all participants do not use BIM tools under the same BIM implementation framework. There are inconsistencies in the BIM process and collaboration across disciplines, resulting in more redundant and wrong data.

Stage 3: *Integration*. The implementation process of the project can be integrated using various BIM tools as the main business means. All participants of the project can share information through the BIM software and platform, realize effective cooperation and communication, and accelerate the implementation of the project in terms of quality and progress.

Stage 4: *Maturity*. Under the complete implementation framework, the project has a clear BIM implementation workflow, which enables the realization of real-time maintenance and updating of information; all participants have good BIM thinking and can effectively

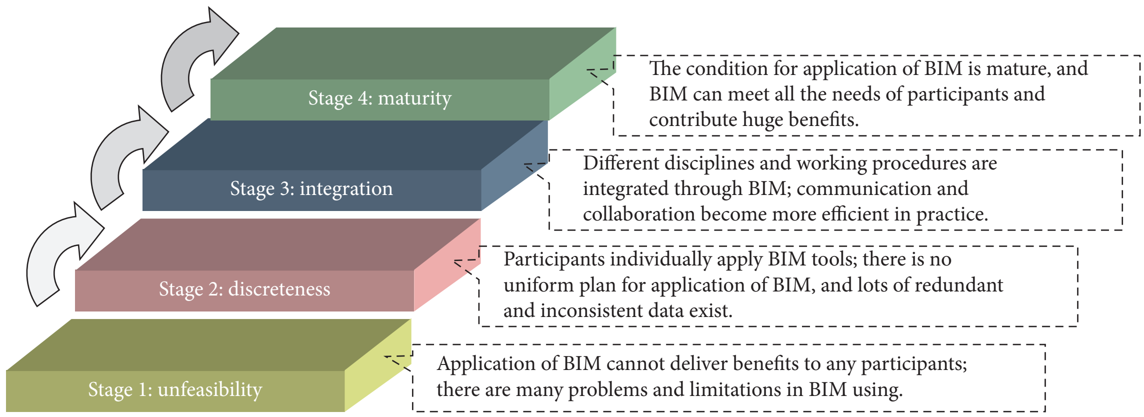

FIGURE 3: Maturity levels of BIM-AMM.

divide the responsibilities related to BIM. At the same time, the BIM capabilities of all parties can meet the implementation conditions of the BIM projects and realize the maximization of BIM value.

4.2. Index System of BIM-AMM. Based on existing BIM maturity-related research results combined with the characteristics of engineering projects and the premised assumptions involved in the implementation of BIM, this paper reviews BIM maturity models that are widely used at present and extracts the measurement elements related to BIM application as a reference for building a BIM-AMM index system. We extracted technology information such as technology infrastructure needs; BIM network environment; interoperability/IFC support; BIM application environment information, such as contracts, responsibilities, standardization, business guidance; and organizational information such as management support, organizational roles, leadership awareness, and project delivery method, as shown in Table 1. Through the analysis of the above information, we found that in the existing BIM maturity measurement methods, the role of BIM policy is rarely mentioned. Under good incentives and policies—such as BIM subsidies—or under mandatory policies of relevant administrative departments, the probability of a project adopting BIM will be greatly increased.

Therefore, fully considering the obtained maturity measurement direction, this paper divides the maturity index into ten dimensions: software, hardware, network capability, law, standard, policy, personal ability, manager experience, owner degree of demand and investment, and project delivery method from the perspectives of technology, social environment, and participants. The index system of BIM-AMM is shown in Figure 4.

4.2.1. Technology Issues

(1) *Maturity of Software Capability.* This comprises the degree to which various requirements in various stages of the whole life cycle of the project can be met, including the appearance display in the early stage; the design and conflicts of buildings, structures, and pipelines in the design stage; the management of cost, progress, safety, and change in the construction stage; and construction, prefabrication, and equipment maintenance in the use stage

(2) *Hardware Performance.* This refers to the software running and data processing speeds, such as the time for design and rendering, whether software can meet the continuous changes of model data, and storage capacity of data

(3) *Network Capability.* This refers to the interconnection ability of the BIM application, the cooperation ability between software products, and whether the project participants can exchange data and realize information sharing

4.2.2. Society Issues

(1) *Laws and Regulations.* A perfect legal system can guarantee the basic rights of all parties in the project, including the division of responsibilities in the application of BIM, the income distribution principle generated by BIM, the contract specifications for BIM application, and the creative format of different information.

(2) *BIM-Related Standards.* This includes BIM standards and other relevant standards, such as IFC. Data based on the same standard can ensure the feasibility of information interoperability among participants.

(3) *Industry Policy and Management System.* This refers to incentive measures and promotion requirements of the state, industry management departments, and local governments for projects which apply BIM technology. Although the organization of the BIM project and the project itself cannot directly improve the BIM policy, different projects face different BIM policy situations for different locations, which is a necessary measurement aspect in BIM-AMM.

4.2.3. Participant Issues

(1) *Existing BIM Talents of Project Participating Enterprises.* This refers to whether the number and ability of BIM

Table 1: Measurement aspects referenced by BIM-AMM.

Research results and measurement aspects of BIM maturity			
References	Measurement aspects		
BIM-CMM [13]	Data richness	Information accuracy	Timeliness/response
	Lifecycle views	Change management	Roles or disciplines
	Graphic information	Interoperability/IFC support	Delivery method
	Spatial capability	Business process	
Building information modeling maturity matrix [36]	Software	Regulatory	Leadership
	Hardware	Contractual	Human resources
	Network	Preparatory	Products and services
			Infrastructure
Structural equation model of building information modeling maturity [21]	Equipment	Standardization	Workflow
	Application	Specification	Data richness
	Hardware upgrade	Role	Info update
	Interoperability	Risk management	Change management
Multifunctional BIM maturity model [20]	Information accuracy	Clash analysis process	Interoperability/IFC support
	Model data	Data exchange	Standard operating process
	Quality assurance and quality control	CAD/BIM workflow	Doc and modeling standards
	Data security and saving	Management support	Project deliverables
	Spatial and coordination	Delivery method	Role and responsibility
	BIM elements	BIM project objective	Compensation expectations
	Technology infrastructure needs	Cross-disciplinary model coordination	BIM and facility data requirements
BIM maturity [22]	Hardware and network environment	BIM expert/working group/department	Personal motivation and willingness to change
	Software	Job instructions and procedure	Requesting actor (internal)
	BIM facilities	Object structure and decomposition	Education, training, and support
	Tasks and responsibilities	Object libraries and attributes	BIM vision and goals
	Collaborative attitude	Data exchange	Information structure
	Management support		
BIM capability assessment reference model (CAREM) [37]	BIM collaboration	BIM skills	
	Interoperability	Corporate-wide BIM deployment	
	Performing BIM		
Measurement aspects referenced by BIM-AMM			
Technology Interoperability/IFC support Software\hardware\hardware upgrade network\application Interoperability Technology infrastructure needs Hardware and network environment BIM facilities	Application environment Regulatory Contractual Standardization Specification Cross-disciplinary model coordination Job instructions and procedure Doc and modeling standards Standard operating process	Participant Delivery method\ leadership\ role Management support Project deliverables Role and responsibility BIM expert\working group\department Personal motivation and willingness to change Requesting actor\collaborative attitude	

technical personnel of each participant can support the adoption of BIM technology as the main means of the project

(2) *Project Manager's Experience.* This refers to the project manager's mastery of BIM and the corresponding BIM project experience accumulation

(3) *Requirements of the Owner/Investor for BIM.* This refers to whether the owner requires the use of BIM and their requirements for the degree of use of BIM technology in the project

(4) *Delivery Mode.* This is the degree to which BIM can bring value to the project delivery mode under the

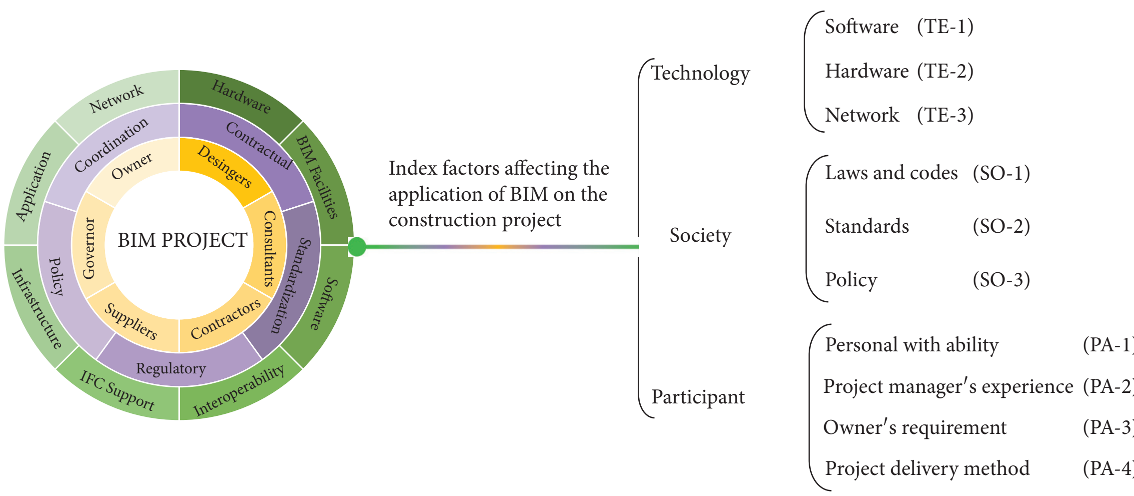

Figure 4: Index system of BIM-AMM.

specific environment and project characteristics and the adaptability of BIM to the project management mode in the whole life cycle

4.3. Evaluation Criteria of BIM-AMM. Evaluation criteria are the most important contents of BIM-AMM. These are composed of the maturity index and maturity level and can be presented in the form of a table. These are a set of standards used to measure each index grade in BIM-AMM in detail. The detailed description in each evaluation standard results from interviews with experts in the industry, as shown in Table 2.

4.4. BIM-AMM Application Process. Before using the maturity evaluation model, the first thing to ensure is that the relevant organizations of the project can clearly understand the meaning of each maturity index, and the evaluation result of each index is an important basis for BIM to adopt decisions and improve the scheme. Usually, it is the direct participants of the project, such as the project manager, who are selected to evaluate the project. As an evaluator, the evaluator conducts organizational self-assessment on the maturity indicators in the model according to their own actual situation and gives a corresponding score. Based on the evaluation results of all evaluators, BIM-AMM is used to judge the BIM maturity of the project. The maturity of the BIM adopted by the project at this stage and at the specific situation of each maturity index is obtained. Whether the project conditions can support BIM at this stage is analyzed, and the gap between BIM and the ideal implementation environment is determined. Through the above process, the weaknesses of BIM adoption can be identified. Through the development of a corresponding improvement plan to improve the weak aspects of BIM, and through reevaluation, the maturity of BIM adoption in the project can be redetermined until all aspects meet the requirements of BIM implementation. The application process of the maturity model is shown in Figure 5.

5. BIM-AMM Case Study

5.1. Case Introduction. The case data were taken from one practical project called the Fuzhou Commerce Plaza Project; this project is located beside the Min River, Fuzhou City, Fujian Province, China. Its total building area is more than 400,000 m^2 and its height is 99.9 m. The required project time was 484 days. We invited five project staff to evaluate the BIM maturity of the project, including the project manager and BIM-related technical personnel, who had a direct understanding of the project. The scoring mechanism was a 1–4 scale corresponding to four different stages. If the maturity of an indicator of the evaluated project was considered to be Stage 1, it was given a score of 1; if it was considered that the maturity of an indicator of the evaluated project was between Stage 1 and Stage 2, the score could be selected as [1.2, 1.4, 1.6, 1.8]—the lower the value was, the closer the maturity level was to Stage 1, and the higher the value was, the closer the maturity level was to Stage 2. The final score of each index was the average value of the sum of maturity scores, and the calculation formula is as follows:

$$S_i = \frac{1}{N}\sum_{j=1}^{N} S_{ij}, \quad (1)$$

where N is the total number of personnel who evaluated the project, S_{ij} is the evaluation score of each evaluator on different indicators, and S_i is the final score of each index, which represents the actual maturity level of each indicator in BIM-AMM.

Taking the software as an example, five project staff scored the conditions of the project software from the perspective of BIM application, and finally, S_i was calculated according to formula (1) to be 3.52, indicating that the maturity of the index has exceeded stage 3 but not reached stage 4. Similarly, taking the project manager's experience as an example, through the evaluation criteria of BIM-AMM, the score is 1.2, indicating that the maturity of the index is only at stage 1, a very low level of maturity. According to the maturity level evaluation criteria and scoring mechanism,

Table 2: Evaluation criteria of BIM-AMM.

Stage				
		Technology		
Stage	TE-1	TE-2	TE-3	
1	Just a few BIM tools have been used and cannot satisfy participants' slightly difficult needs.	Hardware is outdated and there is no restoration system.	Limited network.	
2	Many strong BIM tools for different disciplines have been applied, but interoperation is poor.	Hardware can meet the generic needs of BIM tools, and there is no restoration system.	The network can meet the basic needs of BIM tools but cannot transfer huge data.	
3	Integrated BIM tools can satisfy most of participants' needs and support most collaboration of different disciplines.	Hardware can meet most needs of BIM tools and there is a better restoration system.	Network is stable and has enough capacity for collaboration and communication, but the connect style provided is limited.	
4	BIM tools can satisfy any participant's need and support full collaboration between different disciplines.	Hardware can perfectly meet all the needs of BIM tools, has quick running speed, huge storage, and an excellent restoration system.	Network can meet all the needs of BIM tools for collaboration and real-time communication, and diversification of connection style is provided.	
		Society		
Stage	SO-1	SO-2	SO-3	
1	Hardly any BIM-related laws and codes have been promulgated.	Almost no standards can be used in practice.	There are hardly any policies to encourage the application of BIM.	
2	Just some key BIM-related laws and codes have been promulgated.	Although there are some standards for BIM application, most have shortcomings.	Some positive policies have been issued to encourage participants to use BIM.	
3	A sizeable amount of BIM-related laws and codes have been issued.	Most important standards have been created and are used in practice.	Much more benefits stipulated by policies could be gained if the project applies BIM.	
4	All the laws and codes for BIM application are perfect.	All kinds of standards for BIM application have been established perfectly.	It is required that all construction projects must apply BIM in policies.	
		Participant		
Stage	PA-1	PA-2	PA-3	PA-4
1	There is almost no one who can use BIM tools.	Project manager has no experience in the application of BIM to the construction project.	Owner does not require the application of BIM and has made no investments.	Bad delivery method for BIM application.
2	A few persons have used BIM tools in practice.	Project manager has experience in BIM use, but not in the role of project manager.	Owner has some interest or provides some investments in BIM usage.	Good delivery method for BIM application.
3	Many persons have used BIM tools.	Project manager has experience of using BIM in one or two construction projects.	Owner encourages participants to apply BIM and provides great investment.	Great delivery method for BIM application.
4	All the participants can use and collaborate with BIM tools perfectly.	Project manager has abundant experience in using BIM in construction project management.	Owner requires participants to use BIM and supports all funding.	Perfect delivery method for BIM application.

TE-1 denotes software; TE-2 denotes hardware; TE-3 denotes network; SO-1 denotes laws and codes; SO-2 denotes standards; SO-3 denotes policy; PA-1 denotes a person with ability; PA-2 denotes project manager's experience; PA-3 denotes owner's requirement and investments; PA-4 denotes project delivery method.

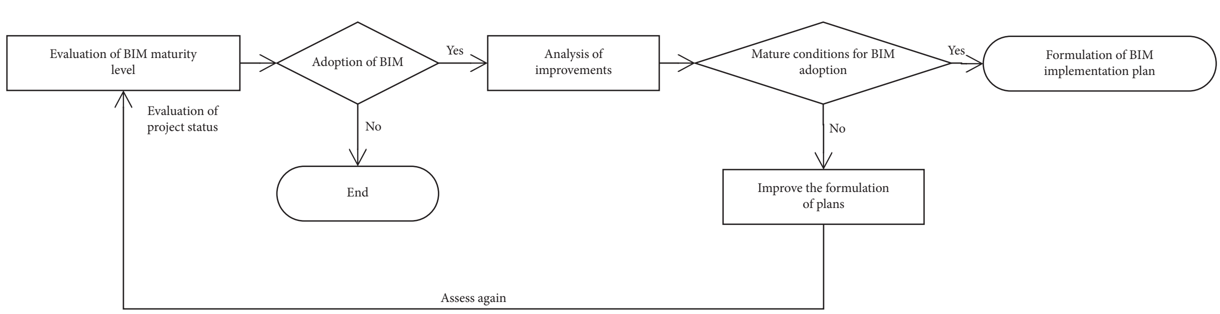

Figure 5: BIM-AMM application process.

Table 3: BIM-AMM evaluation results of case.

Evaluation criteria	Project-related information	S_{ij}					S_i
Software	In this project, BIM tools include the following: (i) Autodesk Revit architecture, structure, MEP, and Navisworks. (ii) GrandSoft for cost.	3.2	3.6	3.8	3.6	3.4	**3.52**
Hardware	All participants have computers and laptops that are up-to-date enough to use BIM tools.	2.8	3.2	3.4	3.2	3.4	**3.2**
Network	Participants have a variety of connection styles for access to the Internet, such as FDDI, WiFi, but the network conditions at the construction site are not good, and the net speed is slow.	2.8	3.2	3.0	3.0	2.8	**2.96**
Laws and codes	Nowadays, in the Chinese construction industry, there are few laws and codes about BIM application. Therefore, if disputes related to BIM use occur, no laws apply.	2.0	2.8	2.0	2.0	2.4	**2.24**
Standards	Because the main BIM tools come from the Autodesk toolkit, problems of interoperation exist between Revit and other types of software.	2.4	2.0	2.6	2.4	2.6	**2.4**
Policy	Although Chinese officials realize the importance of BIM, until now there has not been a positive policy to encourage the usage of BIM.	1.4	1.4	1.6	1.2	2.0	**1.52**
Person with ability	Other than designers, no persons have used BIM in practical projects before.	2.2	2.0	2.0	1.8	2.0	**2**
Project Manager's experience	Project managers have no experience of BIM application.	1.2	1.4	1.2	1.2	1.0	**1.2**
Owner's requirement and investments	Owner agrees to apply BIM only in the design stage and has not invested enough money.	1.4	1.8	2.0	1.2	1.4	**1.56**
Project delivery method	This project adopted the DB delivery method, which is not very suitable for BIM.	1.2	1.4	1.2	1.6	1.0	**1.28**

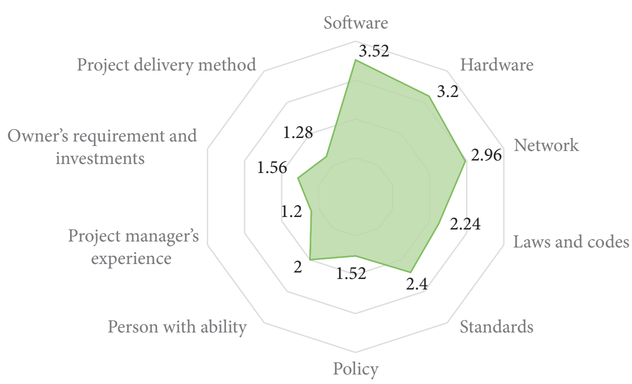

Figure 6: Case analysis results.

the final evaluation results of the detailed information of the project are shown in Table 3.

5.2. Maturity Evaluation Results. The regional map of the index evaluation grade was drawn according to the evaluation results of each maturity index, as shown in Figure 5. The maturity distribution chart of the BIM technology adopted in the project was obtained by connecting the values of each index. From Figure 6, we can clearly see the maturity of each index of the project. The closer the project is to the center, the lower the maturity of the index is, and it needs to be improved on the original basis.

According to the Barrel Principle, only if all indicators meet the implementation conditions of BIM can the project adopt BIM technology to achieve high benefits. If there are serious shortages, even if other aspects have implementation conditions, the overall benefits of BIM can only be low or even bring other adverse consequences. Therefore, whether BIM can produce value for the project depends on the BIM shortages of the project, which are also key for deciding whether the project can adopt BIM:

(1) Whether the operating system and software environment settings are reasonable directly affects whether the whole IT technology environment of the project can support the application of BIM technology. The maturity of BIM technical indicators of the project was basically consistent, just reaching the maturity level of Stage 3. Each organization of the project had good electronic office equipment and basic BIM technology software, which could basically meet the requirements of BIM business processes and cooperation between different disciplines. However, for some project participants, the network environment was slightly worse. In the process of model data updating and backup and large file transmission and communication, data transmission failure and long durations for file transfer could be caused by poor network stability

(2) The maturity of the BIM social environmental conditions of the project was at a low level, the legal and BIM standards were just at the maturity level of Stage 2, while the policy was between Stage 1 and Stage 2, which is a low level of maturity. In addition to international standards and specifications, such as IFC, Cobie, and IOS, in the external environment of the project at that time, although there were some local BIM standards and implementation guidelines, the coverage rate of business and technology at each stage of the project and the applicability of the actual project was very low. At the same time, the BIM contract mode and general agreement were still in vacancy, and new rights, responsibilities, and interests brought about by BIM could not be defined and protected in a legal sense. In addition, without a mandatory adoption policy and

Table 4: Assessment and comparison of existing maturity models.

Aspects	BIM-related maturity model				
	BIM-CMM [13]	BIM maturity matrix [36]	Multifunctional BIM maturity model [20]	BIM maturity [22]	BIM-AMM
Evaluation perspective	BIM software technology	BIM users — (i) Individuals (ii) Organizations (iii) Project teams	BIM users — (i) Enterprises (ii) Industry	BIM users — (i) Enterprises	Project
Application phase	Software development, improvement, and capability testing	Implementation status of BIM users			Preparation period before applying BIM in project
Maturity model dimension	(i) Information	(i) Technology (ii) Process (iii) Policy	(i) Technology (ii) Process (iii) Protocol	(i) Strategy (ii) Organizational structure (iii) People and culture (iv) Processes and procedures (v) IT infrastructure (vi) Data	(i) Technology (ii) Society (iii) Participant
Application process	One-time maturity evaluation				Cycle maturity evaluation with feedback information

effective incentive mechanism, the adoption motivation and benefit guarantee of BIM was greatly reduced. A change of social environmental factors is predictable, but it often takes a lot of time. It can be said that in the progress schedule of the project, there was no favorable BIM condition for the social aspect

(3) It is not difficult to see from the results that the BIM organizational conditions of the project were extremely unfavorable, and the personal BIM levels of technical personnel had just reached Stage 2. The owner did not have BIM awareness. Except for the designers, other project personnel had not had contact with BIM, and the project manager had no BIM project experience; therefore, they were totally unable to carry out BIM-related work. Undoubtedly, these were the biggest obstacles to BIM implementation in this project. The business flow of the selected DB delivery mode was very traditional, which was in conflict with BIM's project management concept of information digitization and management integration. BIM under DB mode is meaningless and even causes more work problems. These problems were close to the Stage 1 level, so it was not feasible to implement BIM

To sum up, even if the project had good BIM technical conditions, BIM was not suitable as the main technical means of the project due to the project's obvious defects in social and organizational aspects. If the external social environment of the project improved within the allowed time range, and the project organization quickly improved BIM skills, such as adjusting staff, increasing the number of work and management personnel with BIM technical ability participating in the project, under a favorable change of policy and project strategy, it is necessary to make another maturity assessment according to the new situation of the project; only if all the preconditions met the implementation requirements of BIM could the ultimate benefits of BIM adoption be ensured.

6. Conclusions

All projects are unique. From the perspective of BIM implementation, no two projects have the same adoption conditions, so the value of BIM to each project is also different. BIM-AMM includes both macro and micro factors involved in the application of BIM in projects. Macro factors are the external conditions of the project, including policies and regulations system, standards, and project management system, while micro factors are mainly reflected in the internal conditions of the project, including organizational philosophy, technical personnel level, and technical equipment. The uncertainty of project adoption of BIM always exists, but it is affected by macro factors and micro factors which were explained above. Therefore, based on the above two points, it is very important to preevaluate the maturity of BIM adoption from the perspective of the project. At the same time, under the maturity index system, the feasibility of in-depth quantification of BIM maturity of the project is increased.

From the perspective of a project, this paper analyzes the influencing factors of BIM maturity and constructs an index evaluation system of BIM-AMM including 10 evaluation indexes from the three aspects of technology, society, and participant. Referring to Nolan's Stages-of-Growth Model, this paper constructs a BIM-AMM based on four maturity levels, introduces the process of BIM maturity preassessment adopted by the project, and uses an actual case study to analyze the applied BIM-AMM.

The effect of BIM implementation is affected by many factors. According to the Barrel Principle, BIM can bring high value to the project only when it is in a mature implementation environment. If there are obvious shortages, the benefits of BIM will be greatly reduced. From the current development of BIM—although BIM has been widely used in construction, transportation, and other fields—in the process of adopting BIM in some projects, the application of BIM cannot reach the highest level due to limitations of software, hardware, network, regulations, standards, and other factors due to the current technology, theory, and management levels. For example, the current BIM-related standards are still in the development stage, so for any project, the standardization and comprehensiveness of BIM standards cannot reach the ideal state. From the perspective of the overall interests of the project, project delivery and management modes have different impacts on the effect of BIM. Under the DBB mode, the overall driving force of BIM is very low, and the owners' sign contracts with the participants at each stage of the project. For BIM projects, decentralized project management mode and the BIM integration concept are in great conflict; BIM cannot play a real role and the use of the DBB mode reduces the feasibility of BIM application in the project. In this case, the owner needs to carefully consider whether to adopt BIM technology in the project or not.

The application of a BIM-AMM can evaluate the maturity of BIM conditions of a project before the full application of BIM in the project. With the help of Nolan's Stages-of-Growth Model and the Barrel Principle, it can provide the basis for the owner to formulate an adoption strategy and BIM improvement scheme.

The difference of BIM application in the project compared to the traditional work mainly lies in the systematic change of project organization, management, and means, which the BIM technical team and the accumulation of BIM experience are directly related to. Project managers and BIM technicians are the main productivity to BIM projects. They directly determine the change of the project business process. At the same time, the change of traditional work cannot be directly reflected. The existing BIM talents, project manager's experience, delivery mode, and other aspects of project participating enterprises can not only reflect the business ability, BIM staffing, and BIM experience of project application but also be easy to measure, which can reflect whether the project organization has made changes in the traditional work culture and business process, as well as BIM project-related business flow to a considerable extent in the maturity of the process.

The research of BIM-AMM can not only clearly judge the level of BIM application in the project at the present stage but also identify the existing BIM defects and understand the problems that the project should focus on from the BIM condition at the present stage to the next maturity stage, so as to improve the stability of BIM value by improving the BIM shortboard.

Considering that the BIM-AMM in this study is different from the maturity model in other studies in the measurement focus and stages, it is difficult to make a comparison from the case study. Taking BIM-CMM, BIM Maturity Matrix, Multifunctional BIM Maturity Model, and BIM Maturity as the comparison object, this paper added Table 4, displaying a comparison between BIM-AMM and other maturity models from the evaluation perspective, the application phase, maturity model dimension, and application process, to reflect the innovation of this research.

Data Availability

No data were used to support this study.

Additional Points

This work has achieved practical significance but has some limitations. In the process of the BIM-AMM index grade evaluation, the evaluation criteria of expert interview and the direct scoring method may cause subjective differences in the evaluation results. Finding a method that can overcome human factors and deeply quantify the maturity level of indicators is a further research direction. The BIM-AMM proposed in this paper is based on a specific time of the project, which cannot dynamically and continuously evaluate the BIM application maturity of the project from the perspective of time continuity, and should be further optimized in the follow-up research.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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