


Article

Research on BIM Application Two-Dimensional Maturity Model

Changqing Sun ^{1,2} , Hong Chen ^{3,4,*}, Ruyin Long ^{3,4,*} and Ruihua Liao ⁵¹ School of Economics and Management, China University of Mining and Technology, Xuzhou 221116, China² Zhongye Changtian International Engineering Co., Ltd., Changsha 410125, China³ School of Business, Jiangnan University, Wuxi 214122, China⁴ Institute of National Security and Green Development, Jiangnan University, Wuxi 214122, China⁵ School of Information Technology, Hunan First Normal University, Changsha 410205, China

* Correspondence: 8202105496@jiangnan.edu.cn (H.C.); 8202105495@jiangnan.edu.cn (R.L.);

Tel.: +86-133-7221-0769 (H.C.); +86-139-5229-8058 (R.L.)

Abstract: The existing project management maturity models and BIM maturity models have obvious deficiencies in evaluating the management level of engineering projects with BIM applications. This study aimed to use accepted assessment indexes to design an innovative BIM application maturity model suitable for different projects with BIM applications. This study proposes the concept of BIM Application Two-Dimensional Maturity (BATM), which simultaneously emphasizes the project business management (PBM) and project BIM application (PBA) maturities. The BATM model assesses the PBM and PBA maturities based on eight performance domains and 37 desired outcomes of PMBOK 7th edition. The application case shows that the use of the BATM model is simple and its effect is obvious. This study is the first to assess the BIM application maturity from the two dimensions of PBM and PBA, and provides new insights into the project BIM application maturity assessment. The application case sets an example for other companies to assess and improve their BATM.

Keywords: project management; project BIM application; two-dimensional maturity; maturity model; PMBOK



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1. Introduction

In recent years, adopting building information modeling (BIM) has become increasingly popular in the design, construction, operations, and maintenance phases of the building's life cycle [1,2]. BIM is a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle [3]. In the engineering industry, owners, designers, builders, and managers have already reported the benefits of adopting the BIM methodology, which has led to its increasing acceptance at a global level [4].

Maturity models, which originated from total quality management [5] and are widely used in various industries [6], are primarily based upon the capability maturity model (CMM) of the Software Engineering Institute. Maturity models allow individuals and organizations to self-assess the maturity of various aspects of their processes against benchmarks [7], and enable organizations to accelerate the enhancement in their capabilities in fields such as business process management [8], software research and development [9], digital government [10], knowledge management [11], and project management [12]. Maturity models assume predictable patterns in every evolutionary phase of organization development [13]. These distinctive phases, with each later phase being superior to a previous phase, provide a roadmap for organizational improvement. The continuous progress of an organization on the evolutionary path implies gradual improvements in the organizational capabilities. The maturity levels represent a staged path for the performance and process improvement efforts of organizations [14].

BIM maturity can be defined as the level of “quality, repeatability and degree of excellence” in relation to performing a BIM-related task or delivering a BIM service or output [15]. Different BIM maturity models have been created to measure BIM maturity in the architecture, engineering, and construction industries [16]. Some models focus on assessing BIM against projects, while others target evaluating organizations [17].

However, the existing BIM maturity models have two main inadequacies. Firstly, most maturity models tend to evaluate the BIM application maturity at specific project phases under specified conditions, such as the design phase [18,19], construction phase [20,21], and facility management [22,23]. Few models can be applied to all phases from design and construction to operations and maintenance. Secondly, each model puts forward its own differing assessment indexes and has its own definition of maturity levels, and there is no commonly accepted model. As a result, it is difficult for users to choose a suitable model for their BIM maturity assessment [24].

In the era of digital twins, for the engineering industry, BIM represents the virtual world, whereas engineering construction represents the real world, and the two are like twins. Therefore, there is a need to study the BIM maturity and the project management maturity at the same time; however, there is no literature in this regard at present.

To this end, this study proposes an innovative BIM maturity model called the BIM Application Two-Dimensional Maturity (BATM) model, which combines the functions of the project management maturity model (PMMM) and BIM maturity model, simultaneously emphasizes project business management (PBM) and project BIM application (PBA) from the two dimensions of the real world (PBM) and virtual world (PBA), and achieves the effect of $1 + 1 > 2$. The application of the BATM model helps in enhancing the maturity level of the project management and BIM application, improving the efficiency of organizational production management, and promoting organizational advancement along a maturity ladder.

The remainder of this paper is organized as follows. The next section provides the background of project management maturity models and BIM maturity models such that the BATM framework can be better understood. The Methods section introduces the BATM concept, definition, model structure, and the related questionnaire, as well as an example in which the BATM model is applied. Subsequently, the important functions and innovations of the study are discussed. Finally, the Conclusions section presents the theoretical and practical implications of the study.

2. Research Background

2.1. Project Management Maturity Models

The maturity in managing projects implies the established, proven, and innovative practices and procedures that lead to success in planning and completing projects [25]. Companies in various industries are pursuing improvements in project management maturity. A PMMM can enable an organization to seek perfect project management by implementing gradual maturity improvement processes within the organization [26]. PMMMs are regarded as the useful tools for evaluating an organization’s current project management capability [27]. Project management capability is the competence required to ensure an organization remains competitive when conducting projects [28]. Capability frameworks are the basis for maturity models that address how capabilities can be developed along an anticipated, desired, or logical path [29].

The successful application of the CMM in the software industry inspired the development of the maturity model for project management. A PMMM is a complete framework and a comprehensive tool for evaluating the maturity level of project management. Since its creation in the 1990s, it has been used to systematically improve the maturity level of project management. As higher project management maturity levels represent the ability of organizations to obtain better results from their projects, the stakeholders of organizations are willing to assess their current project management maturity status for future development and improve to the next phase if desired [30].

After more than 30 years of development, many PMMMs have become available. The Microframe project management maturity model is one of the earliest PMMMs to be applied practically [31]. The Berkeley project management process maturity model, known as PM2 and presented by Ibbs and Kwak, determines and positions an organization's relative project management level based on those of other organizations [32]. A five-scale PMMM known as K-PMMM [33], which was established by Kerzner, analyzes the efficiency of project management organization, drawing attention to the importance of strategic project management to improve know-how in the marketplace. PMS-PMMM, which was released by Project Management Solutions in 2001, combines the five maturity levels proposed by the Software Engineering Institute and the project management knowledge areas proposed by the Project Management Institute (PMI) to form a comprehensive, easy-to-accept project management maturity improvement model [34]. The organizational project management maturity model (OPM3) introduced by the PMI not only provides a systematic assessment and improvement method for the enterprise from a single project to entrepreneur portfolio projects, but also introduces and solidifies the best practice in every business process [27]. The portfolio, programme, and project management maturity model (P3M3), which was developed by the UK's Office of Government Commerce, comprises three independent sub-models (portfolio, programme, and project) and considers all seven processes as equally important. In the P3M3, the lowest maturity of the seven processes is the maturity of the organization [6]. In 2016, the International Project Management Association (IPMA) developed a methodology called "IPMA Delta" in order to certify the ability of an organization to use project management techniques. The assessment results of IPMA Delta show, in detail, the room for improvement, also giving recommendations for the future areas that need to be refined. MMM, focusing on a strategy of continuous improvement and following the four steps of the PDCA cycle to put this approach into practice, was developed by Langston and Ghanbaripour [35].

The only feature on which almost all models seem to converge is the determination of five maturity levels, even if they are not perfectly equal, either in the contents or in the denominations [36]. These levels and the corresponding main models can be summarized as follows:

- Level 1: initial or basic with awareness (OPM3, IPMA Delta, P3M3, CMMI, PM2, PMS-PMMM, MMM).
- Level 2: structured, managed, or repeatable (OPM3, P3M3, CMMI, PMS-PMMM, MMM).
- Level 3: defined, standardized, or institutionalized (OPM3, IPMA Delta, P3M3, CMMI, PMS-PMMM, MMM).
- Level 4: fully managed at the corporate level (OPM3, IPMA Delta, P3M3, CMMI, PM2, PMS-PMMM, MMM).
- Level 5: optimized with continuous learning and improvement (OPM3, IPMA Delta, P3M3, CMMI, PM2, PMS-PMMM, MMM).

In recent years, PMMM research has been expanded, and many scholars have investigated project risk management models [37,38]. Silvius and Schipper developed a sustainable PMMM as a practical tool for the assessment and development of the integration of sustainability in projects [39]. Seelhofer and Graf extended the concept of organizational project management maturity to the national context and developed a systematic framework of national project management maturity and the national PMMM [40].

Since most PMMMs are based on a guide to the project management body of knowledge (PMBOK) of PMI [41], by adopting PMMMs, organizations can systematically plan and improve their project management capabilities and benchmark their performance in accordance with the industry standards [31]. The assessment of maturity through PMMMs enables further improvement directions to be identified [26].

Despite their similarities, PMMMs differ from each other in terms of their assessment methodology. Hence, selecting an appropriate PMMM is a crucial managerial decision, and the organizational environment and project characteristics must be considered well to ensure the suitability of the selected model [30].

2.2. BIM Maturity Model

Over the past decade, a large number of BIM maturity models have been developed to measure the performance of BIM application. BIM maturity models are mainly divided into two categories [17,42]: one is the project BIM maturity model focusing on project application performance, and the other is the organizational BIM maturity model focusing on enterprise implementation capability. The famous project BIM maturity models include NBIMS CMM, iBIM, and VDC Scorecard, and the famous organizational BIM maturity models include BIM PM, BIM MM, BIM Quick Scan, and BIM AP. In addition, there are individual models that can be applied to the BIM maturity assessment of both organizations and projects.

The U.S. National BIM Standard (NBIMS) was published in 2007 and provided information as a guide for the adoption, implementation, and application of BIM to enable core principles. The Capability Maturity Model (CMM) of NBIMS is a matrix with 11 interest areas on the x -axis and 10 maturity levels on the y -axis [43], and is a useful tool for the strategic management in the BIM implementation of an organization [44]. The interactive capability maturity model (ICMM) is a further enhancement of CMM, developed to meet the growing need for an accurate and up-to-date model [45]. Bew and Richards developed the iBIM maturity model in 2008. Its assessment indexes focus on technology, standards, guidelines, classification, delivery, etc. Its maturity is divided into four levels. Level 0 is characterized by paper-based medium delivery methods. Level 1 represents structural elements by 2D or 3D digital objects. Model-based collaboration occurs in Level 2 between different parties, and network-based integration occurs in Level 3 [46]. VDC Scorecard was designed to measure the performance of the projects of virtual design firms with four major areas, 10 divisions, and 74 measures. Its distinct feature is the establishment of confidence levels to measure the degree of objective compliance [47]. VDC Scorecard has both quantitative and qualitative assessment methods with multiple choice and open-ended questions. It assesses performances of BIM projects against the industry benchmark and has five maturity levels.

The BIM Proficiency Matrix (BIM PM) was developed by Indiana University Architect's Office to score the performance of BIM services of designers and contractors in Indiana University projects [48]. BIM PM is composed of 32 measures of eight areas and five maturity levels [17]. It has also been criticized for its heavy focus on the technical aspects of BIM implementation rather than process and protocol. The BIM maturity matrix (BIM MM) is multi-dimensional and can be represented by a tri-axial knowledge model comprising BIM Fields, BIM Stages, and BIM Lenses [49]. The model proposes five BIM maturity levels: initial, defined, managed, integrated, and optimized [50]. BIM MM assessment can be provided by the online BIM Excellence platform. The question number of assessment varies according to the assessment granularity level, and a maturity score is compiled related to 12 positions grouped into five areas [51]. BIM Quick Scan developed by TNO (The Netherlands Organization for applied scientific research) is a benchmarking tool for organizational performance with a reasonably extensive scope covering 44 measures in four main areas, including: organization and management, mentality and culture, information structure and information flow, and tools and applications [43]. It can combine quantitative and qualitative assessments of the "hard" and "soft" aspects of BIM, and distinguish the strengths and weaknesses of BIM application for an organization. Organizational BIM Assessment Profile (BIM AP) was created by Pennsylvania State University Computer Integrated Construction (CIC) Research Program in 2012. Its maturity is measured by 20 planning elements with six themes: Strategy, BIM Uses, Process, Information, Infrastructure and Personnel, Companies. Their maturity levels range from 0 (Non-Existent) to 5 (Optimizing) [22,51].

The multifunctional BIM maturity model (MPMM) focuses on BIM maturity at different scales from individual projects to an organization's full projects portfolio, covering measurements across three domains: technology, process, and protocol. Detailed, operable

rubrics enable the assessment of each subdomain of each domain, and the assessment result points to four maturity levels (0–3) [52].

From the above introduction, it can be seen that these existing studies mainly focus on the technology capability maturity of BIM from different perspectives and conditions, and ignore the digital twin relationship between BIM and projects. In addition, a large number of BIM maturity models have different assessment indexes and different level definitions. As a result, users can be confused and do not know how to choose assessment models.

2.3. Research Gaps

This study aims to fill several main literature gaps, as follows:

- Each of the existing BIM maturity models was developed to achieve a specific BIM assessment purpose [17]; moreover, many models can only be applied to an individual project phase from scheme design to facility maintenance, which leads to the situation of different assessment indexes and different level definitions for different models, increases the difficulty for users to choose an appropriate model [42], and then affects the popularization and use of these models. Determining how to design a BIM maturity model with a generally acceptable assessment index and maturity level system, and make the model applicable to all projects with BIM application, are problems worth studying.
- In the PMMM literature, the assessment indexes of most studies were based on PMBOK [31,41], but PMBOK was not used in the study of the PBA maturity. Because the objects of BIM services are projects and BIM implementation processes are also similar to project management processes, PMBOK should be of guiding and reference value for PBA maturity research. In addition, PMBOK 7th edition pays close attention to eight performance domains and 37 desired outcomes, which is more closely combined with the BIM application and creates favorable conditions for PBA maturity assessment based on PMBOK. However, to date, there is no research about the PBM maturity model or the PBA maturity model based on the PMBOK 7th edition.
- The PBM and PBA maturities are two important aspects of modern project management, and reflect the digital twin relationship from the two dimensions of the virtual and real worlds. In modern project management, the PMMMs can no longer ignore the existence of BIM, and the BIM maturity model also needs to consider the contribution of BIM in project management. However, there is no research that simultaneously assesses their maturities, or that identifies problems and highlights directions for the improvement in PBM and PBA by a maturity assessment.

3. Method

3.1. Concept of BATM

As previously stated, the existing project management maturity models and BIM maturity models have obvious deficiencies in evaluating the management level of engineering projects with BIM applications. Against the background in which the idea of digital twins has become popular and 37 desired outcomes of the PMBOK 7th edition have become an acceptable global standard, in order to enable an organization to accurately understand the capabilities of its project management and BIM applications and then take effective measures for improvement, the PBM and PBA maturities can be evaluated simultaneously based on each desired outcome.

It is in this context that the BATM model is proposed. The BATM is expressed by a two-dimensional value such as (x, y) , in which x reflects the PBM maturity level, and y reflects the PBA maturity level. The BATM model consists of the following items: maturity level definition, assessment indexes, questionnaire, maturity calculation and problem identification methods, improvement advice, etc.

The purpose of putting forward the concept of BATM is to use the PBM and PBA maturities to reflect the level of enterprises' project management and project BIM applications; and, through the BATM model, determine enterprises' strengths and weakness in the PBM

and PBA aspects, identify the improvement directions, and promote the advancement of enterprises' PBM and PBA maturities.

It is noteworthy that the two-dimensional maturity in this study differs significantly from the multi-dimensional maturity in other studies. The two dimensions investigated in this study were the PBM of the real world and the PBA of the virtual world. For example, considering "Effective management of procurements" which is one desired outcome of the project work performance domain in PMBOK 7th edition, the BATM value of (3, 1) means that the PBM maturity level of procurement management in the real world is 3 and the PBA maturity level in the virtual world is 1; it also means that there are obvious deficiencies in its online capabilities for supporting offline project management. However, the multiple dimensions in other studies refer to several aspects of pure project management. For example, Hu presented a three-dimensional PMMM constituted by best practice maturity, process maturity, and organization system maturity [53].

3.2. Classification of Maturity Level

The BATM assessment is inseparable from the level definition of the PBM and PBA maturities. The classification and definition of PBM and PBA maturity level should be clear.

The classification of the PBM maturity levels refers to that of the PMS-PMMM model, and its maturity levels, from 1 to 5, are the initial, managed, defined, quantitatively managed, and optimizing levels, respectively.

The classification of the PBA maturity levels refers to the information technology governance maturity model under the COBIT 4.1 framework. In COBIT 4.1, the maturity levels from 0 to 5 are the non-existent, initial, repeatable but intuitive, defined process, managed and measurable, and optimized levels, respectively [54], which match well with the maturity levels of PMS-PMMM.

The specific feature definitions of the PBM and PBA maturity level are shown in Table 1.

Table 1. Definition of maturity level.

Level	Definition of PBM Maturity Level	Definition of PBA Maturity Level
Level 0		<ul style="list-style-type: none"> The organization does not apply BIM in engineering projects and does not possess PBA awareness.
Level 1	<ul style="list-style-type: none"> Project management is temporary, and even chaotic occasionally. Organization rarely provides a stable environment for implementing projects. The success of a project primarily depends on the efforts of the individual, rather than the standardized management processes of the organization, and organization has begun to realize these problems in project management. 	<ul style="list-style-type: none"> The organization has realized the importance of PBA. Some applications of BIM tools and software exist in some projects, but the effect of PBA is fragmented. No defined and standardized processes exist.
Level 2	<ul style="list-style-type: none"> Organization has established basic processes to track projects, and encourage and support other projects to use these standardized processes. The management primarily depends on personal knowledge or general tools, and the actual effect varies significantly by project. 	<ul style="list-style-type: none"> The organization has purchased systematic PBA tools or constructed a PBA software platform, and has established the corresponding PBA processes, on which the project members can perform their work. The organization has no mandatory requirement for PBA in project management, and the effect of PBA depends entirely on the individual's ability and responsibility.
Level 3	<ul style="list-style-type: none"> Project management processes have been institutionalized and standardized, as well as extended to all projects. The management depends on industry standards, and the organization can master the summary information and detailed information of each project. 	<ul style="list-style-type: none"> The project management processes have been integrated into the PBA processes, the tools and platform of PBA are reliable and verified, and the processes and requirements of PBA have been standardized and documented. The organization requires employees to follow the PBA processes, however, the management of PBA deviation is insufficient.
Level 4	<ul style="list-style-type: none"> Project management processes are combined with the organizational processes. The management depends on organizational standards, the project implementation is under control, and project management decisions are made using project data. The organization has standardized analysis methods to evaluate project performance. 	<ul style="list-style-type: none"> The organization can monitor and measure the implementation and deviation of the PBA, and detailed results of the PBA performance can be acquired and analyzed statistically. PBA is under good control and constant improvement, and various intelligent equipment and software of project management are combined with PBA, thereby contributing to PBM.
Level 5	<ul style="list-style-type: none"> The organization has established and performed the processes for evaluating the efficiency and effectiveness of project implementation. The processes for improving project performance are implemented, and continuous improvement is the focus of project management. 	<ul style="list-style-type: none"> Based on quantitative feedback and continuous improvement, PBA processes have been refined to the level of "best practices". PBA is indispensable for improving the efficiency and effect of PBM in an organization.

3.3. Definition of Model Structure

PMBOK is an excellent reference for analyzing project management capabilities, in which an abundance of “best practice” information is outlined in the document [34]. Because the knowledge content of each PMBOK performance domain is abundant, each performance domain is categorized into several key desired outcomes [55]. In total, there are eight performance domains and 37 desired outcomes in the PMBOK 7th edition.

In the BATM model, the eight performance domains are used as the first level assessment indexes, and the 37 desired outcomes are used as the second level assessment indexes; this constitutes the assessment index system of BATM model. The second level assessment indexes are used to measure the PBM and PBA maturities from the two dimensions of the virtual and real worlds, and the maturities of the first level assessment indexes are summarized from the second level indexes. For example, under the delivery performance domain, the maturity level is measured using five desired outcomes. They include: (1) projects contribute to business objectives and advancement of strategy; (2) projects realize the outcomes they were initiated to deliver; (3) project benefits are realized in the time frame in which they were planned; (4) the project team has a clear understanding of requirements; (5) stakeholders accept and are satisfied with project deliverables. The specific assessment indexes are shown in Table 2.

Table 2. Assessment index system of BATM.

Performance Domains	Code	Desired Outcomes
Stakeholder performance domain	D ₁₁	A productive working relationship with stakeholders throughout the project.
	D ₁₂	Stakeholder agreement with project objectives.
	D ₁₃	Stakeholders who are project beneficiaries are supportive and satisfied while stakeholders who may oppose the project or its deliverables do not negatively impact project outcomes.
Team performance domain	D ₂₁	Shared ownership.
	D ₂₂	A high-performing team.
	D ₂₃	Applicable leadership and other interpersonal skills demonstrated by all team members.
Development approach and life cycle performance domain	D ₃₁	Development approaches that are consistent with project deliverables.
	D ₃₂	A project life cycle consisting of phases that connect the delivery of business and stakeholder value from the beginning to the end of the project.
	D ₃₃	A project life cycle consisting of phases that facilitate the delivery cadence and development approach required to produce the project deliverables.
	D ₄₁	The project progresses in an organized, coordinated, and deliberate manner.
	D ₄₂	There is a holistic approach to delivering the project outcomes.
Planning performance domain	D ₄₃	Evolving information is elaborated to produce the deliverables and outcomes for which the project was undertaken.
	D ₄₄	Time spent planning is appropriate for the situation.
	D ₄₅	Planning information is sufficient to manage stakeholder expectations.
	D ₄₆	There is a process for the adaptation of plans throughout the project based on emerging and changing needs or conditions.
	D ₅₁	Efficient and effective project performance.
	D ₅₂	Project processes are appropriate for the project and the environment.
Project work performance domain	D ₅₃	Appropriate communication with stakeholders.
	D ₅₄	Efficient management of physical resources.
	D ₅₅	Effective management of procurements.
	D ₅₆	Improved team capability due to continuous learning and process improvement.
	D ₆₁	Projects contribute to business objectives and advancement of strategy.
Delivery performance domain	D ₆₂	Projects realize the outcomes they were initiated to deliver.
	D ₆₃	Project benefits are realized in the time frame in which they were planned.
	D ₆₄	The project team has a clear understanding of requirements.
	D ₆₅	Stakeholders accept and are satisfied with project deliverables.
	D ₇₁	A reliable understanding of the status of the project.
Measurement performance domain	D ₇₂	Actionable data to facilitate decision making.
	D ₇₃	Timely and appropriate actions to keep project performance on track.
	D ₇₄	Achieving targets and generating business value by making informed and timely decisions based on reliable forecasts and assessments.
	D ₈₁	An awareness of the environment in which projects occur, including, but not limited to, the technical, social, political, market, and economic environments.
Uncertainty performance domain	D ₈₂	Proactively exploring and responding to uncertainty.
	D ₈₃	An awareness of the interdependence of multiple variables on the project.
	D ₈₄	The capacity to anticipate threats and opportunities and understand the consequences of issues.
	D ₈₅	Project delivery with little or no negative impact from unforeseen events or conditions.
	D ₈₆	Opportunities are realized to improve project performance and outcomes.
	D ₈₇	Cost and schedule reserves are utilized effectively to maintain alignment with project objectives.

The BATM structure can be classified into three layers: project layer, performance domain layer, and desired outcome layer. Because the mode structure is based entirely on PMBOK 7th edition, we did not conduct an empirical analysis of it.

3.4. Questionnaire

The questionnaire consists of three parts. The first part introduces the purpose and requirements of the questionnaire, the second part explains the definition of PBM and PBA maturity levels, and the third part is the scoring table for experts to score. The left side of the scoring table lists the assessment indexes of the BATM model, including eight performance domains and their corresponding 37 desired outcomes. The right side is the selection area of PBM and PBA maturity levels, and the weights of desired outcomes can be set according to their performance domains.

In the questionnaire, a scale of 1 to 5 for PBM maturities and a scale of 0 to 5 for PBA maturities were adopted to measure the responses. Level 1 corresponds to score 1, level 2 corresponds to score 2, etc. Because the first, third, and fifth levels of the PBM and PBA maturities are the initial level, the defined level, and the optimized level, respectively, and their second and fourth levels are also similar, we can deem that their five maturity levels are relatively consistent. In addition, as there may be no PBA in some projects, the PBA maturity levels include the non-existent level. The format of the scoring table is shown in Table 3.

Table 3. Scoring table of BATM questionnaire.

Assessment Indexes		PBM Maturity					Weight	PBA Maturity					Weight	
		L1	L2	L3	L4	L5		L0	L1	L2	L3	L4		L5
Stakeholder performance domain	D11	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D12	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D13	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
Team performance domain	D21	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D22	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D23	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
Development approach and life cycle performance domain	D31	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D32	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D33	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
Planning performance domain	D41	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D42	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D43	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
Project work performance domain	D44	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D45	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D46	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
Delivery performance domain	D51	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D52	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D53	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
Measurement performance domain	D54	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D55	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D56	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
Uncertainty performance domain	D61	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D62	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D63	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
Measurement performance domain	D64	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D65	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D71	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
Uncertainty performance domain	D72	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D73	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D74	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
Measurement performance domain	D81	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D82	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D83	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
Uncertainty performance domain	D84	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D85	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D86	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____
	D87	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	_____

3.5. Calculation of BATM Level

After experts return the scoring table of the BATM questionnaire, the questionnaire organizers first identify whether experts' responses are qualified (in the two-dimensional maturity options of a management process of the scoring table, multiple selections and no selection are regarded as unqualified), then deal with the qualified data to obtain the

three-layer BATM. The courses of evaluating the BATM involve the maturity determination of desired outcome layers based on the two dimensions of PBA and PBM, and that of performance domain layers and the project layer according to certain weight ratios. In the following expressions, w_{ikj} is the weight of expert k in the desired outcome j of performance domain i , i.e. the weight in the scoring table; w_{ik} , decided by the organizers, is the weight of expert k in performance domain i (for simplicity, the weights among experts can be considered not to change with performance domains); w_i , also decided by the organizers, is the weight of performance domain i ; n is the number of desired outcomes in performance domain i ; and l is the number of experts. When determining the expert weight w_{ik} , the questionnaire organizers need to consider the basic information, such as the experts' education background, their corresponding positions, and their working years in each position. However, in order to simplify the statistical workload, experts' scores can also be treated equally; that is, the default value 1 can be used as the experts' weights.

The BATM value of each desired outcome (m_{PBM}^{ij} , m_{PMA}^{ij}) can be obtained by Formulas (1) and (2), which are equal to the weighted average of the desired outcome maturity values provided by the experts and the corresponding expert weights.

$$m_{PBM}^{ij} = \frac{\sum_{k=1}^l (m_{PBM_{ikj}} \cdot w_{ik})}{\sum_{k=1}^l w_{ik}} \quad (1)$$

$$m_{PMA}^{ij} = \frac{\sum_{k=1}^l (m_{PMA_{ikj}} \cdot w_{ik})}{\sum_{k=1}^l w_{ik}} \quad (2)$$

The BATM value of each performance domain (m_{PBM}^i , m_{PMA}^i) can be obtained using Formulas (3) and (4). They are equal to the weighted average of the experts' performance domain maturity values and corresponding expert weights, in which the experts' performance domain maturity values equal the weighted average of the desired outcome maturity values and corresponding desired outcome weights provided by the experts in their scoring tables.

$$m_{PBM}^i = \frac{\sum_{k=1}^l \left(\frac{\sum_{j=1}^n (m_{PBM_{ikj}} \cdot w_{ikj})}{\sum_{j=1}^n w_{ikj}} \cdot w_{ik} \right)}{\sum_{k=1}^l w_{ik}} \quad (3)$$

$$m_{PMA}^i = \frac{\sum_{k=1}^l \left(\frac{\sum_{j=1}^n (m_{PMA_{ikj}} \cdot w_{ikj})}{\sum_{j=1}^n w_{ikj}} \cdot w_{ik} \right)}{\sum_{k=1}^l w_{ik}} \quad (4)$$

The BATM value of the project layer (m_{PBM} , m_{PMA}) is equal to the weighted average of all performance domain maturity values and the corresponding performance domain weight. They can be obtained by Formulas (5) and (6), in which m_{PBM} and m_{PMA} represent the project layer's PBM and PBA maturities, respectively.

$$m_{PBM} = \frac{\sum_{i=1}^8 (m_{PBM}^i \cdot w_i)}{\sum_{i=1}^8 w_i} \quad (5)$$

$$m_{PMA} = \frac{\sum_{i=1}^8 (m_{PMA}^i \cdot w_i)}{\sum_{i=1}^8 w_i} \quad (6)$$

4. Results

4.1. Survey Method

In 2021, The BATM assessment was applied to an engineering company engaged in general contracting. Data were acquired using the questionnaire survey method, and 50 participants were selected for the survey from project staff who had worked in the company for more than 5 years. About half of the participants had used BIM software or participated in BIM training, and the other half were project managers and other management personnel who knew something about BIM but had no experience of operating BIM software. Their information is listed in Table 4.

Table 4. Participant information table.

Gender	Educational Background		BIM	Post Project Management	Work Experience			
	Male	Female			Undergraduate	Graduate	<10	≥10
	42	8	37	13	6	44	11	39

After understanding the purpose of the survey, the participants carefully determined the PBM and PBA maturities of 37 desired outcomes according to the definition of maturity levels and their understanding of the actual PBM and PBA maturities in the company. Ultimately, a total of 49 valid questionnaires were acquired (in an unqualified questionnaire, some options were not answered).

4.2. Statistical Analysis

Content validity analysis: Because the BATM questionnaire was developed based on the PMBOK 7th edition, which is an acceptable standard, the researchers organized a pilot study to evaluate the internal validity. In this pilot study, researchers conducted comprehensive interviews with seven project personnel who had participated in at least two projects adopting BIM. Based on the positive assessment of these project managers, the conclusion obtained from them was that the content of the questionnaire was closely related to the PBM and PBA maturities, its structure was simple and clear, and its operability was appropriate.

Reliability analysis: The reliability analysis was conducted using Cronbach's alpha coefficient. According to Kim and Feldt [56], when the internal consistency coefficient of the data reaches 0.70 or higher, the data can be considered to have sufficient reliability. In the study, the item scale was internally consistent because all of Cronbach's alpha coefficients exceeded the threshold value (0.70) (Table 5).

Table 5. Descriptive statistics, Cronbach's alpha, and correlation coefficients.

		Minimum	Maximum	Mean	Std. Deviation	Cronbach Alpha	Correlation Coefficient	t
Stakeholder	PBM	1.00	3.00	2.15	0.72	0.75	0.67	6.27
	PBA	0.00	2.00	1.29	0.70	0.78		
Team	PBM	1.33	3.33	2.71	0.51	0.93	0.53	4.40
	PBA	0.00	2.00	1.47	0.66	0.95		
Development	PBM	2.00	3.33	2.73	0.44	0.91	0.77	8.44
	PBA	0.33	2.00	1.63	0.48	0.76		
Planning	PBM	1.50	3.00	2.43	0.41	0.76	0.79	9.13
	PBA	0.50	2.00	1.50	0.46	0.73		
Project work	PBM	2.00	3.00	2.69	0.33	0.81	0.62	5.55
	PBA	0.00	2.17	1.73	0.47	0.90		
Delivery	PBM	1.00	3.00	2.47	0.43	0.86	0.51	4.14
	PBA	0.00	2.00	1.79	0.45	0.95		
Measurement	PBM	1.00	3.50	2.30	0.56	0.83	0.61	5.34
	PBA	0.00	2.25	1.52	0.52	0.84		
Uncertainty	PBM	1.00	3.43	2.45	0.65	0.94	0.84	10.9
	PBA	0.00	2.00	1.35	0.53	0.87		

Data analysis: To understand the data more effectively, we conducted a descriptive data analysis and a correlation analysis, and the results are listed in Table 5. The mean values reflect the maturity of each performance domain, in which the PBM maturities change from 2.15 to 2.71 and PBA maturities change from 1.29 to 1.79. Correlation analyses were conducted to verify the correlations between the PBM and PBA maturities. As can be seen from Table 5, the correlation coefficients in all performance domains are between 0.51 and 0.84; the t -test statistics are between 4.14 and 10.9, which are greater than $t_{\alpha/2}$ ($\alpha = 0.05$; $t_{\alpha/2} = 2.008$) and indicate clear correlations.

Table 6 shows the significant difference among different performance domain data and among different participant data, in which the results were obtained by the analysis of variance with two factors. The fact that all of the F-values were greater than the values of “F-crit,” and all of the p -values were less than the significance level of 0.05, implies that statistically significant differences existed among the maturities of the eight performance domains and among the feedback of the 49 participants.

Table 6. Analysis of variance with two factors.

Dimension	Source of Difference	Sum of Squares	Degree of Freedom	Mean Square	F	p -Value	F-Crit
PBM	Performance domains	15.28	7	2.18	9.44	1.073×10^9	2.037
	Participants	38.53	48	0.80	3.47	1.513×10^{11}	1.396
PBA	Performance domains	6.50	7	0.93	4.11	2.409×10^4	2.037
	Participants	52.60	48	1.10	4.84	1.735×10^{18}	1.396

4.3. Problems and Measures

The BATMs of the eight performance domains are shown in Figure 1. The PBM and PBA lines represent the PBM and PBA maturities achieved in 2021, respectively. Based on the figure, we discovered the following problems: (1) the PBM maturities of two performance domains (i.e. stakeholder and measurement) are obviously lower than 2.5, and the rest are close to or more than 2.5; (2) the PBA maturities of the stakeholder and uncertainty domains are obviously lower than 1.5, and the rest are close to or more than 1.5; (3) the maturity gaps between PBM and PBA are large, in which the uncertainty and team domains are particularly prominent (their BATM values are (2.45, 1.35) and (2.71, 1.47), and the ratios of their gaps to the PBA maturities are 81.4% and 84.6%, respectively).

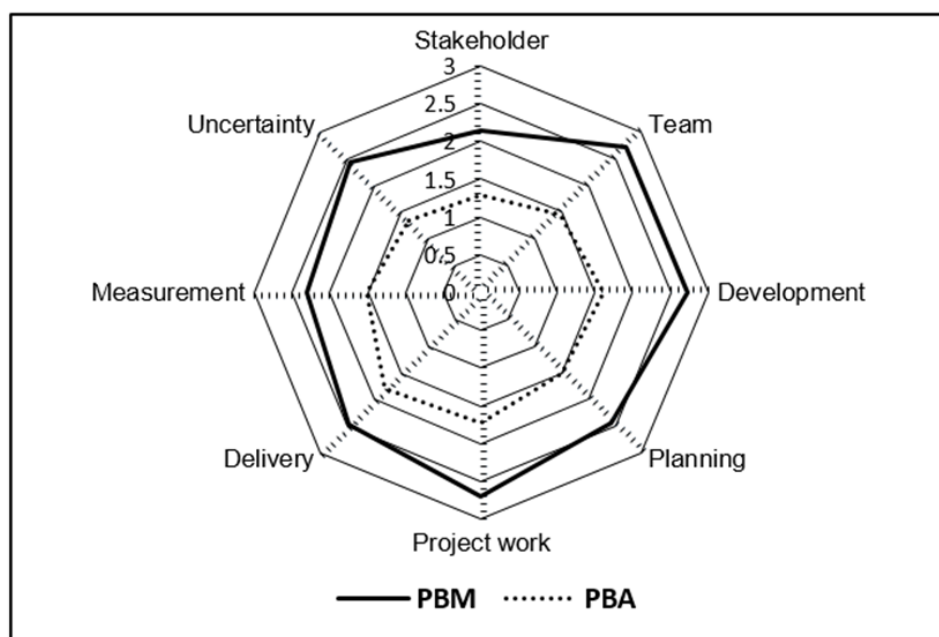


Figure 1. Assessment result of BATM model.

The obvious gaps between the PBM and PBA maturities shows that PBA not only does not guide and support PBM, but also lags far behind BPM, and there is a significant room for PBA to develop in the project, performance domain, and desired outcome layers. The organization should strengthen its support for PBA, ensure the PBA maturity catches up with the PBM maturity, and form a good interaction situation.

Through this assessment, the problems faced by the company were determined and the improvement directions were identified. In terms of the PBA maturity, the improvement priorities were the stakeholder and uncertainty domains. Regarding the PBM maturity, the improvement priorities were the stakeholder and measurement domains. In order to narrow the gap between PBA and PBM, the improvement priorities were the uncertainty and team domains.

The results of the BATM assessment aroused significant attention of the company leaders, and the company took a series of measures to improve the PBM and PBA maturities, referring to the improvement priorities provided by the BATM assessment.

5. Discussion

BIM technology has been developed globally for a period of more than 20 years. Because BIM applications exist in different phases of the project life cycle, including design, construction, operation, and maintenance, and BIM applications involve many stakeholders, such as the designers, equipment supplies, construction companies, consulting-related enterprises, project owners, and even relevant government departments, the whole process of BIM applications is complex. As a result of the complexity of BIM applications, they are not as good as expected under many circumstances [57], although BIM has been well applied in some countries and some projects. To promote BIM applications, various BIM application maturity assessment models based on different enterprise perspectives and different project phases have been developed [17,22,42–52].

However, all of the BIM application maturity models have several obvious deficiencies. First, the assessment indexes of all models are different, and a unified assessment index system has not been derived. Second, these models also have huge discrepancies in the definition of maturity levels, with the number of maturity levels ranging from three to ten. Third, these models are built under specific business perspectives and specified project conditions, and have application limitations under other project situations. These deficiencies make it difficult for various BIM application maturity models to be popularized and applied. BIM application maturity models do not have the good effect expected by the public, and create difficulties for users in choosing these models [24]. Hence, a holistic model enabling BIM maturity assessments is necessary [17].

Considering the digital twin relationship between BIM applications and engineering projects, and that the purpose of BIM applications is to achieve the project objectives and BIM application processes are deeply integrated with project implementation processes, in this study, the eight performance domains and 37 desired outcomes of PMBOK 7th edition were selected as the assessment indexes of BATM. The selection of such indexes not only ensures that the BATM indexes are consistent with the processes and objectives of BIM applications and project management, but also avoids the dilemma of designing different assessment indexes for different purposes; thus, projects and organizations can then promote the improvement in BIM application maturity under the unified standard. At the same time, the assessment indexes based on PMBOK also indicate that BATM is applicable to all types of projects, whether they are building projects or highway projects. The selection of BATM assessment indexes is an innovation of this study. In addition, it should be noted that the BIM-related software, hardware, personnel, standards, and other indexes are not the assessment indexes of the project BIM application maturity, but are those of the organizational BIM capability maturity.

In the engineering industry, the main purpose of BIM applications is to serve the engineering projects. It is clear that the high level of BIM applications plays an assisting and supporting role in the project implementation, and the high level of project manage-

ment creates higher requirements for BIM applications. In the context of the continuous development of digital technology, BIM applications and project implementations are increasingly embodied in a digital twin relationship. Through the comparison of the project management maturity in the real world and the BIM application maturity in the virtual world, it is easier to identify the inadequacies and problems in project management and BIM applications. Under the guidance of this idea, this study proposes the BATM model for BIM maturity assessment from the two dimensions of the virtual and real worlds. The two-dimensional maturity ideology of the virtual and real worlds is another innovation of this study.

With regard to the maturity level, this paper refers to a large number of documents and selects the five-level scheme, which has a more intuitive definition of the levels and is more commonly used [6,27,34–36,50]. The five levels of PBA maturity are the initial, repeatable but intuitive, defined process, managed and measurable, and optimized levels (the non-existent level occurs without PBA), and the five levels of PBM maturity are the initial, managed, defined, quantitatively managed, and optimizing levels. The five level schemes of the two dimensions are basically the same.

The application case of the BATM model shows that the model is simple and its effect is obvious. Based on the statistical analysis of expert scores and the radar graph of the two-dimensional maturity values, the deficiencies existing in the PBM and PBA can be visually and accurately identified. Furthermore, the priority improvement direction of BIM application can be determined immediately, and organizations and projects can advance along the BATM ladder.

In the case of multiple BATM assessments, the dynamic changes in two-dimensional maturity can be clearly observed, which will be more effective for the improvement in maturity.

6. Conclusions

6.1. Theoretical Implications

In terms of theoretical contribution, most importantly, this study provides a scheme using generally accepted indexes to assess the BIM maturity for projects with BIM applications. This is the first study to present the BATM concept with the PBM and PBA maturities from the two dimensions of the virtual and real worlds, and the first to assess the PBM and PBA maturities based on the eight performance domains and 37 desired outcomes of PMBOK 7th edition. Furthermore, this study establishes a complete BATM assessment system by combining with an application case. Finally, the study further develops the maturity theory of project management and BIM applications.

6.2. Practical Implications

The practical implications are as follows. Firstly, because the assessment indexes of the BATM model are based on the PMBOK 7th edition, the BATM model can be applied to different project types and different project phases, which eliminates the user's difficulty in choosing a model from various PBA models with different assessment indexes, and increases the practical value of the BATM model. Secondly, the eight performance domains and 37 desired outcomes of PMBOK are generally accepted, so they are more convenient and easier to use than the indexes of other models. Thirdly, the comparison between the PBM and PBA maturities makes it easier to identify the deficiencies and problems in project management and BIM applications, and then to take effective measures to improve their maturities. Fourthly, the actual application case showed that the questionnaire can be used easily by the participants, and set an example for other companies to improve their PBM and PBA capability.

6.3. Limitations and Future Studies

This paper focuses on the project BIM application maturity. The limitation of the paper is that it does not research the organizational BIM capability maturity. Similar research of the organizational BIM capability maturity can be carried out in the future. In addition, this paper takes an engineering company engaged in general contracting business as an example; however, the effect of BATM application to design or construction enterprises needs to be further validated.

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Abbreviations

Comparison Table of Important Abbreviations.

No.	Abbreviation	Meaning
1	BIM	Building information modeling
2	BATM	BIM application two-dimensional maturity
3	PBM	Project business management
4	PBA	Project BIM application
5	PMBOK	Project management body of knowledge
6	CMM	Capability maturity model
7	PMMM	Project management maturity model
8	PMS-PMMM	The PMMM leased by Project Management Solutions
9	PMI	Project Management Institute
10	IPMA	The International Project Management Association
11	NBIMS	U.S. National BIM Standard
12	OPM3	Organizational project management maturity model
13	P3M3	The portfolio, programme, and project management maturity model
14	CMMI	Capability maturity model integration
15	PM2	The Berkeley project management process maturity model
16	MMM	The management maturity model developed by Langston and Ghanbaripour
17	COBIT	Control objectives for information and related technology

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