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BIM Implementation Maturity in Chinese Construction Projects: Evaluation Model and Empirical Investigation

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ABSTRACT

As a new round of breakthrough reforms in construction sector, BIM has already gained great attention and promotion. However, BIM will encounter many problems in the actual implementation process, such as how to use it to maximize efficiency, and how to evaluate the implementation of BIM in construction projects. Due to the late start of BIM technology in China, the development of this technology in various conditions and environment is relatively slow, thus there is still a gap between China and developed countries. Now in China, there is no uniform standards or normative methods to measure the current situation and level of BIM implementation in construction projects, so less improving suggestions can be raised.

Scientific evaluation tool is an effective management method to improve the BIM competence. Based on the reference of foreign typical model, this study considers the characteristics in Chinese construction projects, and then raises an evaluation analysis framework of maturity of BIM Implementation. Based on the theoretical model, this paper combines empirical research and comparative analysis to know the status of maturity of BIM Implementation in Construction Projects in China. Also, this study investigates the improving approaches based on empirical study, aiming to further enhance the maturity of BIM and promote sustainable implementation in China. In details, the main research works are as follows.

Firstly, this study makes an objective comment on research status of the whole research areas, summarizing the evaluation indexes of foreign typical evaluation models and combine the characteristics of Chinese situation, identify the analytical factors of BIM competence, which contains 4 first-level evaluation indicators (process, technology, organization and human) and 19 second- level evaluation indicators. Then, through interviewing and investigating experts, the study defines the weight of factors and the rate of BIM competence, totally build an evaluation model of maturity of BIM implementation in construction projects in China.

Next, the study determines the measuring items of all analytical evaluation indicators and design the survey questionnaire, and then carries out the empirical investigation, which contains 63 construction projects in Shanghai, providing validation for the effectiveness of the theoretical model and data base for further in-depth analysis.

Finally, in combination with relevant research literature and empirical research, the empirical results are analyzed and discussed. On the one hand, based on the empirical data of the 63 construction projects, the study reveals implementation maturity degree of Chinese construction projects from four aspects: process, technology, organization and human. Then the study reveals the promotion path and means of the maturity of BIM implementation in construction projects, and provides the management basis for the improvement of BIM competence. On the other hand, through comparative analysis, correlation analysis and other methods, the study realizes the horizontal comparison of maturity of BIM in four dimensions: project type, project contracting mode, project investment scale, BIM implementation model.

Key Words: Building Information Modeling (BIM), Maturity of BIM Implementation, Construction Projects in China, Evaluation Model

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1 Introduction

1.1 Background

BIM is a favored topic in the architecture engineering and construction (AEC) industry (Succar, 2010). BIM has been developed for more than a decade, and its benefits are now widely recognized (He, 2010). The perceptions of the industry toward BIM have changed along with its development. Unlike simple modeling methods in the past, BIM is currently regarded as workflows based on Information Technologies (IT), which emphasize cooperation and communication and require support from all organizational levels (Succar, 2009). The challenges in implementing BIM have also shifted from overcoming technical difficulties to seamlessly integrating BIM into daily working processes and achieving continuous improvements (Zhao, 2011; Pan et al., 2011; He et al., 2012; Li et al., 2015; Kekana et al., 2014).

By the introduction of IFC standards at the end of the twentieth Century, China has began to contact the concept and technology of BIM. In recent years, BIM technology and its value have been widely recognized in China, and gradually applied to construction projects, including not only large-scale, complex buildings, but also the most common buildings.

Although, more and more attention has been paid in the BIM implementation in China, most of the construction project management in China is mainly based on experience management, and does not rely on data decision-making. Compared with other developed countries, BIM technology in China is not backward but has great differences. It can be analyzed from four aspects: BIM implementation point, BIM software, BIM standard, BIM market development and policy guidance.

For better adoption of BIM, organizations at industry level and stakeholders at project level, should first evaluate the current conditions in BIM implementation to identify appropriate improvement paths that best match the characteristics of users (CIC, 2012; Luu et al., 2008;). As you can tell, the BIM Maturity, which refers to the extent to which the BIM is explicitly “defined, managed, integrated, and optimized”, is different across these firms/projects. The adoption of BIM is more than the update of the hardware or software infrastructure. It is a systematic approach to the lifecycle information related to a building (Smith and Tardif 2009). So how can individual, teams, projects, and organizations position BIM Maturity of their own and other's (Succar 2011), as well as to improve their BIM Maturity? To meet the demands, several rating tools have been developed to compare the BIM Maturity across the industry. Despite the increasing number of measurement tools, research on evaluating BIM maturity remains in its infancy (Dib et al., 2012). On one hand, measurement tools are developed separately, featuring unique advantages but suffering from specific drawbacks. As a result, selecting a tool for evaluation is confusing for BIM users. On the other hand, research on BIM measurement tools in China is relative rare, and as a result of the above differences, the maturity evaluation model of foreign countries may be unable to fit in with the national conditions of China.

In China, as the lack of BIM maturity measurement tools, the projects can not be fully aware of the current implementation of BIM and the advantages or disadvantages of all aspects, unable to make objective assessment and comparison, which means the projects will not be able to adjust and change through targeted management measures to enhance the ability of BIM. A reasonable and effective BIM maturity evaluation model is of great significance for strengthening the construction of BIM ability and achieving the comprehensive promotion and sustainable BIM technology in the industry.

1.2 Research Area

Based on the above research background, as a leading industry change of innovative technology , BIM has attracted extensive attention in China, and the related policies also proposed that BIM should be promoted as one of the most important work of science and technology in the construction field. However, as mentioned above, due to the large difference between domestic BIM development and foreign countries, the typical BIM maturity evaluation models abroad can not be directly applied to Chinese construction projects. Due to the lack of unified and standardized evaluation methods and standards in the field of BIM, it is difficult to correctly understand the implementation status of BIM in the project, and propose corresponding measures to improve, which has increased the difficulty of the promotion of BIM.

A scientific and effective evaluation tool is an important means to enhance the management, and help to improve BIM ability. What's more, the reasonable and effective BIM maturity evaluation model could reflect the current state of BIM ability through different levels of maturity, combining quantitative and qualitative research, to guide the business process improvement. Under these circumstances, the thesis based on the theory of capability maturity and draw on several internationally recognized BIM capacity evaluation methods, build an evaluation system of BIM maturity suitable for construction projects in China. At the same time, combined with empirical research, we explore ways and means to provide theoretical guidance for strengthening BIM ability and further promot the sustainable development of BIM technology in Chinese construction industry, which provides a reference for the comprehensive promotion of BIM in China.

Based on the above ideas, this paper will gradually explore the following key research issues, and finally solve the problem, and build a BIM maturity evaluation model that is suitable for Chinese construction projects.

(1) What is the current status of the international measurement tools for BIM maturity? What are the characteristics of each tool? What lessons can be provided to build the BIM maturity evaluation model for Chinese construction projects?

(2) What aspects can be used to reflect BIM maturity of the construction projects? What are the factors that have impacts on BIM maturity of the project? What are the differences in the influence of various factors?

(3) How to verify the applicability and effectiveness of the built BIM maturity evaluation model?

(4) How to analyze the results of BIM maturity in empirical projects? How to provide guidance and optimization for BIM use based on the results of the evaluation?

1.3 Research significance

With the expansion of BIM in the construction industry, experts are more aware of the importance of BIM maturity evaluation model.

However, because of the BIM multidimensional characteristics, it is very difficult to establish the BIM maturity assessment model (Smith and Tardif, 2009). Although many attempts have been made to put forward the standard of measuring BIM ability, many researches only explain one dimension of BIM, and mainly focus on the final BIM model, rather than the process. Moreover, the reliability and validity of the model remains to be confirmed because many studies lack a large number of empirical cases.

The purpose of this paper is to summarize and analyze the typical BIM maturity evaluation model, and based on these theoretical concepts and ideas, integrate Chinese BIM characteristics, and make the evaluation model suitable for construction projects in China, being more comprehensive, effective, accurate and practical. This will help to make up for the lack of unified and scientific BIM maturity evaluation tools in the construction industry in China.

Meanwhile, BIM maturity evaluation model is applied to construct the maturity level of a project, which acquires a clearer understanding of BIM ability of the project and the macro construction industry in China. This will help to guide and promote the adoption of BIM in Chinese construction industry.

1.4 Research content and methodology

1.4.1 Research content

The purpose of this paper is to build a BIM maturity evaluation model to adapt to Chinese construction projects, and then make an empirical analysis, finally for the sake to promote BIM concept and technology in China. This paper takes BIM maturity as the research object, and selects and defines the evaluation index of measuring the maturity level of BIM, in order to build BIM maturity evaluation model. Finally, the paper selects construction projects in Shanghai as empirical cases, using the empirical results to reveal the BIM ability in different fields and dimensions. Also the paper analyzes the influence of different areas and dimensions on BIM maturity, and then reveals the BIM implementation maturity upgrade path and means. On the other hand, through comparative analysis, correlation analysis and other methods, the study realizes the horizontal comparison of maturity of BIM in four dimensions: project type, project contracting mode, project investment scale, BIM implementation model.

The main research contents include the following aspects:

First, the paper summarizes relevant literature and practical experience of the typical BIM maturity evaluation models in the world, comparing and analyzing strength and weakness of each model, and concludes the characteristics of the model. It helps to lay the foundation for building BIM maturity evaluation model in the paper.

Secondly, on the basis of analyzing the typical models, the paper builds a preliminary BIM maturity evaluation model in construction projects in China, which selects and determines evaluating indicators. And then it combines the relevant Chinese status to further improve the model, highlighting the characteristics of the adoption of BIM technology in China, which strengthens the pertinence of the evaluation model.

Thirdly, through the related weight analysis method, the paper describes the weight of the impact of each evaluation indicator, and defines the rating of BIM maturity, and ultimately improve the BIM maturity evaluation model.

Fourthly, the empirical research is carried out, and the maturity evaluation model is used to determine the maturity of the research projects. This paper uses questionnaire survey method to carry out empirical research on the adoption of BIM technology of construction projects in Shanghai city. According to the specific implementation of BIM in the project, the project maturity is determined using the evaluation model, and also the applicability and validity of the theoretical model is verified.

Finally, based on the results of data analysis, the paper reveals BIM maturity of the research projects in different evaluating indicators. At the same time, we can get a clearer understanding of the degree of BIM applied in the research projects according to the findings and the problems found in the process. What's more, through comparative analysis, correlation analysis and other methods, the study realizes the horizontal comparison of maturity of BIM in four dimensions: project type, project contracting mode, project investment scale, which helps to further understand the macro situation of BIM adoption in China, and to provide guidance and reference for China's construction industry to promote.

1.4.2 Research methodology

（1）Literature research

Literature research is the first step to select topics, collect data and analyze problems. Its role is to summarize past, guide and put forward new topics and promote the new development of theory and practice. As an ancient and vital scientific research methodology, the literature research methodology plays an important role in the academic research. This thesis reviews and analyzes the current status of BIM related research based on the literature review of BIM in the world, and determines the research topic of "Maturity of BIM Implementation in Construction Projects in China: Evaluation Model and Empirical Investigation".

（2）Inductive deduction

Inductive method and deductive method are complementary and interrelated methods in academic research. The inductive method generalizes the existing limited experiential materials, and the deductive method generalizes the general conclusions of the induction to the unknown fact. This paper summarizes and analyzes several internationally evaluation models of BIM implementation maturity through extensive collection, extensive reading and deep understanding. On this basis, the thesis deduces the theoretical framework, which lays the foundation for the establishment of the evaluation model framework, also for the analysis and determination of evaluation indicators, and the maturity levels.

（3）Questionnaire survey

Questionnaire survey is an investigation method that indirectly collects data for research. It is a way to indirectly get data and information by sending out a consultation form to the questioners and asking for advice and suggestions on the questions. The method of questionnaire is used to get real data and ensure the rigor and objectivity of the research. In this study, the method of questionnaire survey was adopted two times. The questionnaire(1) is used to establish the weight of the evaluation index of the model. The author selects BIM experts as the respondents, gets the opinion of the BIM experts on the importance of the evaluation indicators through questionnaires, and then uses the analytic hierarchy process (AHP) to determine the weights. The questionnaire (2) is used to evaluate the maturity of BIM implementation in Shanghai. Based on this, we get the real situation of BIM implementation in the projects, which is an important process in the empirical research of this paper.

（4）Combination of qualitative and quantitative

The combination of qualitative and quantitative research can complement each other and reinforce each other. Qualitative research provides theoretical basis for quantitative research. In turn, the results of quantitative research will support the qualitative research. A qualitative and quantitative method is applied in the research process. For example, in the process of determining the evaluation model, the existing models are fully analyzed and summarized, which is a qualitative research method that can be effectively deducted on the basis of summarizing experience. On the other hand, the questionnaire is a quantitative research method usually used for survey research, which acquire the results by quantifying the data. And also, the analytic hierarchy process (Analytic Hierarchy Process, referred to as AHP) is a decision-making method combining qualitative and quantitative, which is used in determining the BIM maturity evaluation index weights.

1.4.3 Research technical roadmap

The technical roadmap of this thesis is shown in Figure 1.1.

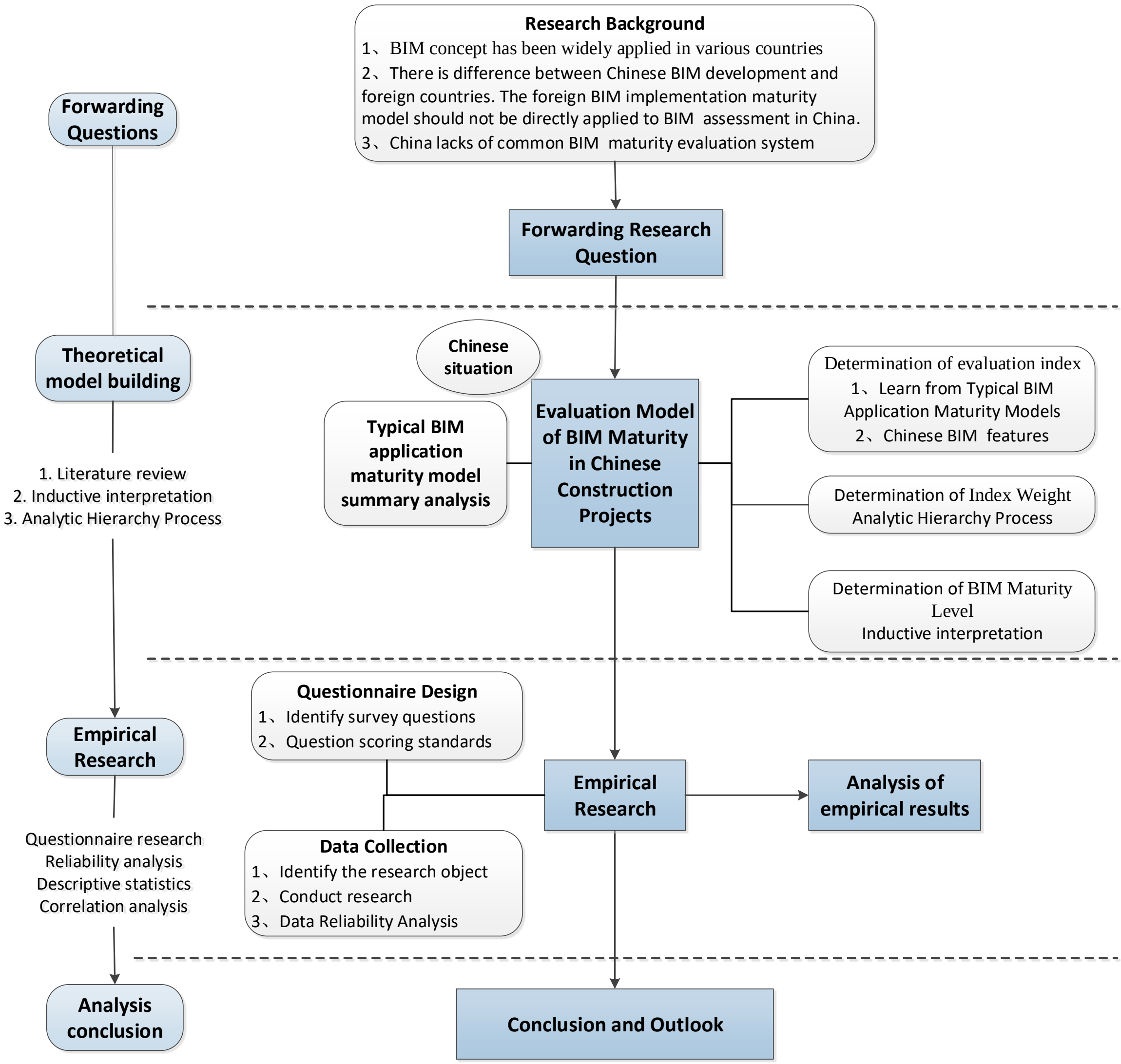

Figure 1.1 Thesis Roadmap

2 Literature review and theoretical foundation

2.1 Maturity Model

(1) Capability Maturity Model(CMM)

At the end of the 1980s, the research of maturity model began at the Institute of software engineering at the Carnegie Mellon University (Software Engineering Institute, SEI). In 1985, the main researchers of SEI put forward the basic idea of Software Capability Maturity Model (Capability Maturity Model CMM). The United States Department of defense procurement requires SEI to develop a software process improvement and capability model in order to reduce the potential risk assessment, also called Software Engineering Institute Capability Maturity Model for Software (SEI-SW-CMM) (Cai, 2002).

In the next few years, SEI has deepened and perfected the CMM.

The Software Engineering Institute of Carnegie Mellon University(SEI) added the concept of maturity classification on the basis of CMM in 1986, and applied it to the research and development of software, and gradually formed the CMM framework currently being used in the software industry. In 1991, the SW-CMM 1.0 version of the capability maturity model was released, which immediately gained recognition of the enterprise and its customers.

In 1993, SEI then launched the SW-CMM 1.1 version of the capability maturity model (ISO/IEC, 1998), which is widely used all over the world. Later, the SW-CMM 1.1 version has become a standard to measure software process improvement.

CMM is divided into 5 levels, including 52 goals, 18 key process areas and more than 300 key practices, which can be applied to evaluate and enhance the management of software development.

(2) Project Management Maturity Model(PM3)

The International Project Management Association is the first to begin to study the maturity model in Project Management. At first, it is mainly used to study the planning of high technology enterprises. Next, the angle of research turns to project management, drawing on the CMM model and referring to different standards, then builds a variety of Project Management Maturity Model，PM3.

PM3 is mainly used to evaluate and improve the competence of the enterprise or construction project management, according to the current situation of project management and referring to project management maturity model, we can find problems and propose corrective advices, to further upgrade the management level of the enterprise or projects.

The mechanism of Project Management Maturity Model is to find the problems of the organization or project by comparing the actual results and expected results of the project, put forward the improvement suggestions referring to the maturity model, and promote the project towards the direction of continuous improvement. Data show that the use of project management maturity model in enterprises and projects is beneficial to improve customer satisfaction and enterprise production performance. In general, what the project management maturity evaluates is the organizational process capability, which depends on the changes of various details, not the final result of the project.

Table 2.1 summarizes several common model of project management maturity abroad, and gives a brief summary of its characteristics and indicators of maturity.

Table 2.1 Characteristics and Indicators of maturity model

Models	Promoter	Indicators	Characteristics	Evaluation method
K-PM3、MF-PM3 and PM2	Harold Kerzner	The evaluation indexes of maturity include 9 major knowledge categories in project management and other factors in the organization, and include the basic ideas of strategic planning.	From the operation level of project management to the height of strategic planning, the transformation from single project to project cluster has been completed.	The questionnaire survey method, each level has 80 radio, 42 election, 25 scoring title
PMS-PM3	Project Management Solutions Company in US	5 maturity levels, mainly utilizes 9 knowledge systems of project management	The final result is decided by the lowest level of evaluation, that is, "barrel principle". The drawback is that	Questionnaire survey and self evaluation

			it is not combined with the key process area of project management maturity, and the design of index is not very reasonable.	
（PM）2	Young Hoon Kwak and C.Willim Ibbs	The indexes cover all the 5 phases of the whole life cycle of the project and the scope of the project management knowledge, and includes key processes of each stage and level.	The whole life cycle theory of the project can be introduced to reflect the overall project management level of the organization, and the process evaluation is emphasized.	Questionnaire survey, including organizational information, organizational project management process maturity assessment and actual project performance evaluation
OPM3 and OGC-PM3	Project Management Institute (PMI)	The index contains 3 dimensions, the first is the 9 categories of project management, the second is the 5 stage of the project life cycle, and the third is the level of project management (from single project to portfolio project).	The level of evaluation is up to the organization level. There are only 4 levels of the model. The disadvantage is that there is no quantitative index system for evaluating the maturity of the project management.	Self evaluation: determine the current state of the organization and develop an improvement plan

2.2 Building Information Modeling

In order to identify the relevant research on the overall situation of BIM at present, the thesis refers to the document retrieval process of Ke et al. (2009), searching BIM literatures from the Scopus database, to identify BIM related key research fields and development trend.

In the first stage, the thesis uses the "Title / Abstract / Keyword"to search related documents in Scopus database, to understand the overall situation of BIM related literature and identify the main source journals. The retrieval conditions taken at this stage are:1) "Title / Abstract / Keyword" containing any key word of "building information model、building information modeling/modelling、building product model、virtual design and construction、construction virtual prototyping";2) Literature type is article or review; 3) Time of publication is from 2008 to 2017. Through the above methods, 577 papers related to BIM are retrieved.

The first phase of the retrieval results show that the composition of the existing BIM literature journals is more complex, so this paper refers to Chau (1997), selecting 7 journals as target: Automation in Construction（AIC）、Journal of Construction Engineering and Management（JCEM）、Journal of Management in Engineering（JME）、International Journal of Project Management（IJPM）、Building Research and Information（BRI）、Construction Management and Economics（CME）、Engineering, Construction and Architectural Management（ECAM）. Besides, considering Journal of Computing in Civil Engineering（JCCE）publishes more article about BIM, the thesis also choose this one as target. Therefore, a total of 8 target journals have entered the second stage of literature retrieval analysis.

In the second stage, this thesis adopts the method similar to the first stage, and searches the BIM related literatures of only the 8 target journals in Scopus database. The retrieval conditions taken at this stage are: 1) "Title / Abstract / Keyword" containing any key word of BIM、building information modeling*、building product model 、virtual design and construction 、virtual prototyping 、nD model* 、 three-dimensional model*、four-dimensional model*、five-dimensional model*. 2) Literature type is article or review; 3) Time of publication is from 2008 to 2017. Through the above methods, 458 papers related to BIM are retrieved. After culling editorial、book review、letter to editor、discussions/closures and other types of literature, a total of 446 papers were obtained.

The distribution of the above 446 papers during the period of 2008~2017 is shown in Table 2.4. On the whole, the number of BIM papers published by 8 target journals is increasing year by year. As shown in Figure 2.4, BIM is attracting more and more attention from academia worldwide.

Table 2.2 BIM papers published in the 8 journals during the period of 2008~2017

期刊	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	总计
AIC	2	4	14	17	10	30	39	52	36	54	258
BRI	0	0	0	0	1	2	0	1	0	10	14
CME	0	1	0	1	0	2	2	4	5	3	18
ECAM	0	0	0	1	1	1	0	5	3	7	18
IJPM	0	0	0	1	0	1	0	2	1	7	12
JCCE	0	2	2	1	4	4	4	8	17	7	49
JCEM	1	1	2	1	4	7	8	2	11	16	53
JME	0	1	0	0	1	1	8	2	5	6	24
总计	3	9	18	22	21	48	61	76	78	110	446

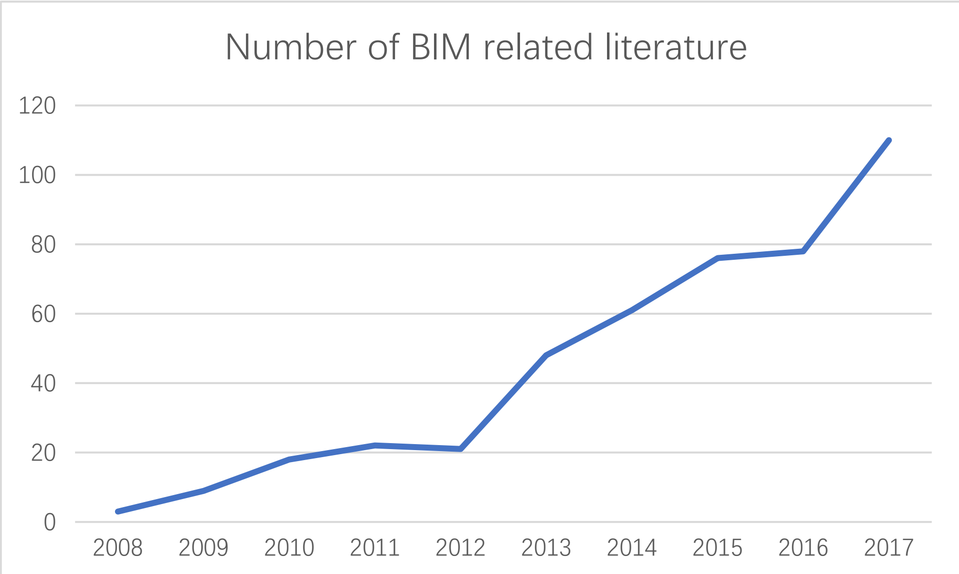

Figure 2.1 BIM papers published in the 8 journals during the period of 2008~2017

Because the implementation of BIM in the whole lifecycle involves many aspects, such as technology, organization, culture, talents and so on. The research focus of BIM literature also shows obvious diversity. This thesis classifies all the papers according to the following 6 themes: BIM model, BIM combined with other technologies, BIM technology interoperability, BIM organization and process problem, BIM behavior evaluation, BIM education.

(1) BIM model creation

The literature of this topic focuses on technology and tools for parameterized modeling, so as to express better graphic and functional information of building facilities. The BIM model can express design intent (i.e. create as-designed BIM model), or describe actual construction situation of new facilities (i.e. create as-builtBIM model) or express status of the existing facilities (i.e. create as-is BIM model). The theme of "BIM model creation" can be further divided into two subtopics: as-designed BIM model and as-built/as-is BIM model.

The existing literature on the previous subtopic focuses on exploring how to improve the relevance between various information of various types (Staub-French et al.，2008；Rafiqand and Rustell，2014), and how to model building components with complex shapes（Lee and Kim，2012）；The latter subtopic is mainly focused on exploring how to create BIM models automatically or semi-automatically from graph or point cloud data based on other technologies, such as laser scanning technology (Anil et al.，2013；Hinks et al.，2009；Styliadis，2008；Xiong et al.，2013), reducing subjective errors and efficiency losses that may be caused by manual creation (Tang et al.，2010).

(2) BIM combined with other technologies

In order to achieve full value of BIM technology, all kinds of parameterized information in the BIM model must be applied effectively, so how to combine Laser scanning, Augmented Reality, Radio Frequency Identification and other technologies has become one of the most focused research topics in the current BIM field.

From the existing literature on the combination of BIM and other technologies, the major BIM implementations are mainly include: Interactive design (Lee and Ha，2013；Rekapalli and Martinez，2009；Shen et al.，2013；Yan et al.，2014), Automatic review of design scheme（Eastman et al.，2009；Martins and Monteiro，2013；Melzner et al.，2013；Tan et al.，2010）, Simulation of energy consumption and other sustainability（Kim and Anderson，2013；Schlueter and Thesseling，2009；Wong et al.，2013）, Automatic monitoring of construction process（Akula et al.，2013；Cho et al.，2012；Elbeltagi et al.，2011；Golparvar-Fard et al.，2011）, Construction safety management（Guo et al.，2013；Park and Kim，2013）, and facilities operation and maintenance（Becerik-Gerber et al.，2010；Larsen et al.，2011；Lee and Akin，2011；Motawa and Almarshad，2013）

(3) BIM technology interoperability

The interoperability between different project participants and different implementations is an effective measure to solve many problems in the construction industry. Lack of interoperability is also one of the factors that impede the further implementation of the BIM model in the design and construction process. Therefore, in order to realize the integrated implementation of BIM in different fields, the key is to improve and effectively apply the standards related to BIM, such as IFC（Industry Foundation Classes）, MVD（Model View Definitions） IDM（Information Delivery Manual）and IFD（International Framework for Dictionaries）. The existing literature on the theme of BIM technology interoperability mainly focuses on the improvement of the above standards and their specific implementation（East et al.，2013；Eastman et al.，2010；Jeong et al.，2009）.

(4) BIM organization and process problem

In recent years, the research on BIM organization and process has received much attention, because the implementation of BIM in construction projects is not only related to technical problems, but also closely related to organization and process problems such as project process adjustment, participant responsibility and return redistribution（Eastman et al.，2011）. The existing research literature on the theme of BIM organization and process mainly focuses on the following three aspects：The characteristics of BIM technology and its implementation behavior（Davies and Harty，2013；Linderoth，2010；Moum，2010；Taylor and Bernstein，2009），The influencing factors of BIM implementation behavior（Sebastian，2010；Taylor，2007；Won et al.，2013），BIM implementation framework and strategy（Arayici et al.，2011；Isikdag and Underwood，2010；Li et al.，2008；Porwal and Hewage，2013）。

(5) BIM behavior evaluation

With the difference between the theoretical BIM implementation scheme and the industry BIM practice is becoming more and more obvious, BIM behavior evaluation has gained more focus. And the literatures could be divided into the following two categories: The first category of literature focuses on the implementation of BIM in construction projects in different countries and regions（Eadie et al.，2013；Hanna et al.，2013；Jensen and Jóhannesson，2013）；The second category of literature mainly focus on the performance impact of identifying or measuring the BIM implementation behavior（Barlish and Sullivan，2012；Bryde et al.，2013；Love et al.，2013）.

(6) BIM education

The issue of BIM education has also become a more independent research topic in the existing BIM literature. The formation of this theme is due to the lack of BIM talents in the project practice（ Eadie et al.，2013；NBS，2014）, also closely related to the potential assistant role of BIM technology for the traditional engineering management education. Corresponding to this, the focus of literature on the theme of BIM education also includes how to develop the BIM curriculum system（Sacks and Pikas，2013；Pikas et al.，2013）、how to apply BIM to the traditional engineering management education（Peterson et al.，2011）.

2.3 Evaluation Model of BIM Maturity

Because of the multidimensional features of BIM, experts are more aware of the difficulties in establishing BIM maturity assessment models (Smith and Tardif, 2009). Although there are many attempts to put forward the standard and system to measure BIM capability, many researches only explain one dimension of BIM, and pay more attention to BIM model rather than the whole process of BIM implementation. Moreover, the reliability and validity of the model remains to be confirmed because many studies lack a large number of theories and experiences.

Although the development of evaluation method of BIM is relatively delayed (Kam et al., 2014), there have been some foreign experts and scholars are trying to research on the theory and practice in the field, established and applied some BIM maturity evaluation method. This section will compare and analyze the typical models of BIM maturity evaluation, which are highly recognized and applied internationally, and lay a foundation for the subsequent research framework.

(1) BIM CMM

The first BIM maturity measurement tool is NBIMS CMM, proposed by the National Institute of Building Science in 2007 as part of its famous National BIM Standard. The tool evaluates BIM-assisted projects based on 11 areas of interest against 10 increasing levels of maturity. (NBIMS, 2007; Giel, 2014). The final score of BIM maturity is calculated by the weighted summation of all areas. The score is mapped to a maturity model with six levels to indicate the maturity degree the BIM user achieves. Certification levels possible in the CMM include: minimum BIM, certified, silver, gold and platinum, for a maximum score of 100 points. As of 2011, the minimum score required for the distinction of minimum BIM was set to 60 points (NIBS 2012). However, the weights of measures can be adjusted by users according to their own needs, which dramatically reduce the objectivity of this tool.

(2) BIM Maturity Matrix

BIM Maturity Matrix was developed in 2009 to overcome these deficiencies. Based on established theories (Suucar, 2010), BIM Maturity Matrix provides comprehensive explanations for each measure to minimize inconsistencies and expands the measuring scope to cover non-technical aspects of BIM (Giel and Issa, 2013). BIM Maturity Matrix contains three main areas and adopts a five-level scale to conduct measurements. However, the number of measures is subjective to an innovative granularity system, which will be elaborated further. Considering the lack of information on BIM Maturity Matrix at a high level of granularity, only granularity at Level 2 is included, comprising 12 and 36 measures. The total BIM maturity level is calculated by averaging the scores of all measures.

(3) BIM Scorecard

Inspired by Characterization Framework, VDC Scorecard was developed in 2012 by Stanford University to conduct methodological, adaptive, quantifiable, holistic, and practical assessment (Kam, 2013). VDC Scorecard includes 4 main areas, 10 divisions, and 74 measures. The tool has several distinct features, such as the establishment of confidence level, which analyzes input data and quantitative measurements of the degree of objective compliances. VDC Scorecard is also a benchmarking tool where the answers of each measure will be assessed against the industry norm and converted into a five-level percentile ranking to indicate the maturity level of BIM in comparison with other users.

(4) BIM QuickScan

BIM QuickScan was launched by Netherlands Organisation for Applied Scientific Research (TNO) in 2009, which consists of four main areas and 50 questions that are organized in the form of a multiple-choice questionnaire (Sebastian and Berlo, 2010). The selection of measures and framework formation are based on Delphi method of five rounds (Berlo et al., 2012). The scoring approach is a weighted summation. BIM QuickScan has two versions, namely, free online self-scan and chargeable certified scan, which is conducted by consultants. These consultants provide professional advice for both measurement outcomes and potential improvements. Practical BIM maturity benchmarking system is first established using this tool. The system is a collection of hundreds of data samples. Based on the system, BIM market conditions in the Netherlands and even in Europe are revealed, and the tool can be optimized through continuous feedbacks.

(5) BIM Proficiency Matrix

Indiana University developed IU BIM Proficiency Matrix two years later. This tool is created using Excel spreadsheet, which is composed of 8 areas, 32 measures, and 5 maturity levels (CIC, 2012). Unlike NIBMS CMATURITY MATRIX, each measure has the same weight in IU BIM Proficiency Matrix. To evaluate BIM implementation, a score between zero and one is assigned to each measure. Zero indicates the non-existence of corresponding BIM functions, whereas one specifies that functions are fully applied (Indiana University, 2009).

(6) Characterization Framework

Some tools also developed during that time exhibit large-scale imitations, lacking distinct features and thus are excluded from the study. However, Characterization Framework, which was proposed in a doctoral thesis in 2011, opened new opportunities for BIM maturity measurements. Although the classification of Characterization Framework, which is composed of three main areas, 14 sub-divisions, and 56 measures (Gao, 2011), is similar with other tools, it characterizes evaluation schemes. The framework introduces quantitative blank-filling and open-ended questions to complement conventional scale or multiple-choice approaches. Furthermore, Delphi, complex statistical analysis, and face-to-face user interviews are conducted simultaneously for validation and optimization, which is also a distinctive contribution of the framework.

(7) BIM assessment profile

BIM in the O&M phase has begun. Pennsylvania State University published a guideline of key components and steps that facility owners need to integrate in their businesses, which include the BIM assessment profile. The assessment profile is composed of 6 areas, 20 measures, and 5 maturity levels to evaluate the BIM maturity of facility owners (CIC, 2012). By utilizing the tool and guideline, facility owners can understand current BIM maturity levels and identify correct paths to initiate or improve BIM implementations.

(8) Owner's BIM CAT

Owner's BIM CAT, which was developed in 2013, is another tool that regards owners as major users. The tool features 3 main measuring divisions, 12 sub-divisions, and 66 measures. Owner's BIM CAT is selected because of the extensive measuring scope, which covers almost all aspects of BIM implementations with a life cycle view (Azzouze et al., 2015).

Although the review scope is not exhaustive and some existing tools are excluded in the study, the selected tools are the most distinct and representative ones, which are all based on established research. Moreover, majority of the tools have been more or less validated through various methods, which relatively guarantees effectiveness and reliability.

Based on the above analysis, the characteristics of the above nine models are summarized as shown in table 2.15. Their evaluation frameworks and evaluation methods have their own strengths and weaknesses.

Table 2.3 The characteristics of each model

Evaluation Model	BIM CMM	BIM Maturity Matrix	BIM Scorecard	BIM QuickScan	BIM Proficiency Matrix	BIM Characterization Framework	BIM Assessment Profile	Owner's BIM CAT
Proposer	National Institute of Building Sciences（NIBS）	Bilal Succar	Center For Integrated Facility Engineering（CIFE）	Netherlands Organisation for Applied Scientific Research（TNO）	Indiana University (IU)	Dr.Gao from Stanford University	Pennsylvania State University	B. Giel,R. R. A. Issa
	Research Institutions	Individual Scholars	Research Institutions	Research Institutions	Research Institutions	Individual Scholars	Research Institutions	Individual Scholars
	USA	Australia	USA	Netherlands	USA	USA	USA	USA
Time	2007	2008	2009	2009	2009	2011	2012	2013
Evaluation index	11 areas with a 10-level scale	3 main areas	4 main areas, 10 divisions, and 56measures	4 main areas and 50 questions	8 areas, 32 measures	3 main areas, 14 sub-divisions, and 56 measures	6 areas, 20 measures	3 main measuring divisions, 12 sub-divisions, and 66 measures
Maturity level	6 maturity levels	5 maturity levels	5 maturity levels	Compare total score directly, not set permanent upper limit , and update the highest score per year	5 maturity levels	3 maturity levels	5 maturity levels	

Strengths	The number of problems is less; the frame structure is simple and easy to operate; the model is verified and optimized through field detection and actual data; Indexes are targeted。	Problems are described in detail; the coverage is extensive and thoughtful; Suitable for all scale organizations; Easy to use and clear in steps; Emphasizes the matching of BIM and organization strategy and resources; Professional and flexible.	The index is highly quantified; The index design is comprehensive, quantitative and qualitative is combined; The range of evaluation is extensive; The confidence degree is checked by statistical method, and the reliability is strong; Has been verified in 108 projects, and its effectiveness is strong.	Authoritative and recognition is high; Index design is comprehensive; Evaluation quantification is high; Evaluation process is rigorous; Evaluation methods are flexible; Keep pace with the times; Has been verified and optimized through practical implementation.。	The number of problems is less; The frame structure is simple; Easy to use; The index covers the whole life cycle。	A high degree of quantification; More detailed description of the problems; Emphasizes the actual impact of BIM	The user guide is exhaustive, the scope of evaluation is comprehensive, and the matching degree of BIM and organization strategy and resources is emphasized; Emphasizes and helps organizations to transform and enhance BIM implementations; Easy to understand and implement.	The scope of measurement is the most extensive; Refers to the previous models and integrates these advantages.

Weaknesses	The evaluation is low in quantification; The user guidance and problem descriptions are rough; Evaluation methods are single and subjective; Indicators are more concerned about the technical level of BIM, and less considered in organization and management; Verification and optimization are relatively qualitative and	The evaluation process is too complex; Lack practical implementation to verify and optimize the model; The operability needs to be verified。	The evaluation object is complicated; The evaluation problems are too many and the process is tedious; The evaluation results are easily influenced by the subjective judgment of different evaluators; The user's Guide is lacked	The user guidance and problem description are rough; More applicable to the Netherlands situation; Self assessment is too subjective; Professional assessment threshold is high; No maximum rating is easy to produce evaluation bias; Consulting service charges, increase investment。	The quantitative assessment is in low degree; All index weight is same, without distinction; the user guide and a description of the problem is rough; the single evaluation method and subjective indicators; one-sided, technical level mainly focus on the implementation of BIM; feasibility is low; the lack of practical implementation for verification and optimization of the model。	Questions are projects-orientated, may not suitable for organizations without adjustments; No user guides, implementation is difficult, time and resources exhaustive; High requirement for input data in terms of timeliness and quality; Lacks measures for maturity of BIM standards	Questions are projects-orientated, may not suitable for organizations without adjustments; No user guides, implementation is difficult, time and resources exhaustive; High requirement for input data in terms of timeliness and quality; Lacks measures for maturity of BIM standards; No benchmarking functions; Specially designed for facility owner, low universal applicability and low flexibility	Number of questions is quite large; No user guides and question descriptions are rough; The classification structure is very complex; Difficult to implement, especially to ensure the completeness given the large number of questions; Overlaps between questions in different fields; Lacks field tests, empirical studies and practical data collections for validation and optimization

	subjective.							

The above BIM maturity evaluation models show a lot of similarities. First of all, most of the tools categorized the evaluation variables. No matter which term is defined, the purpose is to group the evaluation variables based on the logical similarity. Another similarity is that these evaluation models use the weight system to score. For example, in BIM CMM, the highest weight is assigned to the interoperability/IFC support and Information Accuracy; but in BIM Scorecard, Technology) and Performance is assigned a higher weight.

The difference between the existing BIM evaluation systems is the way of evaluation. BIM CMM and BIM Scorecard pay more attention to the evaluation of single project, while BIM Maturity Matrix, BIM QuickScan, and BIM QuickScan are evaluating the implementation process of the organization. Therefore, one of the disadvantages of the existing model is that it is impossible to evaluate the organization and project at the same time (Sebastian and Berlo, 2010).

In addition, the several recognized models are proposed by scholars or institutions in developed countries, which have been applied and tested in the international situation or their own national situation. But due to the BIM implementation in China has its unique characteristics, these methods are not completely adapt to the Chinese situation. At present, there is less independent research on the evaluation model of BIM technology implementation in China. Only a few scholars have introduced the existing international methods through translation, and have not made innovations suited to China's national conditions.

To sum up, the research on BIM implementation maturity evaluation is deeper than that in China, and there are many mature project cases abroad. But in China, because there is not many comprehensive implementation practices of BIM, there are few researches on BIM implementation maturity evaluation. Most of them are in theoretical aspect, and lack of BIM engineering implementation practices. The evaluation of the implementation of BIM in the whole lifecycle is not very mature, especially lack quantitative research.

As mentioned above, Shanghai plays a leading role in the implementation of BIM in China. The relevant documents issued by the government provide strong support for the implementation of BIM. In many documents, the significance and relevant work of the pilot demonstration project are mentioned but few documents refer to the detailed evaluation system and methods. On the BIM implementation maturity, only "2017 Shanghai Building Information Model Technology Implementation and Development Report" adopts the relevant concepts to evaluate BIM capability, however, the index selection is also completed through the maturity model from abroad, there is no system of theoretical evaluation system.

From the whole point of view, in recent years, the international research on BIM implementation maturity evaluation has shown an obvious trend of growth, and more and more attention is paid. However, the domestic research and analysis of the maturity evaluation of BIM in the project in China is still relatively short. Although the international research on BIM implementation maturity evaluation has been paid more and more attention, and formed a set of evaluation systems, but as described in section 1.1.3, BIM in China and in western countries are fundamentally different in the environment and industry background, so it is difficult to copy and reproduce BIM paradigm in project from western countries to China directly. Studying BIM in Chinese construction projects has a strong dependence and dynamic background. Because there is a big difference between Chinese and foreign BIM development, some foreign research results of BIM maturity is not suitable for Chinese situation, and advanced evaluation index has not been introduced by China, such as BIM CMM theory, because it is difficult to fully understand the various indicators, and the operation process is not simple.

The thesis makes up these shortcomings, integrates representative maturity evaluation model and combines Chinese situation, to obtain the key evaluation indexes. Finally, the BIM implementation maturity evaluation system suitable for China's construction projects is built. This thesis takes the development of Chinese BIM as the starting point. On one hand, it helps non users plan their BIM directions, and on the other hand helps users relocate and improve their BIM capabilities, making it easier to quantify BIM and its value.

3 BIM Implementation Maturity Evaluation Model

This paper will build an evaluation model of BIM implementation maturity which is suitable for the implementation status and characteristics of BIM in the field of Construction Engineering in China. It is used to comprehensively evaluate and analyze the BIM technology implementation ability of China's construction projects.

3.1 Analysis of the applicability of the model

BIM implementation maturity model can be divided into two levels: macro and micro. On the macro level, it is the evaluation model of the enterprise level. On the micro level, it refers to the evaluation of BIM capability from the aspects of process, technology, organization and personnel in a project construction life cycle.

On the enterprise level, in addition to the introduction of the corresponding software, BIM implementation needs to develop a feasible implementation plan to adjust the working processes and organizational structure, strengthening the training of the staff so that they can truly understand the core concept of BIM, master and use key technologies and methods. Enterprise level is the premise and foundation of the project level. Only enterprises are provided with the ability of BIM planning, professional BIM talent, perfect BIM training system, adapting to professional collaboration and parallel work mode, using the necessary building information modeling software, hardware and infrastructure, and in the vision of enterprise strategy, they can be able to successfully use BIM in projects.

This paper starts from the micro level, focusing the BIM implementation of project level. The model built in this paper refers to the evaluation systems described above, and its establishment is based on the actual situation of BIM implementation in China's construction field, which is more suitable for China's situation. The model is very forward-looking. It gives the growth mode of building information model to the whole life cycle in China's construction projects, so it has both judgement and guidance functions. It helps project participants understand the BIM capacities in real projects, and strengthen the advantages and make up for deficiencies, to improve the ability of BIM, to find the direction and measures of improvement in order to improve the BIM effects. So as to gradually improve the level of BIM implementation of all construction projects and even the whole industry, and achieve the value growth of BIM industry chain, step by step, and promote the implementation of BIM to achieve a higher level.

3.2 Determination of evaluation index

In order to objectively and accurately evaluate the implementation maturity of the project BIM, it is necessary to analyze and determine the evaluation index. And then through the achievement of these indexes, the BIM maturity level of the project is reflected comprehensively.

Referring to the existing maturity models, the evaluation system constructed in this paper is also spread out by different evaluation elements according to the hierarchical structure. The evaluation indexes of the project are spread through two levels: the first-level "evaluation area" and the second-level "evaluation dimension".

3.2.1 Determination of Areas of BIM Implementation Maturity Model

First of all, the thesis determines the first-level "evaluation area" of BIM implementation maturity evaluation model from a large level. It refers to the research of Wu Chengke (2017), which divides all the assessment contents in accordance with the following 5 areas: Process, Technology, Organization, Human and Standard. His thesis is based on the original research(Giel and Issa, 2013; Succar, 2009) and experts' opinions. He also pointed out that this classification method is a typical attempt, other classification methods are equally desirable in other ways.

The questionnaire is the basic element of the maturity assessment model (Wu, Xu, Mao, and Li, 2017). In order to verify the above 5 areas' comprehensiveness, this study will carefully study the questions involved in the typical models mentioned above.

Matching the questions with the involved areas, we find that the five areas of Process, Technology, Organization, Human and Standard can cover the eight models comprehensively. The summary is shown as Table 3.1.

Table 3.1 Evaluation Questions of each Model

	Process	Techniques	Organization	Human	Standards
NBIMS CMM	Degree of IFC supporting IPD process, Degree of change management	To what degree the model is nD intelligent; to what degree model incorporate with spatial			

	processes, Degree of BIM integration in business, Timeliness of responses, Life cycle views	information and GIS; to what degree information is accurate based on ground truth			
BIM Maturity Matrix	To what degree knowledge infrastructure is developed, to what degree model production process and service are defined and well managed	To what degree real-time network solution is achieved; to what degree software and BIM uses are in line with organizational strategies or plans; to what degree software and hardware are adequate and under control and monitoring	To what degree BIM vision is established and commonly communicated; to what degree BIM implementation are integrated with organizational strategies; How the leadership treat BIM; to what degree BIM budget is accord with techniques	To what degree BIM responsibilities and roles are defined; to what degree staff is capable of BIM; to what degree training or education are provided	To what degree detailed guidelines are available; to what degree 3D models are managed under detailed standards; to what degree an agreement is established to manage BIM intelligent property
BIM Scorecard	Response to RFI on time when it is made within how many calendar days? Efficiency of VDC/BIM meetings, which of the following process gained expected benefits?	What is the average information loss after model exchange? What is the most common format of model exchange? Select model-based analysis used, Contribution of BIM	List most important VDC/BIM objectives; how many objectives are quantifiable? How often objectives are tracked? To what degree objectives are achieved based on actual performance	How satisfied are the stakeholders with the results of BIM? What's the stakeholder's attitude towards BIM? Have designated BIM Champion? What's the BIM skill of	Select contents covered by BIM guidelines' scope; Have you established any BIM guidelines or BEP and list them (if any)

		techniques to the users.	data	project team member?	
BIM QuickScan	Use/Re-use of information from partners? Where in the process do you use BIM? Are the information flows within your company described?	What is the semantic level of your BIM? For what implementations do you use BIM? What is the reuse of BIM data? Do you use open standards to communicate?	Is there complete company support for BIM (at all levels of the organization)? Is the term "BIM" a part of the vision and strategy? Is it clear what your organization wants to achieve with BIM?	Are there BIM Champions within organization? Do you provide for structured training of staff? Do your employees enjoy working with BIM? What is, on average, the BIM practical experience level of your employees	Do you use open standards to communicate with external partners? Do you prefer a specific kind of contract with your partners? Are there quality controls in place for BIM?
BIM Proficiency Matrix	Design collision detection process, Introduction of structural and MEP model, IPD methodology innovations, Processes in coordination meetings, Generations of post bid model documentation	To what degree model is geometrically correct; to what degree models reflect built environment and design intent; to what degree model produces correct quantity schedule			To what degree BEP is properly created and implemented
Characterization Framework	Most questions are similar with those mentioned above; plus	To what degree BIM models improve the accuracy of cost estimation; Demonstrate	Cost of managing BIM; To what degree BIM vision is established;	Number of individuals using BIM; Number of individuals building	

	Explain the actual impacts on working processes with BIM	useful functionality of BIM software; Demonstrate types of model uses	What impact does BIM bring on businesses of the user	BIM; Number of Stakeholders initiating BIM efforts	
BIM Assessment Profile	Degree of internal and external BIM processes documentation and management, Existence of transition plans for each operating unit	To what degree BIM data is received and used in O&M; to what degree BIM uses are adopted in O&M, To what degree BIM software selection match organizational plans	To what degree clear organizational missions and visions are established and communicated; to what degree management supports are provided; to what degree BIM objectives or missions are in line with strategies	To what degree BIM responsibilities and roles are defined; to what degree training or education are provided	To what degree standards are used to determine O&M data needs; to what degree standards are used for model breakdown structure
Owner's BIM CAT	Most questions are similar with those mentioned above	Most questions are similar with those mentioned above	Most questions are similar with those mentioned above	To what degree hiring, evaluation and training practices are planned and implemented; to what degree BIM responsibilities and roles are defined	To what degree detailed working guidelines are available; to what degree BEP templates are implemented; to what degree delivery procedures are well defined and disseminated

On the other hand, by comparing other global BIM related studies, it is confirmed that the five major areas cover almost all the assessment factors, which are covered by standards, guides, protocols, specifications from Australia, Britain, China, Finland and Singapore.

The author further verifies the above five major areas among his research team and other experts. BIM team members and experts said that the Standard area assessment covers mainly reference and control regulations, contracts, guidance and supervision and so on (Succar, 2012). The objective of Standard is to better balance the overall implementation and control of BIM in the project, and can be understood as the top stage of the Process area, so the evaluation contents of Standard and Process have greater overlap. As a consequence, it will be unable to distinguish Standard and Process , so include Standard in the Process area.

In summary, Process, Technology, Organization and Humman are four major areas which cover almost all maturity evaluation indexes. This study suggests that it is more comprehensive, objective and acceptable to choose these four areas as the first level evaluation indexes, on this basis, combines China situation and domestic construction project characteristics and expand the next level evaluation dimensions. The first level evaluation areas are explained as follows:

1) BIM implementation Process maturity (P): evaluate the project's management, coordination and improvement of resources, activities, workflow, service mode and other contents related to BIM. (Succar，2012；Kam et al.，2014)

2) BIM implementation Technology maturity (T): evaluate the projects in maintaining and upgrading software and hardware configuration, information sharing, information accuracy, data enrichment, data exchange mode and so on. (Sebastian and Berlo，2010；IU，2009)

3) BIM implementation Organization maturity (O): evaluate BIM strategy deployment from organizational level, including stakeholders coordination, leadership support and communication style and atmosphere. (Sebastian and Berlo，2010；Kam et al.，2013；Kam et al.，2014)

4) BIM implementation Humman maturity (H): evaluate the technical experience, ability, acceptance of BIM, division of labor and role distribution of BIM personnel in the projects. (Sebastian and Berlo，2010；Kam et al.，2014)

3.2.2 Determination of Dimensions of BIM Implementation Maturity Model

In this section, we will further define the subdivision analysis dimensions, that is, the second-level evaluation indexes, and refine the evaluation basis in each areas, making the model more detailed and reasonable.

First of all, according to the Process, Technology, Organization, Humman four major areas, the thesis extracts and summarizes the main assessment aspects of the 8 models. The principles are as follows:

1) All first mentioned assessment aspects in different ways are taken into consideration.
2) Study the interpretations of the dimensions detailedly, and merger the dimensions of similar interpretations, and the name of the dimension is adopted by different models.
3) After reading the dimension interpretation, if it is not related to the project level, the thesis eliminated it directly.
4) When distinguishing the area for each dimension, the thesis put the dimension in the area of the original model; If no major area is divided in the original model, after reading the elements of each dimension, the thesis matches it with the definition of the four major areas and then classifies it.

Thus, we get 18 initial evaluation dimensions for the BIM Maturity evaluation model.

Table 3.2 Summary of evaluation dimensions of each model

			NBIMS CMM	BIM Maturity Matrix	BIM Scorecard	BIM QuickScan	BIM Proficiency Index	Characterization Framework	BIM Assessment Profile	Owner's BIMCAT
Process (P)	1	Development of BIM Execution Plan (BEP) or Adoptions of BEP Templates			√				√	√
	2	Full lifecycle implementation	√	√	√					
	3	Coordination and transmission of the models	√		√	√		√		√
	4	Quality Control of BIM Implementation		√		√				√
	5	Delivery Processes of BIM Relating Products and Services	√	√				√		√
Technology (T)	1	BIM Functions Adoption and Software Selections		√		√		√	√	√
	2	BIM Relating Hardware Implemented		√					√	√
	3	Data and Information Richness and Accuracy	√				√	√		√
	4	BIM Collaborative management platform	√		√	√				
	5	Model Based Calculations and Analysis	√		√		√	√		√
Organization (O)	1	BIM Visions, Goals and Strategies at Organization Level		√		√		√	√	√
	2	Development of Contracts of		√		√				

		BIM Related Rewards and Risks Allocations								
	3	Senior Management Support		√	√	√		√	√	√
	4	Actual Impacts of BIM on Organizations			√					
Humm an （H）	1	BIM Related Staff Experiences, Skills and Knowledge of BIM Staff/Stakeholders		√	√	√		√		√
	2	Awareness, Attitudes, Enjoyments and involvements of Employees/Stakeholders towards BIM				√				√
	3	BIM Related Training and Education		√	√	√			√	√
	4	Arrangement of BIM Related Duties and Roles		√	√				√	√

3.2.3 Analysis of BIM characteristics in China and dimensions expansion

The preliminary analysis of BIM dimensions from the eight major models is universal, and does not reflect the Chinese situation. This paper is to construct the BIM Maturity Evaluation model for China's construction projects, so it is necessary to fully consider the status and characteristics of BIM implementation in China's construction projects.

The above analysis of the initial dimensions maybe incomplete due to the limitation of source channels. Therefore, in order to highlight the characteristics of China's BIM technology implementation, enhance the pertinence of the evaluation model and ensure the integrity of the analysis elements, the following two steps are adopted in this study to improve and supplement the above initial dimensions:

(1) Referring to the existing domestic standards and documents, we analyzed the documents and materials for the guidance of BIM, and revised and supplemented the evaluation dimensions of the model through the requirements and norms of BIM implementation in China's construction projects.

Considering that Shanghai is in the forefront of BIM implementation and popularization, which has carried out a lot of works like BIM technology implementation pilots, BIM key technology research, BIM technology standard and supporting policy formulation, BIM technology implementation capacity building and BIM publicity. Shanghai has been a leading domestic demonstration city in improving the policy and market environment of BIM and enhancing the ability (Shanghai urban and rural construction and Management Committee, 2017B). Therefore, when doing the dimension expansions, the reference materials are mainly from Shanghai, including BIM technology standard, BIM development outline and BIM industry report. This thesis focuses on the following reports as examples:

1) *The Outline of Shanghai city BIM Technology Popularization in 13th Five-Year Development Plan. The Outline* clarifies the guiding ideology, principles, development goals, key tasks and safeguards of the BIM technology popularization in Shanghai, providing the basis for the development of BIM.

2) *The Guide for implementation of BIM in Shanghai. The Guide* specifies the various aspects of BIM in detail, which is a standardized document currently applied by all construction enterprises in Shanghai for reference, and is authoritative and operable.

3) *The Report for 2017 Shanghai BIM implementation and Development. The Report* analyzes and summarizes the implementation status and problems of BIM in Shanghai, formulating suggestions for popularization and implementation, publicizing and popularizing BIM knowledge. The reporting contents are comprehensive, systematic and objective, providing basis and reference for industry development, enterprise implementation and government decision-making.

4) *Research Report on the value of BIM implementation in China. The Research report* gives a detailed analysis of the current situation of BIM implementation in China's construction projects and reflects the characteristics of BIM from several angles.

(2) Through field investigation and expert interview research, the characteristics and practical problems of the BIM implementation in China's construction project are combed.

On the one hand, the author collects BIM experts and staff's opinions, and after some expert interviews, summarize the practical problems, and then, starting from the problem, supplement and extend the model evaluation dimensions. On the other hand, the author interviewed BIM experts through one to one method. Experts are selected randomly through the BIM expert database, including owners, design enterprises, construction enterprises, BIM consultants and experts from BIM related industry associations or research institutes. These experts all have more than five years of research or practical experience in BIM related fields, and have been in contact with more than three BIM projects.

Improvements and additions are made to the initial dimensions of each area of the evaluation model are as follows:

(1) Process Area

1) Full lifecycle implementation of BIM

The Outline points out that achieving "BIM+ design, construction, operation and maintenance of the whole lifecycle" construction mode " is the overall goal of BIM in "13th Five-Year" in Shanghai.

The Guide proposed a detailed BIM implementation illustration for all phases of the lifecycle preliminary design, design, construction preparation, construction implementation, operation and maintenance.

Research Report on the value of BIM implementation in China emphasizes the importance of implementing BIM in the whole lifecycle.

in the pilot project evaluation process, the author finds that, the BIM experts currently evaluate the projects by the degree of completion of the various implementation points as the standard to a large extent. Thus, in China's project level BIM assessment, the completion of the specific BIM implementation points in the whole life cycle occupies a more important position.

In the above initial dimensions, there exits "BIM full lifecycle implementation" dimension, but its original concept is more focused on the depth of BIM implementation, that is, all stages of BIM implementation. And the BIM implementation breadth, that is, the completion of the BIM implementation points, has not been emphasized. So here updates the concept of this dimension as: "Evaluate the implementation of BIM in various stages of life cycle, as well as the completion of all implementation points in the whole lifecycle."

2) Coordination and transmission of the models

Through expert interviews and practical research, we know that, in domestic construction projects, the design process of BIM is still mainly in the use of the way of 2D design, and the positive three-dimensional design projects are very rare. At the same time, because the traditional mapping mechanism is two-dimensional mapping in China, so many projects use BIM modeling in formalism.

The Report for 2017 Shanghai BIM implementation and Development points out that the model is the foundation of all BIM implementations. All parties have their own habits in modeling. When modeling, considering the following implementation requirements, standardizing the modeling mode, and improving the model reuse rate is needed.

Therefore, whether it can realize the forward three-dimensional design, and satisfy the subsequent implementation needs is an important measure for a project to evaluate BIM maturity. "Modeling method" is the factor of domestic construction project of BIM assessment, which belongs to the " Coordination and transmission of the models " dimension, so update the concept as: "The degree of forward modeling, and the model's convergence of the various stages."

3) Delivery Processes of BIM Relating Products and Services

*The Guide for implementation of BIM in Shanghai.*defines Model depth and delivery results, pointing out that the depth of the building model should be required to meet the requirements of the BIM process. It is not advisable to put forward excessive depth requirements which exceed the implementation requirements, but the connection and transmission of model data at all stages should be done well, especially the connection between design and construction models, so as to avoid over modeling and repeated modeling. *The Guide* also provides depth requirements of the professional models at different stages of the whole life as a reference for the depth requirements of the project model. At the same time, through expert interviews, we know that the DBB mode is still the main form of China's construction project contracting mode, so the specific requirements for project depth are particularly important for the success of BIM implementation. On the other hand, *Research Report on the value of BIM implementation in China* also indicates that Model Level of Depth (LOD) is an important tool for defining the deliveries of the project parties（McGraw Hill Construction，2015）. Therefore, the index of model depth evaluation should be fully considered in evaluating the BIM maturity.

Research Report on the value of BIM implementation in China mensions, design enterprises and construction enterprises in China put "more clearly defined project deliverables" as one of the most important factors to improve the efficiency of BIM (McGraw Hill Construction, 2015), this emphasizes the importance of standards for delivery, which makes BIM deliverables of each phase conform to the standard.

In addition, when *The Guide* talks about BIM Relating Products and Services, it says except the building models, the deliverables should include the simulation analysis report, collision inspection report, bill of quantities(BOQ) and other BIM results documents, including the 2D and 3D drawings output from the 3D building information model. In practice investigation and expert investigation, it is learned that in domestic construction projects, the traditional drawing mechanism only looks at the blueprint, and lacks the strict examination of BIM, which brings difficulty to BIM's advancement in the project. So the delivery results and reports at various stages play an important role in measuring the BIM maturity.

Therefore, in combination with the requirements in *The Guide,* and Chinese features, we think what the dimension “Delivery Processes of BIM Relating Products and Services” evaluates includes 4 aspects, “delivery quality of BIM results”, “Whether the model depth meets the requirements”, “Does the delivery standard of the model be formulated”, “are other results delivery documents are provided”. Accordingly, supplement and update the concept of the dimension “Delivery Processes of BIM Relating Products and Services” as: “The degree of reasonable modeling and delivery in accordance with the model level depth (LOD) requirements, whether the project formulates standards for BIM delivery, and whether provides the simulation analysis report, collision inspection report, bill of quantities(BOQ) and other BIM results documents”.

4) Response and Implementation of BIM policy

China's construction industry is not like foreign construction industry, which is mostly market-oriented. Instead, there is coexistence of market and government supervision. In China, the government has made great efforts to promote the BIM implementation, and the government can play a role in eliminating the resistance and promoting the awareness of BIM.

Take Shanghai as an example, BIM has been listed as an important work of technological innovation in the engineering construction field. The city of Shanghai has determined the guidance of BIM development policy, and has formulated corresponding policies and measures for BIM implementation, forming a good policy environment. At present, it is further accelerating the research of generic technology, implementing the government's supporting policies and related incentive systems, as well as the transformation of government approval and supervision process, and the reform of relevant laws and regulations.

Therefore, whether the project has positively response to the policies, for example, if the standard formulation, training and contract have cooperated with the policies, should be included in Chinese BIM implementation maturity evaluation system. Moreover, a series of policies issued for BIM will greatly promote BIM implementation, but whether this passive promotion can really turn into the enhancement of BIM also needs to be evaluated.

Therefore, increase the dimension " Response and Implementation of BIM policy ", interpreted as: “The degree of projects response to and carry out the policies for BIM, in order to effectively promote BIM implementation.”

To sum up, summarized the changes of dimensions in Process area as Table 3.3.

Table 3.3 Changes of dimensions in Process area

Dimension	Change	Area	Interpretation
Full lifecycle implementation of BIM	Supplementing	Process	Evaluate the implementation of BIM in various stages of life cycle, as well as the completion of all implementation points in the whole lifecycle.
Coordination and transmission of the models	Supplementing		The degree of forward modeling, and the model’s convergence of the various stages.
Delivery Processes of BIM Relating Products and Services	Supplementing		The degree of reasonable modeling and delivery in accordance with the model level depth (LOD) requirements, whether the project formulates standards for BIM delivery, and whether provides the simulation analysis report, collision inspection report, bill of quantities(BOQ) and other BIM results documents
Response and Implementation of BIM policy	Adding		The degree of projects response to and carry out the policies for BIM, in order to effectively promote BIM implementation.

(2) Technology Area

1) BIM Cooperative Management Platform

The Outline of Shanghai city BIM Technology Popularization in 13th Five-Year Development Plan proposed that the establishment of BIM platform is the key task of the implementation and popularization of BIM in Shanghai. It points out that BIM data management platform should be established, which provides unified information platform support for data exchange and cooperation among all parties involved.

The Guide for implementation of BIM in Shanghai also emphasizes the importance of BIM platform, pointing out that the platform is combining with project management processes and responsibilities of all parties to manage well.

In the BIM implementation process of construction project lifecycle, project participants should make full use of the advantages of the platform to realize sharing and exchange of models, and ensure that model data can be effectively transmitted between different stages and different subjects. Although the initial dimensions measures the model of coordination, software platform and BIM network, but there is no specific dimension to evaluate the "BIM management platform”, so here renames the initial dimension of "BIM network" to “BIM collaborative management platform ", and updates the concept as: the development and implementation of collaborative management platform of BIM, whether to make the definition of the collaborative approach, providing the conditions of information sharing and transmission for stakeholders.

2) BIM Research

The Outline of Shanghai city BIM Technology Popularization in 13th Five-Year Development Plan points out that China BIM technology and implementation environment is not mature, the implementation of BIM technology has some difficulties. Information between all kinds of software, does not exchange and share well, which restricts the efficiency and value of BIM.

Through expert interviews, we know that the growth of the software is very fast, not only including the existing software updating, such as Revit in the last ten years is renewing constantly; but also including the redevelopment of software in order to satisfy the requirements of projects.

Therefore, BIM research is very important, which is also an important evaluating indicator for Chinese BIM. So here adds the dimension “BIM research”, interpreted as “According to their own needs, the project can reasonably redevelop existing BIM tools, including the development of BIM deep implementation software platform, and improvement of BIM related software functions.”

3) Model-based Calculation and Analysis

During the expert interview, many experts pointed out that the evaluation index is too detailed and has been included in the "BIM life cycle implementation" indicator, and recommend that it should be deleted.

In summary, summarize the changes of dimensions in Technology area as Table 3.4.

Table 3.4 Changes of dimensions in Process area

Dimension	Change	Area	Interpretation
BIM Cooperative Management Platform	Supplementing	Technology	The development and implementation of collaborative management platform of BIM, whether to make the definition of the collaborative approach, providing the conditions of information sharing and transmission for stakeholders.
BIM Research	Adding		According to their own needs, the project can reasonably redevelop existing BIM tools, including the development of BIM deep implementation software platform, and improvement of BIM related software functions.
Model-based Calculation and Analysis	Deleting		

(3) Organization Area

1) BIM Team Stability

Through expert interviews, it has been learned that BIM personnel in domestic construction projects are frequently moving and talent loss is serious. As the project is carried out, it may also have new demands for BIM talents, and it is necessary to constantly adjust the BIM team and introduce new talents. Therefore, whether the stability of the BIM team can be guaranteed is an important factor affecting the maturity of BIM implementation. Therefore, the dimension "BIM team stability" is added here. The explanation is: the project reduces the flow of BIM personnel and is flexible to adjust the BIM team structure and ensures the level of the BIM team with a higher technical level.

2) BIM Communication

Through expert interviews, it has been learned that due to the traditional background of the Chinese construction industry, all BIM personnel of different participants are concentrated in one office space, and the practice of communicating at any time is difficult to promote in China. However, the implementation of BIM technology is inseparable from effective communication, so whether there is sufficient communication and exchange is an important factor in assessing the maturity of BIM implementations in China's construction projects.

The communication on the project can be divided into formal and informal. Formal communication depends on the meeting system, while informal communication includes usual social software and face-to-face communication. In order to assess whether the BIM related information is adequately communicated, the explanation of the dimension “BIM business communication and exchange” is supplemented and updated in the organizational area: the extent to which the project regularly holds specific BIM-related meetings according to demand, and the degree of comprehensiveness and diversity of communication methods among project members.

3) Dimensions “BIM Visions, Goals and Strategies at Organization Level” and “Actual Impacts of BIM on Organizations” are more used at the Organizational Level, so these two are deleted.

In summary, summarize the changes of dimensions in Organization area as Table 3.5.

Table 3.5 Changes of dimensions in Organization area

Dimension	Change	Area	Interpretation
BIM Team Stability	Adding	Organization	The project reduces the flow of BIM personnel and is flexible to adjust the BIM team structure and ensures the level of the BIM team with a higher technical level
BIM Communication	Supplementing		The extent to which the project regularly holds specific BIM-related meetings according to demand, and the degree of comprehensiveness and diversity of communication methods among project members.
BIM Visions, Goals and Strategies at Organization Level	Deleting		
Actual Impacts of BIM on Organizations	Deleting		

(4) Humman **Area**

1) Education and Training

The Outline of Shanghai city BIM Technology Popularization in 13th Five-Year Development Plan points out that “insufficient capacity of management technicians is currently the main problem in the implementation of BIM in Shanghai. Employees' lack of BIM capabilities cause the current BIM implementation is still mainly in the initial stage of modeling." It also says it is needed to establish a multi-level talent training system as a safeguard measure for BIM capacity building.

The Report for 2017 Shanghai BIM implementation and Development says that domestic BIM higher education and qualification certification are still in the initial development stage. Complete BIM talent education system and talented person career development environment has not formed. With the rapid popularization of BIM technology, the demand for BIM technical talents from social enterprises is also growing.

Research Report on the value of BIM implementation in China mentions the lack of BIM knowledge and skills is the two major obstacles in popularizing BIM implementations in China. One of the challenges for BIM to further develop is to cultivate talents with suitable experience and skills.

Therefore, whether the BIM personnel in the project have received sufficient knowledge and skills training have played a pivotal role in the success of BIM. The "educational and training" dimensions in the above are mostly used at enterprise level. But this article discusses project-level BIM capabilities. Here, the definition is updated: The degree to which the project personnel receive regular BIM knowledge and skills training during the project.

2) BIM roles and Responsibilities

The Guide for implementation of BIM in Shanghai says when implementing a full-life or multi-phase implementation, the project shall set up the positions of the BIM technical leader and BIM technical engineer, and they should have sufficient construction management and BIM technology experience, and should be assumed by the project manager who is familiar with BIM technology, in order to ensure the full integration of BIM technology and project implementation to ensure effectiveness. At the same time, *the Guide* also defines in detail the responsibilities of BIM technical leaders and BIM technical engineers

Due to the slightly different definitions of Roles and Responsibilities of BIM in the above initial dimensions, the BIM roles and responsibilities were updated to meet

China's situation: The project set up BIM technical leaders and BIM technical engineers, and their construction management and BIM experiences can guarantee the degree of integration of BIM technology and project.

In summary, summarize the changes of dimensions in Humman area as Table 3.6.

Table 3.6 Changes of dimensions in Humman area

Dimension	Change	Area	Interpretation
Education and Training	Supplementing	Humman	The degree to which the project personnel receive regular BIM knowledge and skills training during the project.
BIM roles and Responsibilities	Supplementing		The project set up BIM technical leaders and BIM technical engineers, and their construction management and BIM experiences can guarantee the degree of integration of BIM technology and project.

To sum up, summarize the changes of dimensions in all areas as Table 3.7.

Table 3.7 Changes of dimensions in the evaluation model

Dimension	Change	Area	Interpretation
Full lifecycle implementation of BIM	Supplementing	Process	Evaluate the implementation of BIM in various stages of life cycle, as well as the completion of all implementation points in the whole lifecycle.
Coordination and transmission of the models	Supplementing		The degree of forward modeling, and the model's convergence of the various stages.
Delivery Processes of BIM Relating Products and Services	Supplementing		The degree of reasonable modeling and delivery in accordance with the model level depth (LOD) requirements, whether the project formulates standards for BIM delivery, and whether provides the simulation analysis report, collision inspection report, bill of quantities(BOQ) and other BIM results documents
Response and Implementation of BIM policy	Adding		The degree of projects response to and carry out the policies for BIM, in order to effectively promote BIM implementation.
BIM Cooperative Management Platform	Supplementing	Technology	The development and implementation of collaborative management platform of BIM, whether to make the definition of the collaborative approach, providing the conditions of information sharing and transmission for stakeholders.
BIM Research	Adding		According to their own needs, the project can

			reasonably redevelop existing BIM tools, including the development of BIM deep implementation software platform, and improvement of BIM related software functions.
Model-based Calculation and Analysis	Deleting		
BIM Team Stability	Adding	Organization	The project reduces the flow of BIM personnel and is flexible to adjust the BIM team structure and ensures the level of the BIM team with a higher technical level
BIM Communication	Supplementing		The extent to which the project regularly holds specific BIM-related meetings according to demand, and the degree of comprehensiveness and diversity of communication methods among project members.
BIM Visions, Goals and Strategies at Organization Level	Deleting		
Actual Impacts of BIM on Organizations	Deleting		
Education and Training	Supplementing	Humman	The degree to which the project personnel receive regular BIM knowledge and skills training during the project.
BIM roles and Responsibilities	Supplementing		The project set up BIM technical leaders and BIM technical engineers, and their construction management and BIM experiences can guarantee the degree of integration of BIM technology and project.

In order to ensure that the description is scientific and objective, the author also interviewed professors and seniors in the BIM field, constantly adjusted and optimized the evaluation indicators, and constantly modified according to the opinions of the professors and experts, and finally determined the evaluation model of BIM implementation for Chinese construction projects. The model is divided into 19 dimensions and covers four major areas. Among them, the Process area includes six dimensions; the Technology area contains five dimensions; the BIM Organization area contains four dimensions; and the Human area contains four dimensions, as Table 3.8.

Table 3.8 Dimensions of the evaluation model

Area		Dimension	Change
Process（P）	P1	Development of BIM Execution Plan (BEP) or Adoptions of BEP Templates	
	P2	Full lifecycle implementation of BIM	Supplementing
	P3	Coordination and transmission of the models	Supplementing
	P4	Quality Control of BIM Implementation	
	P5	Delivery Processes of BIM Relating Products and Services	Supplementing
	P6	Response and Implementation of BIM policy	Adding
Technology（T）	T1	BIM Functions Adoption and Software Selections	
	T2	BIM Relating Hardware Implemented	
	T3	Data and Information Richness and Accuracy	
	T4	BIM Cooperative Management Platform	Supplementing
	T5	BIM Research	Adding
Organization（O）	O1	Development of Contracts of BIM Related Rewards and Risks Allocations	
	O2	Senior Management Support	
	O3	BIM Team Stability	Adding
	O4	BIM Communication	Supplementing
Human（H）	H1	BIM Related Staff Experiences, Skills and Knowledge of BIM Staff/Stakeholders	
	H2	Awareness, Attitudes, Enjoyments and involvements of Employees/Stakeholders towards BIM	
	H3	Education and Training	Supplementing
	H4	BIM roles and Responsibilities	Supplementing

3.3 Index Weight

3.3.1 The process of weight determination

This paper has adopted Analytic Hierarchy Process (AHP) to do the weight determination. We design the “Survey of BIM Implementation Maturity Evaluation Index for China Construction Projects” (see Appendix A for details). This questionnaire uses the Likert 5-point Scale to measure, with "not at all important" (1 point), "not important" (2 points), "general" (3 points), "important" (4 points), and "very important" (5 points) as evaluation indicators. Based on their own understanding of BIM and practical experience, the judges made relative importance judgments on four primary indicators and 19 secondary indicators one by one.

In order to make the determined weights more persuasive and referable, this paper has made rigorous selections of invited experts, and conducted comprehensive screening based on job titles, BIM project experience, and BIM theoretical level, and finally determined 22 scoring experts. These experts come from owner, design, construction, engineering consulting, scientific research institutions and software enterprise. They have more than five years of research or practical experience in BIM related fields and have participated in more than three BIM projects. In addition, in order to ensure the independence of the assignment results, the 22 scoring experts did not overlap with the experts interviewed in the previous section. The scoring process is distributed to all experts in the form of an online questionnaire at the same time. The information of experts are shown in Table 3.9.

Table 3.9 Information of Interviewed Experts

NO	From	Companies
1	Design	Tongji University Architectural Design Institute (Group) Co., Ltd.
2		Shanghai Modern Architectural Design (Group) Co., Ltd.
3		Shanghai Modern Architectural Design (Group) Co., Ltd.
4		Shanghai Urban Construction Design and Research Institute
5	Construction	China Construction Eighth Engineering Bureau Co., Ltd.
6		Shanghai Construction Engineering Group Engineering Research Institute
7		China Railway Construction Engineering Group Co., Ltd.
8	Owner	Shanghai World Expo Development Group
9		Shanghai Shendi Project Management Co., Ltd.
10		Shanghai Center Building Development Co., Ltd.
11	BIM consulting	Shanghai Jianke Cost Consultation Co., Ltd.
12		Shanghai Huizhijian Construction Consultant Co., Ltd.
13		Shanghai Jianke Engineering Consulting Co., Ltd.
14		Shanghai Jianke Engineering Project Management Co., Ltd.
15	Software enterprise	Shanghai Luban Software Co., Ltd.
16		Shanghai Juyi Technology Development Co., Ltd.
17		Shanghai Luban Software Co., Ltd.
18	Scientific	Tongji University

19	Research institution	Tongji University
20		Tongji University
21		Shanghai Jiaotong University
22		Shanghai Jiaotong University

Take the average score of 22 experts as the final score of the evaluation index, and then rank the importance of each index according to the score. Higher scores are important indexes. Then construct a two-by-two comparison judgment matrix followed by reference to the difference of each evaluation index, using Excel to calculate the weight of each index and perform a consistency check. Specific steps are divided into the following two steps:

1) Construct a two-by-two comparison judgment matrix $A = (a_{ij})_{m \times n}$, followed by reference to the difference of each evaluation index. a_{ij} denotes the relative importance between the ith element and the jth element, and the value is represented by a real number. The meaning of each value is shown in Table 3.10.

Table 3.10 Factor importance scale meaning table

Degree of importance	Meaning
1	When compareing the two elements, they have equal importance
3	When compareing the two elements, the former is slightly important than the latter
5	When compareing the two elements, the former is obviously important than the latter
7	When compareing the two elements, the former is strongly important than the latter
9	When compareing the two elements, the former is extremely important than the latter
2,4,6,8	The median value of the above judgment
Reciprocal	If the importance ratio of i and j is a_{ij}, then the importance ratio of j and i is $a_{ji} = 1/a_{ij}$.

2) To show that the judgment matrix is logical, it is necessary to check the consistency of the matrix.

First, calculate the consistency index C.I.（Consistency Index）:

$$C.I. = \frac{\lambda_{max} - n}{n-1} \qquad (3.3)$$

Secondly, calculate the Consensus Ratio (C.R.) and use the R.I. (Random Index) to check whether the consistency of the matrix meets the requirements:

$$C.R. = \frac{C.I.}{R.I.} \qquad (3.4)$$

It is generally believed that when C.R.<0.10, the consistency of the matrix is acceptable.

Table 3.14 gives the values of the average random consistency index R.I. obtained by calculating the 1-10 reciprocal matrixes 1000 times.

Table 3.14Mean Random Uniformity Indicator R.I. Value Table (Source: T.L. Saaty, 2010)

Matrix order	1	2	3	4	5	6	7	8	9	10
R.I.	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.49

(1) First level Indicator Weights and Consistency Test

The average scores of the 22 experts on Process area (P), Technology area (T), Organization area (O), and Humanl area (H) were: 4.5, 4.318, 4.227, 4.091, and the order of importance was: P >T>O>H. Refering to Table 3.13 to construct a pairwise comparison judgment matrix $A = (a_{ij})_{m\times n}$, as shown in Table 3.11 Judgment Matrix of the first level IndicatorTable 3.11.

Table 3.11 Judgment Matrix of the first level Indicator

S	P	T	O	H	Wi	λ_{max}	CI=(λ-n)/(n-1)	CR=CI/ R.I.
P	1	2	3	4	0.467	4.031	0.010	0.0115
T	1/2	1	2	3	0.278			
O	1/3	1/2	1	2	0.160			
H	1/4	1/3	1/2	1	0.095			

Calculate the maximum eigenvalue of this judgment matrix λmax(O)= 4.031, and the consistency index C.I.= 0.010, the average random consistency index R.I.(4)=0.90, the Consensus Ratio C.R.= 0.0115＜0.1, Therefore, the judgment matrix has acceptable consistency. From this calculation, the subjective weights of the first-level indicators are shown in Table 3.12.

Table 3.12 First level Indicator Weights

P	T	O	H
Process Area	Technology Area	Organization Area	Human Area
0.4668	0.2776	0.1603	0.0953

(2) The weight of each secondary indicator in the Process area and Consistency Test

22 experts rated the six secondary evaluation indicators in the process area as follows: 4.591, 3.864, 4.455, 4.364, 4.364, 3.864. The order of importance was: P1>P3>P5=P4>P2=P6. Refering to Table 3.13 to construct a pairwise comparison judgment matrix $A = (a_{ij})_{m\times n}$, as shown in Table 3.13.

Table 3.13 Judgment Matrix of secondary indicators in the process area

P	P1	P2	P3	P4	P5	P6	Wi	λ_{max}	CI=(λ-n)/(n-1)	CR=CI/R.I.
P1	1	5	2	4	4	5	0.395	6.067	0.0134	0.012
P2	1/5	1	1/4	1/2	1/2	1	0.062			
P3	1/2	4	1	3	3	4	0.264			
P4	1/4	2	1/3	1	1	2	0.108			
P5	1/4	2	1/3	1	1	2	0.108			
P6	1/5	1	1/4	1/2	1/2	1	0.062			

Calculate the maximum eigenvalue of this judgment matrix λmax(O)= 6.067, and the consistency index C.I.= 0.0134, the average random consistency index R.I.(6)=1.24, the Consensus Ratio C.R.= 0.012＜0.1, Therefore, the judgment matrix has acceptable consistency. From this calculation, the subjective weights of each secondary indicator in the Process area are shown in Table 3.14.

Table 3.14 The weight of each secondary indicator in the Process area

P1	P2	P3	P4	P5	P6
Development of BIM Execution Plan (BEP) or Adoptions of BEP Templates	Full lifecycle implementation of BIM	Coordination and transmission of the models	Quality Control of BIM Implementation	Delivery Processes of BIM Relating Products and Services	Response and Implementation of BIM policy
0.3949	0.0624	0.2644	0.1079	0.1079	0.0624

(3) The weight of each secondary indicator in the Technology area and Consistency Test

22 experts rated the five secondary evaluation indicators in the Technology area as follows: 4.273, 3.682, 4.727, 4.364, 3.682. The order of importance was: T3>T4>T1>T5=T2. Refering to Table 3.10 to construct a pairwise comparison judgment matrix $A = (a_{ij})_{m\times n}$, as shown in Table 3.15.

Table 3.15 Judgment Matrix of secondary indicators in the Technology area

T	T1	T2	T3	T4	T5	Wi	λ_{max}	CI=(λ-n)/(n-1)	CR=CI/R.I.
T1	1	2	1/3	1/2	2	0.153	5.036	0.0091	0.0081
T2	1/2	1	1/4	1/3	1	0.088			
T3	3	4	1	2	4	0.414			
T4	2	3	1/2	1	3	0.258			

T5	1/2	1	1/4	1/3	1	0.088			

Calculate the maximum eigenvalue of this judgment matrix λmax(O)=5.036, and the consistency index C.I.=0.0091, the average random consistency index R.I.(5)=1.12, the Consensus Ratio C.R.= 0.0081＜0.1, Therefore, the judgment matrix has acceptable consistency. From this calculation, the subjective weights of each secondary indicator in the Technology area are shown in Table 3.16.

Table 3.16 The weight of each secondary indicator in the Technology area

T1	T2	T3	T4	T5
BIM Functions Adoption and Software Selections	BIM Relating Hardware Implemented	Data and Information Richness and Accuracy	BIM Cooperative Management Platform	BIM Resear ch
0.1531	0.0879	0.4135	0.2576	0.0879

(4) The weight of each secondary indicator in the Organization area and Consistency Test

22 experts rated the four secondary evaluation indicators in the Organization area as follows: 4.136, 4.636, 4.000, 3.636. The order of importance was: O2>O1>O3>O4. Refering to Table 3.10 to construct a pairwise comparison judgment matrix $A = (a_{ij})_{m\times n}$, as shown in Table 3.17.

Table 3.17 Judgment Matrix of secondary indicators in the Organization area

O	O1	O2	O3	O4	Wi	λ_{max}	CI=(λ-n)/(n-1)	CR=CI/R.I.
O1	1	1/2	2	3	0.278	4.031	0.0103	0.0115
O2	2	1	3	4	0.467			
O3	1/2	1/3	1	2	0.160			
O4	1/3	1/4	1/2	1	0.095			

Calculate the maximum eigenvalue of this judgment matrix λmax(O)=4.031, and the consistency index C.I.=0.0103, the average random consistency index R.I.(4)=0.90, the Consensus Ratio C.R.= 0.0115＜0.1, Therefore, the judgment matrix has acceptable consistency. From this calculation, the subjective weights of each secondary indicator in the Organization area are shown in Table 3.18.

Table 3.18 The weight of each secondary indicator in the Organization area

O1	O2	O3	O4
Development of Contracts of BIM Related	Senior	BIM Team	BIM

Rewards and Risks Allocations	Management Support	Stability	Communication
0.2776	0.4668	0.1603	0.0953

(5) The weight of each secondary indicator in the Human area and Consistency Test

22 experts rated the four secondary evaluation indicators in the Human area as follows: 4.273, 4.545, 3.682, 4.273 The order of importance was: H2>H4=H1>H3. Refering to Table 3.10 to construct a pairwise comparison judgment matrix $A = (a_{ij})_{m\times n}$, as shown in Table 3.19.

Table 3.19 Judgment Matrix of secondary indicators in the Organization area

H	H1	H2	H3	H4	Wi	λ_{max}	CI=(λ-n)/(n-1)	CR=CI/R.I.
H1	1	1/2	3	1	0.239	4.0206	0.0069	0.0076
H2	2	1	4	2	0.433			
H3	1/3	1/4	1	1/3	0.088			
H4	1	1/2	3	1	0.239			

Calculate the maximum eigenvalue of this judgment matrix λmax(O)=4.0206, and the consistency index C.I.=0.0069, the average random consistency index R.I.(4)=0.90, the Consensus Ratio C.R.=0.0076 ＜ 0.1, Therefore, the judgment matrix has acceptable consistency. From this calculation, the subjective weights of each secondary indicator in the Human area are shown in Table 3.20.

Table 3.20 The weight of each secondary indicator in the Human area

H1	H2	H3	H4
BIM Related Staff Experiences, Skills and Knowledge of BIM Staff/Stakeholders	Awareness, Attitudes, Enjoyments and involvements of Employees/Stakeholders towards BIM	Education and Training	BIM roles and Responsibilities
0.2395	0.433	0.088	0.2395

3.3.2 The weight of each Evaluation Index

According to the calculation of the above-mentioned Analytic Hierarchy Process, the weighted results of each evaluation index of the BIM implementation maturity model for Chinese construction projects are determined as shown in Table 3.21.

Table 3.21 Weights of Indicators in BIM implementation Maturity Model for Chinese Construction Projects

First level	Weight	Secondary level Indicator	Relative	Absolute

Indicator				Weight	Weight
Process （P）	46.7%	P1	Development of BIM Execution Plan (BEP) or Adoptions of BEP Templates	39.49%	18.44%
		P2	Full lifecycle implementation of BIM	6.24%	2.92%
		P3	Coordination and transmission of the models	26.44%	12.35%
		P4	Quality Control of BIM Implementation	10.79%	5.04%
		P5	Delivery Processes of BIM Relating Products and Services	10.79%	5.04%
		P6	Response and Implementation of BIM policy	6.24%	2.92%
Technology （T）	27.8%	T1	BIM Functions Adoption and Software Selections	15.31%	4.25%
		T2	BIM Relating Hardware Implemented	8.79%	2.44%
		T3	Data and Information Richness and Accuracy	41.35%	11.50%
		T4	BIM Cooperative Management Platform	25.76%	7.16%
		T5	BIM Research	8.79%	2.44%
Organization （O）	16%	O1	Development of Contracts of BIM Related Rewards and Risks Allocations	27.76%	4.44%
		O2	Senior Management Support	46.68%	7.47%
		O3	BIM Team Stability	16.03%	2.56%
		O4	BIM Communication	9.53%	1.52%
Human （H）	9.5%	H1	BIM Related Staff Experiences, Skills and Knowledge of BIM Staff/Stakeholders	23.95%	2.27%
		H2	Awareness, Attitudes, Enjoyments and involvements of Employees/Stakeholders towards BIM	43.27%	4.11%

		H3	Education and Training	8.83%	0.84%
		H4	BIM Roles and Responsibilities	23.95%	2.27%

3.4 BIM Maturity Level

In order to conduct a quantitative comprehensive evaluation of BIM maturity in Chinese construction projects, and at the same time to make a more scientific explanation of the evaluation results, we refer to the rating system of existing typical evaluation models as Table 3.22 and conduct the BIM maturity levels.

Table 3.22 Rating system of Typical Evaluation Models

Level	BIM Scorecard	BIM CMM	BIM Proficiency Matrix	BIM Maturity Matrix s
0		Score 0-39：		
1	0%-25%： Traditional Practice	Score 40-49： Lowest level	Score 0-12： Lowest level	Initial level
2	25%-50%： Typical Practice	Score 50-69： Certification level	Score 13-18： Certification level	Definable level
3	50%-75%： Advanced Practice	Score 70-79： Silver level	Score 19-24： Silver level	Management level
4	75%-90%： Best Practice	Score 80-89： Gold level	Score 25-28： Gold level	Integrated level
5	90%-100%： Innovation Practice	Score 90-100： Platinum level	Score 29-32： Ideal level	Optimization level

According to the above table, the BIM capabilities and effects of each model are upgraded step by step with increasing levels. It is a process system that continuously improves from the initial disorder to high levels and is continuously optimized. The five levels are the most common. Because different scoring methods may lead to different total scores, we use percentage as a rating standard. Each level is determined according to oppinions of research team and industry experts, especially considering BIM in China, and the lowest two levels of maturity are not set too high. Therefore, it is determined that the maturity level of BIM in Chinese construction projects is divided into the following five levels: Initial level (0%-20%), Definable level (20%-50%), Management level (50%-75%), Integrated level (75%-90%), Optimization level (90%-100%).

3.5 Chapter Summary

This chapter draws lessons from the typical foreign BIM maturity evaluation models, and based on the actual situation of Chinese construction industry, integrates Chinese characteristics into it, and builds an evaluation model for BIM maturity.

First, establish an evaluation index system and define the conception of each indicator, including three steps: first, determine the analysis areas of BIM maturity model; second, further determine the analysis dimension of each area; thirdly, through document reading and expert interviews, the situation in China is considered and the evaluation indicators are updated. Then, AHP is used to assign the weights of indicators at all levels, and at the same time, the maturity level of BIM implementation in Chinese construction projects is divided and the evaluation criteria are determined.

To sum up, an assessment model for the BIM maturity in Chinese construction projects has been obtained, as shown in Figure 3.1.

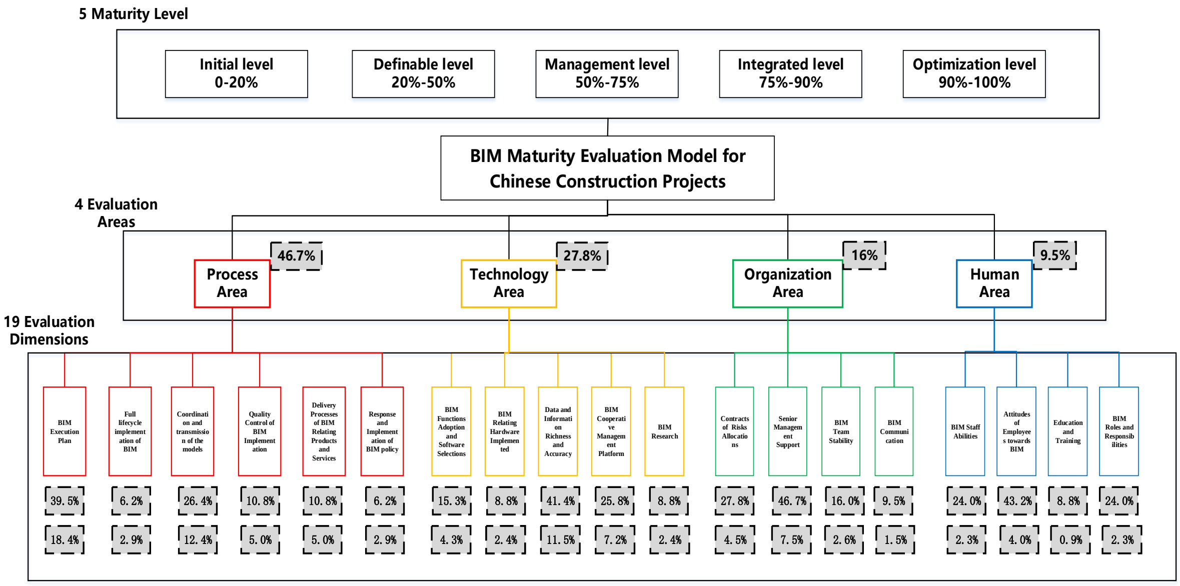

Figure 3.1 Evaluation Model of BIM Maturity in Chinese Construction Projects

4 Evaluation of BIM Maturity in Chinese Construction Projects and Empirical Analysis

4.1 Measurement Form and Questionnaire Design

4.1.1 Measurement Form

（1）Measurement items

On the basis of analyzing the BIM maturity evaluation model of Chinese construction project constructed in Chapter 3, in order to collect the data needed for each indicator, some secondary evaluation indicators need to set up the third level indicators, ie, to compile a well-structured and reasonable measurement form.

The thesis takes the following two approaches to complete the measurement item:

1) Directly cite the measurement items that have been confirmed in the research literature in related fields with high reliability and validity.

2) Learn from the existing research literature and combine the status quo of BIM implementations in Chinese construction projects. Start brainstorming in the research team, develop measurement items that meet the needs, and improve and modify the existing scales. Finally, we get the measurement form as Table 4.1.

Table 4.1 Measurement Form of BIM Maturity evaluation model

No	Measurement Itens	Index		Source
		Second Level	First Level	
P1-1	BIM Execution Plan	Development of BIM Execution Plan (BEP) or Adoptions of BEP Templates （P1）	Process Area	CIC,2012；Giel and Issa,2014
P1-2	BIM Execution Objective			Kam et al.， 2014；Kam et al.， 2013；Berlo， 2012；Sebastian and Berlo，2010； Succar， 2012；Succar， 2010； NIBS，2007
P2-1	BIM Implementation Depth	Full lifecycle implementation of BIM （P2）		NIBS，2007；Succar，2010；Succar，2012；Kam et al.，2013；Kam et al.，2014；McGraw Hill Construction，2015

P2-2	BIM Implementation Breadth			NIBS，2007；Succar，2010；Succar，2012；Kam et al.，2013；Kam et al.，2014；McGraw Hill Construction，2015
P3-1	Modeling method	Coordination and transmission of the models（P3）		Expert Interview
P3-2	Data Interactivity			NIBS，2007；Sebastian and Berlo，2010；Sebastian and Berlo，2010；Kam et al.，2013；Kam et al.，2014；Giel and Issa,2014；Gao,2011
P3-3	Timeliness of Information Transfer			NIBS，2007；Giel and Issa,2014
P4-1	BIM model Audit	Quality Control of BIM Implementation（P4）		Succar，2010；Succar，2012；Sebastian and Berlo，2010；Sebastian and Berlo，2010
P4-2	BIM model Modification			Succar，2010；Succar，2012；Sebastian and Berlo，2010；Sebastian and Berlo，2010；
P5-1	Depth of Modeling	Delivery Processes of BIM Relating Products and Services（P5）		McGraw Hill Construction，2015
P5-2	Delivery Requirements			McGraw Hill Construction，2015
P5-3	Delivery Quality			NIBS，2007；Succar，2010；Succar，2012；Giel and Issa,2014；Gao,2011；McGraw Hill Construction，2015
P5-4	Other delivery documents			McGraw Hill Construction，2015；Expert Interview
P6-1	Response and Implementation of BIM policy	Response and Implementation of BIM policy（P6）		McGraw Hill Construction，2015；Expert Interview
T1-1	Software Investment	BIM Functions Adoption and Software Selections（T1）	Technology Area	Succar，2010；Succar，2012；Sebastian and Berlo，2010；Sebastian and Berlo，2010；CIC,2012；Giel and Issa,2014；Gao,2011
T1-2	Software Standard			Succar，2010；Succar，2012；Sebastian and Berlo，2010；Sebastian and Berlo，2010；CIC,2012；Giel and

				Issa,2014；Gao,2011
T1-3	Software Features			Succar，2010；Succar，2012；Sebastian and Berlo，2010；Sebastian and Berlo，2010；CIC,2012；Giel and Issa,2014；Gao,2011
T2-1	Hardware Investment	BIM Relating Hardware Implemented（T2）		Succar，2010；Succar，2012；CIC,2012；Giel and Issa,2014
T2-2	Hardware connectivity			Succar，2010；Succar，2012；CIC,2012；Giel and Issa,2014
T3-1	Data and Information Richness and Accuracy	Data and Information Richness and Accuracy（T3）		NIBS，2007；IU， 2009；Giel and Issa,2014；Gao,2011
T4-1	BIM Cooperative Management Platform	BIM Cooperative Management Platform（T4）		Berlo，2012；Sebastian and Berlo，2010； NIBS， 2007
T5-1	Software Platform Development	BIM Research（T5）		Expert Interview
T5-2	Software functionality improvements and improvements			Expert Interview
O1-1	Responsibility Division	Development of Contracts of BIM Related Rewards and Risks Allocations（O1）	Organization Area	Kam et al.， 2014；Kam et al.， 2013；Berlo， 2012；Sebastian and Berlo，2010； Succar， 2012；Succar， 2010； NIBS，2007
O1-2	Profit Distribution			Succar，2010；Succar，2012；Sebastian and Berlo，2010；Sebastian and Berlo，2010
O1-3	Trust and Cooperation			Kam et al.， 2014；Kam et al.， 2013；Berlo， 2012；Sebastian and Berlo，2010； Succar， 2012；Succar， 2010； NIBS，2007

O2-1	Senior Management Support	Senior Management Support（O2）		Succar，2010；Succar，2012；Sebastian and Berlo，2010；Sebastian and Berlo，2010；CIC,2012；Kam et al.，2013；Kam et al.，2014；Giel and Issa,2014；Gao,2011
O3-1	BIM Team Stability	BIM Team Stability（O3）		Expert Interview
O4-1	BIM Conference Sysstem	BIM Communication（O4）		Kam et al.， 2014； Kam et al.， 2013；McGraw Hill Construction， 2015
O4-2	BIM Informal Communication			McGraw Hill Construction，2015； 专家访谈
H1-1	BIM Staff Capabilities	BIM Related Staff Experiences, Skills and Knowledge of BIM Staff/Stakeholders（H1）	Human Area	Succar，2010；Succar，2012；Sebastian and Berlo，2010；Sebastian and Berlo，2010；Kam et al.，2013；Kam et al.，2014；Giel and Issa,2014
H2-1	BIM Acceptance	Awareness, Attitudes, Enjoyments and involvements of Employees/Stakeholders towards BIM（H2）		Sebastian and Berlo，2010；Sebastian and Berlo，2010；Giel and Issa,2014
H3-1	Education and Training	Education and Training（H3）		Succar，2010；Succar，2012；Sebastian and Berlo，2010；Sebastian and Berlo，2010；CIC,2012；Kam et al.，2013；Kam et al.，2014；Giel and Issa,2014；McGraw Hill Construction，2015
H4-1	BIM roles and Responsibilities	BIM roles and Responsibilities（H4）		Succar，2010；Succar，2012；CIC,2012；Giel and Issa,2014；Kam et al.，2013；Kam et al.，2014

(2) Measurement tool

Likert Scale is a measurement tool widely used in modern surveys and research. It has been widely used in academic research and industry surveys such as construction engineering. As five-level Likert scale has higher internal consistency than other patterns of Likert scale. This study also uses a five-level Likert scale to measure each variable. "1,2,3,4,5 points" for "Completely Non-Compliant ", "Non-Compliant ", "neutral", " Compliant ", and "very Compliant "

The higher the score, the higher the degree of recognition of the question description by the researcher, otherwise the lower the score. So the score value of the item can be directly used as the measurement index score.

（3）Weights of third level indicators

For each third level indicator under each secondary index, the contribution is considered to be the same, that is, the secondary index score is the average of the scores of the third level indicators under the index.

4.1.2 Design of Questionnaire

(1) Structure of Questionnaire

Based on the third level indicators described in Section 4.1.1, this paper designed a questionnaire “BIM Implementation Maturity Evaluation of Chinese Construction Projects” (see Appendix B for details). The questionnaire is semi-open and mainly consists of two parts:

1) Basic information of the project: project name, project type, project investment scale, project investment attributes, project contracting mode, BIM implementation mode and implementation phase, aiming to provide basic reference and classification basis for subsequent data analysis.

2) BIM Implementation Maturity Survey: Respondents selected the most appropriate content for each measurement item according to the actual situation, and measured the maturity of BIM implementation in different areas.

(2) Questionnaire Correction

In order to improve the readability and relevance of the questionnaire, after the formation of the initial questionnaire, this paper uses the following two methods to adjust and correct the questionnaire:

1) Conduct workshops among the author’s research team on the research questionnaires, to discuss the internal correlation, comprehensibility, and rationality of the questions. Then modifies the questionnaire based on the opinions and suggestions of team members.

Conduct a small-scale pre-testing: Taking into account the feasibility of pre-research and implementation efficiency, this paper selects five BIM professionals as pre-research objects to fill in questionnaires. Combined with the interviewees’ experience in the process, necessary adjustments were made to the questionnaires in terms of sentences and formats to eliminate potential ambiguities and unclear points. After repeatedly revision, the questionnaires shown in Appendix B were finally formed.

4.2 Sample selection and data collection

4.2.1 Sample selection

The objects of this investigation is Chinese construction projects. In order to be able to obtain available sample information more efficiently, and to avoid the influence of differences in the situation of different regions in terms of policies, regional habits, etc., the scope of the research target area is finally determined in the city of Shanghai. In order to improve the representativeness of the sample project, the author pays great attention to the differences in the types of projects, project contracting modes, project investment scale, project investment attributes, and BIM implementation methods and implementation phases in the data collection process. In order to increase the number of questionnaires issued and the randomness of statistics, questionnaires were distributed in three ways, including field visits, e-mails, and questionnaires (www.wjx.cn). Moreover, due to the fact that the research is more professional and requires respondents to have an accurate understanding and control of the overall BIM implementation of the project, so we choose the relevant responsible person or BIM professionals as the responders.

4.2.2 Data collection

A total of 74 projects were investigated and 92 questionnaires were sent out. The Intraclass Correlation Coefficient (ICC) analysis showed that there was no significant difference in different questionnaires from the same project. Taking into account the comparability of the data between projects, each project eventually only adopted a more reliable recovery questionnaire. Respondents are from the owners, designers, construction contractors and many other types of participants, who all have good understanding of BIM implementation of the surveyed project.

After retrieving the questionnaire, the author conducted a preliminary review of the filling of each questionnaire. The author removes the surveys which have more default data or consecutive responses for each item. And questionnaires that may have overlaps between research projects are excluded. After eliminating all kinds of invalid questionnaires, 63 valid questionnaires were finally obtained, of which 15 (23.81%) were from field visits, 15 (23.81%)

were from email, and 33 (52.38%) were from Web research platform.

The basic information of the sample projects is shown in Table 4.2. The surveyed projects have good diversity and representativeness in terms of project investment scale, project types, project contracting mode and investment attributes. $\chi 2$ Test and Analysis of Variance (ANOVA) show that there is no significant difference in questionnaire information collected in different ways.

Table 4.2 Summary of Research Projects

Variable	Category	Quantity	Proportion
Project Type	Residential	7	11.48%
	Business and office	20	31.75%
	Industry	2	3.28%
	Transport Infrastructure	17	27.87%
	Medical Treatment	5	8.20%
	Entertainment	8	12.7%
	OtherS	4	6.56%
Investment Attributes	Public Projects	46	75.41%
	Private Project	17	27.87%
Project Contracting Mode	Design-Build（DB）	13	21.31%
	Engineering，Procurement and Construction（EPC）	27	44.26%
	Design-Bid-Build（DBB）	23	36.51%
Pilot/Non-Pilot	Pilot Project	26	42.62%
	Non-Pilot Project	37	60.66%

4.3 Sample Reliability Analysis

4.3.1 Reliability Test

Reliability reflects whether the questions in the survey questionnaire are measuring the same concepts, thereby verifying the reliability of the assessment system. This paper selects the Cronbach's α coefficient to measure the internal reliability of the questionnaire. Generally speaking, an α value greater than 0.7 is acceptable, and it is considered that this set of data has research value. Results of running the SPSS reliability analysis process indicate that he overall α coefficient value of this questionnaire is 0.951 (＞0.7), whose reliability is good, indicating that the quality of the questionnaire design is high and the data collection is successful, which ensures the reliability and stability of the analysis. Further check the internal consistency of the four first-level indicators in the evaluation system. The results are shown in Table 4.3. The α-coefficients of the four areas in the Process, Technlogy, Organization and Human are all greater than 0.7, of which the reliability is acceptable, which proves that there is better internal consistency among the evaluation indicators.

Table 4.3 Results of Reliability Test

First-level Evaluation Index	Secondary-level Evaluation Index		α Coefficient Value	
Process Area	P1	Development of BIM Execution Plan (BEP) or Adoptions of BEP Templates	0.902	0.951
	P2	Full lifecycle implementation of BIM		
	P3	Coordination and transmission of the models		
	P4	Quality Control of BIM Implementation		
	P5	Delivery Processes of BIM Relating Products and Services		
	P6	Response and Implementation of BIM policy		
Technology Area	T1	BIM Functions Adoption	0.861	

		and Software Selections		
	T2	BIM Relating Hardware Implemented		
	T3	Data and Information Richness and Accuracy		
	T4	BIM Cooperative Management Platform		
	T5	BIM Research		
Organization Area	O1	Development of Contracts of BIM Related Rewards and Risks Allocations	0.859	
	O2	Senior Management Support		
	O3	BIM Team Stability		
	O4	BIM Communication		
Human Area	H1	BIM Related Staff Experiences, Skills and Knowledge of BIM Staff/Stakeholders	0.785	
	H2	Awareness, Attitudes, Enjoyments and involvements of Employees/Stakeholders towards BIM		
	H3	Education and Training		
	H4	BIM roles and Responsibilities		

4.3.2 Validity Test

Validity refers to the degree to which a survey can accurately measure the things that need to be measured. The more consistent the measurement result with the content to be examined, the higher the validity, conversely, the lower the validity. There are three types of validity: content validity, structural validity and guideline validity. In this paper, SPSS KMO values (Kaiser-Mayer-Olykin Measure of Sampling Adequacy) and Bartlett Test of Spherieity are used to analyze the validity of the questionnaires, and a factor analysis process (Data Reduction) is used to verify the consistency and convergence of items in the measurement system.

First, we use the KMO and artlett Test of Spherieity to test whether the data in this group can be factorized. It is generally considered that factor analysis is feasible when the KMO is greater than 0.65 and the Bartlett sphere test has a significance coefficient of Sig<0.05. The verification results of the four major areas are shown in Table 4.4-Table 4.7.

Table 4.4 Process Area-KMO and Bartlett Test of Spherieity

KMO（Kaiser-Meyer-Olkin）		.803
Bartlett Test of Spherieity	Approx. Chi-Square	428.476
	df	91
	Sig.	.000

Table 4.5 Technology Area-KMO and Bartlett Test of Spherieity

KMO（Kaiser-Meyer-Olkin）		.796
Bartlett Test of Spherieity	Approx. Chi-Square	150.411
	df	21
	Sig.	.000

Table 4.6 Organization Area-KMO Bartlett Test of Spherieity

KMO（Kaiser-Meyer-Olkin）		.763
Bartlett Test of Spherieity	Approx. Chi-Square	310.073
	df	36
	Sig.	.000

Table 4.7 Human Area-KMO and Bartlett Test of Spherieity

KMO（Kaiser-Meyer-Olkin）		.686
Bartlett Test of Spherieity	Approx. Chi-Square	57.616
	df	6
	Sig.	.000

As shown in Table 4.4-Table 4.7, the KMO values are all greater than 0.65, and the Bartlett statistics are significant, indicating that the validity of each factor in the evaluation system meets the requirements for factor analysis. Separately run the process of factor analysis for sub-level index sets in each area.

1) Process Area

As shown in Table 4.8, except that the factor loads of items P3-2 and P5-3 are 0.687 and 0.68 respectively, close to 0.7, the factor loads of the remaining items are all greater than 0.7. Six factors were extracted by principal component analysis. The cumulative variance contribution rate was 83.696%> 0.8, indicating that the subordinate measurement index set of Process area has great internal consistency and aggregation validity.

Table 4.8 Process Area- Rotated factor loading matrix

	Extracted factor					
	1	2	3	4	5	6
P1-1	.762	.272	.164	.229	.178	.168
P1-2	.791	.138	.255	.105	.171	.338
P2-1	.236	.911	.100	.170	.182	.148
P2-2	.207	.915	.132	.167	.188	.133
P3-1	-.113	.036	.902	.050	-.019	-.051
P3-2	.537	.304	.687	.054	.185	.237
P3-3	.261	.251	.799	.195	.043	.215
P4-1	.252	.259	.162	.857	.019	-.039
P4-2	.098	.083	.125	.848	.288	.252
P5-1	.495	.168	-.125	.353	.759	.250
P5-2	.316	.261	-.136	.430	.722	.170
P5-3	.129	.018	-.073	.541	.680	.447
P5-4	.262	.186	.124	.129	.820	-.116
P6-1	.119	.321	.126	.261	.354	.745

2) Technology Area

As shown in Table 4.9, the factor loads of all items are greater than 0.7. Five factors were extracted by principal component analysis. The cumulative variance contribution rate was 93.118%>0.8, indicating that the subordinate measurement index set of Technology area has great internal consistency and aggregation validity.

Table 4.9 Technology Area- Rotated factor loading matrix

	Extracted factor				
	1	2	3	4	5
T1-1	.909	.174	.022	.195	.105
T1-2	.808	.010	.513	.194	-.044
T1-3	.807	.038	.514	.182	-.039
T2-1	. 362	.834	.101	-.059	.212

T2-2	.297	.862	.275	.124	.197
T3-1	.286	.367	.825	.209	.058
T4-1	.202	.110	.197	.921	.208
T5-1	-.099	.322	.063	.209	.840
T5-2	.220	-.032	-.015	.051	.934

3) Organization Area

As shown in Table 4.10, the factor loads of all items are greater than 0.7. Four factors were extracted by principal component analysis. The cumulative variance contribution rate was 89.564%>0.8, indicating that the subordinate measurement index set of Organization area has great internal consistency and aggregation validity.

Table 4.10 Organization Area- Rotated factor loading matrix

	Extracted factor			
	1	4	3	2
O1-1	.761	.436	.300	.347
O1-2	.937	.084	.937	.221
O1-3	.962	.191	.090	.073
O2-1	.113	.924	.147	.161
O3-1	.432	.194	.737	.267
O4-1	.245	.192	.265	.848
O4-2	.158	-.002	.035	.941

3) Human Area

As shown in Table 4.11, the factor loads of all items are greater than 0.7. Four factors were extracted by principal component analysis. As the indicators in Human area are all single indicator variable, the cumulative variance contribution rate was 100%, indicating that the subordinate measurement index set of Human area has great internal consistency and aggregation validity.

Table 4.11 Human Area- Rotated factor loading matrix

	Extracted factor			
	1	2	3	4
H1-1	.965	.198	.085	.150
H2-1	.218	.931	.215	.196
H3-1	.092	.230	.902	.355
H4-1	.191	.222	.388	.874

The above analysis results from the two dimensions of reliability and validity show that the reliability of the questionnaire design is high. The evaluation model of BIM maturity for Chinese Construction Projects constructed in this paper and the relevant conclusions based on the obtained data have high credibility.

4.4 Analysis Results of Empirical Research

This section will introduce the process and results of the analysis of the data obtained from empirical research using the theoretical model constructed. On the one hand, based on the empirical results, it reveals the general status of BIM maturity in Chinese construction projects, and deeply analyzes the BIM implementation maturity status of the surveyed projects in the four major areas and their subordinate evaluation dimensions. On the other hand, the comparison of BIM implementation status and level differences between projects of different project types, different project contracting mode, different project investment scale, different BIM implementation model. Finally, provide methods and paths for improving projects' BIM maturity.

4.4.1 Comprehensive Analysis of BIM Implementation Maturity

According to the evaluation model established in this paper, the BIM implementation maturity score of the investigated projects is calculated, and the maturity level is obtained according to the finalized classification in Section 3.3. The results are shown in Figure 4.1. 30 projects are at Level 4 "BIM Implementation Integration Level (3.75-4.5 points)", and 31 projects are at Level 3 "BIM Implementation Management Level (2.5-3.75 points)".

The survey results show that currently Shanghai's construction projects are paying more attention to BIM technology, and the implementation of BIM is moving towards a mature process.

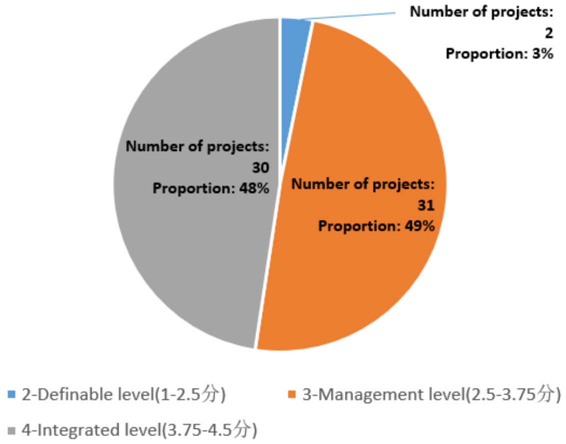

Figure 4.1 BIM Maturity Rating Distribution of Surveyed Projects

The comprehensive scores of the maturity of the 63 projects are further calculated, as well as the average scores in various fields, as shown in Table 4.12 and Figure 4.2. From this, the comprehensive score of the maturity of the surveyed projects is 3.698, and the overall level of maturity is Level 3 “BIM Implementation Management Level (2.5-3.75 points)”.

Table 4.12 Comprehensive score of BIM maturity and Average score in each area

Comprehensive score of BIM maturity	3.698	Process Area	3.62
		Technology Area	3.763
		Organization Area	3.726
		HumanArea	3.843

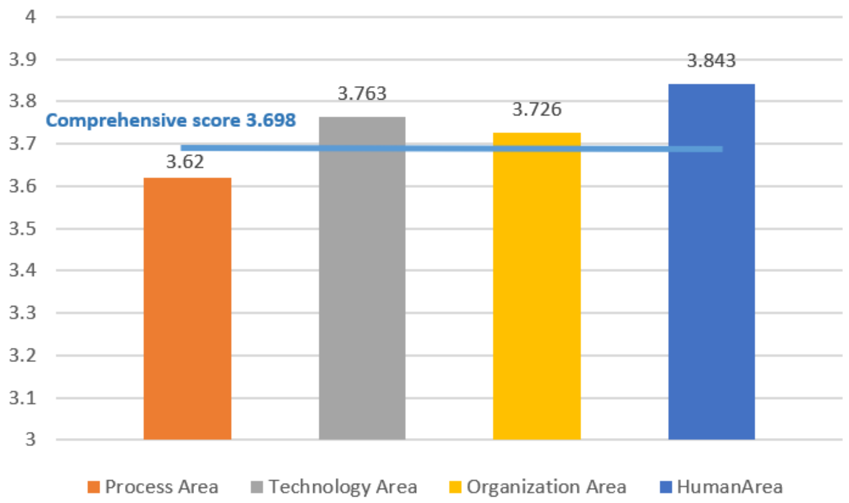

Figure 4.2 Comprehensive score of BIM maturity and Average score in each area

A correlation analysis was performed for all areas, the commonly Pearson correlation coefficient was adopted in this study to evaluate the degree of correlation between the data. The resulting parameters are represented by the symbol r, $-1 \leq r \leq 1$. When the absolute value of the r is closer to 1, the correlation between the parameters is considered to be stronger. At the same time, the significance degree of the relevance degree result is evaluated by calculating the corresponding P-Value. The most commonly used P-value threshold is 0.05 (5%). When P-value is less than or equal to 0.05, the parameters are regarded as significant correlation. The results are shown in Table 4.13.

Table 4.13 Correlation test of BIM maturity in various areas

First level Indicator		Correlation coefficient	P Value
Process Area (P) vs	Technology Area (T)	0.554	0.018*
	Organization Area	0.546	0.015*

	(O)		
	Human Area (H)	0.602	0.024*
Technology Area (T) vs	Organization Area (O)	0.422	0.089
	Human Area (H)	0.411	0.121
Organization Area (O) vs	Human Area (H)	0.654	0.008**

The results show that there is a certain correlation between the four areas that evaluate BIM maturity in Chinese construction projects, that is, the improvement of maturity in a certain area will have a certain impact on the maturity of other areas. Among them, the maturity of organization area(O) and human area (H) are significantly related at the 0.01 level. The process area (P) is significantly related to the other three areas at the 0.05 level. Therefore, to improve the level of BIM maturity, the project needs to comprehensively upgrade from four areas. Focusing only on one or a few of these factors is one-sided.

The scores of various areas and their subordinate indicators are shown in Table 4.14, and Figure 4.3 - Figure 4.6.

Table 4.14 Maturity Evaluation Results of each area

Score of Process Area	Second level Indicator		Score of Second level Indicator	Second level Indicator		Score of Third level Indicator
3.620	P1	Development of BIM Execution Plan (BEP) or Adoptions of BEP Templates	3.690	P1-1	BIM Execution Plan	3.968
				P1-2	BIM Execution Objective	3.413
	P2	Full lifecycle implementation of BIM	3.611	P2-1	BIM Implementation Depth	3.587
				P2-2	BIM Implementation Breadth	
	P3	Coordination and transmission of the models	3.175	P3-1	Modeling method	2.556
				P3-2	Data Interactivity	3.619
				P3-3	Timeliness of Information Transfer	3.349
	P4	Quality Control of BIM Implementation	3.897	P4-1	BIM model Audit	3.857
				P4-2	BIM model Modification	3.937

	P5	Delivery Processes of BIM Relating Products and Services	3.888	P5-1	Depth of Modeling	3.730
				P5-2	Delivery Requirements	3.778
				P5-3	Delivery Quality	3.921
				P5-4	Other delivery documents	4.095
	P6	Response and Implementation of BIM policy	4.127	P6-1	Response and Implementation of BIM policy	4.127
Score of Technology Area	Second level Indicator		Score of Second level Indicator	Second level Indicator		Score of Third level Indicator
	T1	BIM Functions Adoption and Software Selections	3.958	T1-1	Software Investment	3.952
				T1-2	Software Standard	3.952
				T1-3	Software Features	3.968
	T2	BIM Relating Hardware Implemented	3.714	T2-1	Hardware Investment	3.746
				T2-2	Hardware connectivity	3.683
	T3	Data and Information Richness and Accuracy	3.968	T3-1	Data and Information Richness and Accuracy	3.968
	T4	BIM Cooperative Management Platform	3.524	T3-2	BIM Cooperative Management Platform	3.524
	T5	BIM Research	3.206	T5-1	Software Platform Development	3.111
				T5-2	Software functionality improvements and improvements	3.302
Score of Organization Area	Second level Indicator		Score of Second level Indicator	Second level Indicator		Score of Third level Indicator
3.726	O1	Development of Contracts of BIM Related Rewards and Risks Allocations	3.714	O1-1	Responsibility Division	3.651
				O1-2	Profit Distribution	3.619

				O1-3	Trust and Cooperation	3.873
	O2	Senior Management Support	3.698	O2-1	Senior Management Support	3.698
	O3	BIM Team Stability	3.667	O3-1	BIM Team Stability	3.667
	O4	BIM Communication	4.000	O4-1	BIM Conference Sysstem	3.968
				O4-2	BIM Informal Communication	4.032

Score of Human Area	Second level Indicator		Score of Second level Indicator
3.843	H1	BIM Staff Capabilities	3.968
	H2	Awareness, Attitudes, Enjoyments and involvements of Employees/Stakeholders towards BIM	3.698
	H3	Education and Training	3.746
	H4	BIM roles and Responsibilities	4.016

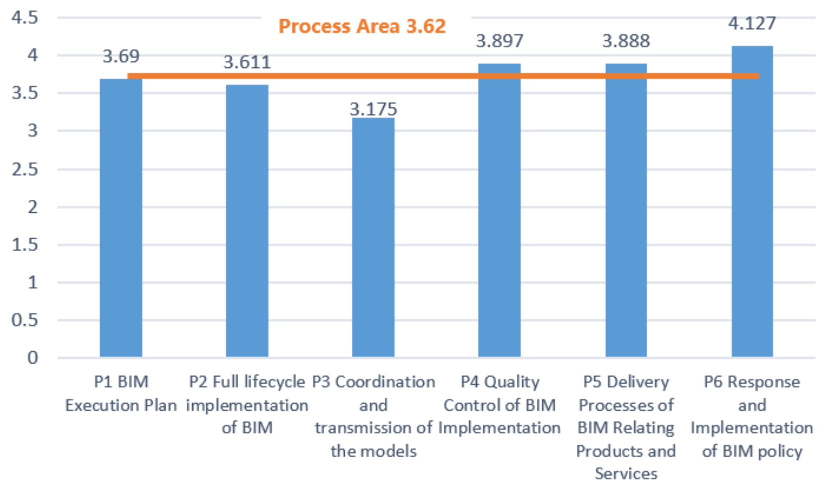

Figure 4.3 Maturity Evaluation Result of Process area

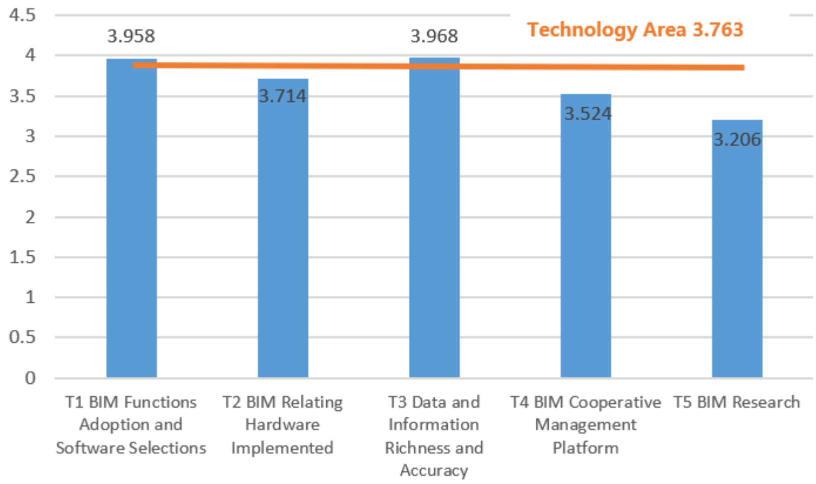

Figure 4.4 Maturity Evaluation Result of Technology area

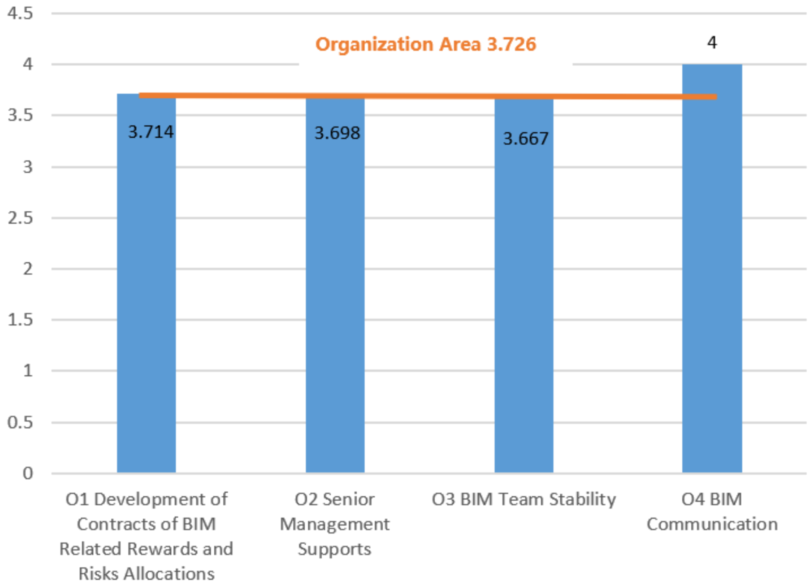

Figure 4.5 Maturity Evaluation Result of Organization area

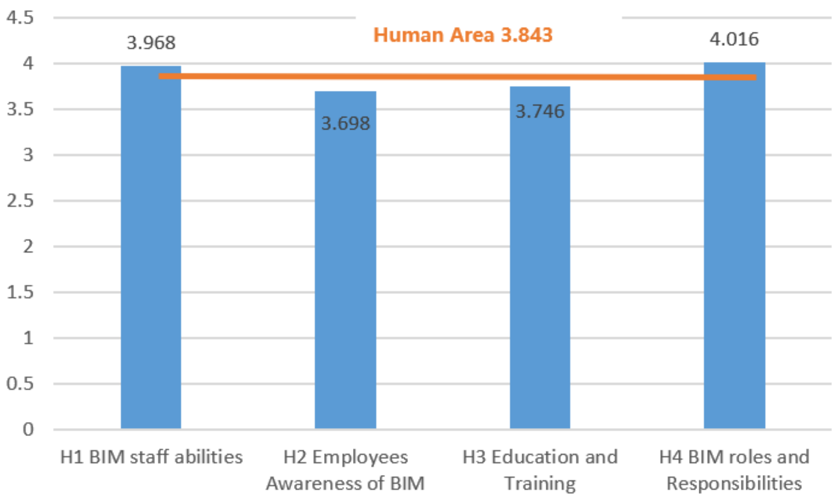

Figure 4.6 Maturity Evaluation Result of Human area

4.4.2 Analysis of BIM maturity in different types of projects

The projects surveyed are classified according to the type of project. The comprehensive scores of maturity and the scores of each area are shown in Table 4.17 and Figure 4.18 and 4.19. According to the comprehensive score of maturity, the highest score of the surveyed project maturity is “Other” category with 3.973 points, which is at level 4 of maturity “BIM implementation integration level (3.75-4.5 points)”. The scores of other types of projects are all at Level 3 “BIM Implementation Management Level (2.5-3.75 points)”, but the lowest score is “Transport Infrastructure”, which is only 3.581 points. The distribution of remaining types of projects is relatively even. From perspective of areas, the scores of maturity in various areas show the same trend as the comprehensive scores of maturity.

Table 4.15 Comparison of maturity score in different Project Types

Project Type	Quantity	Maturity score	Score of each area			
			Process Area	Technology Area	Organization Area	Human Area
Other	4	3.980	3.945	4.008	4.008	4.022
Industry	2	3.749	3.682	3.8	3.789	3.863
Medical	5	3.745	3.673	3.812	3.773	3.851
Entertainment	8	3.737	3.674	3.792	3.765	3.838
Residential	7	3.725	3.651	3.791	3.752	3.849
Business Office	20	3.705	3.602	3.81	3.742	3.839
Transport infrastructure	17	3.575	3.502	3.611	3.589	3.802

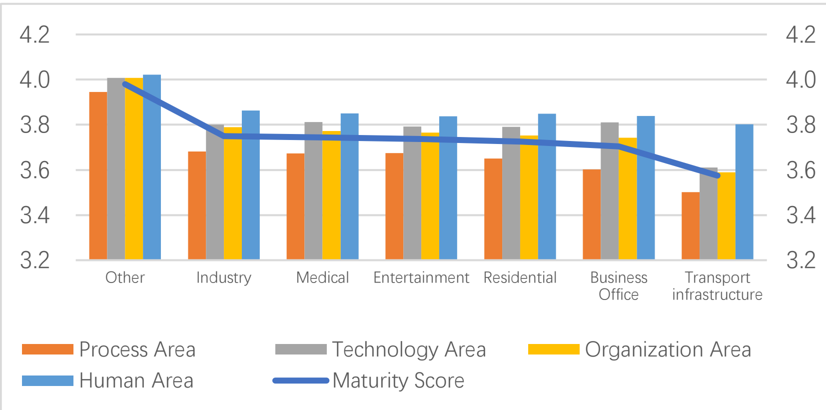

Figure 4.7 Comparison of maturity score in different Project Types

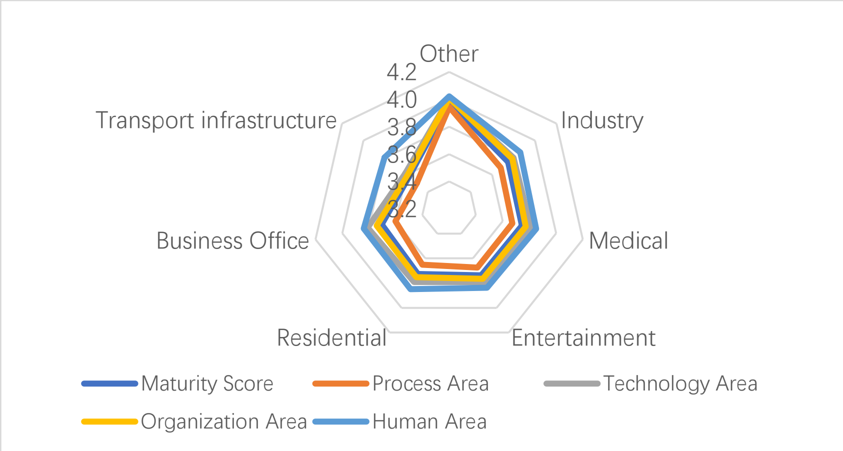

Figure 4.8 Comparison of maturity score in different Project Types

Analysis by One-Way ANOVA showed that the project type variables were significantly related to the evaluation results of P2 “BIM full life cycle implementation” and P6 “Response and Implementation of BIM policy”. Among them, the four projects that belong to the “Other” type are large-scale municipal engineering projects, including water conservancy facilities, power facilities, and bridges. On the one hand, they all responded positively to the BIM policy. On the other hand, these four projects are also pilot projects for BIM implementation throughout the life cycle. The higher maturity score indicates that BIM technology is better applied in large-scale projects and it also reflects the positive impact of government enforcement on BIM implementations. For these municipal projects, which are also pilot projects for BIM implementations, government agencies may intervene in the implementation of various emerging technologies such as BIM. The results show that the intervention of government departments, whether they are in the form of industry regulation or individual project intervention, may have an impact on the implementation attitudes and behaviors of the project owners and other participants, and thus affect the Project BIM Implementation Maturity.

It is worth noting that the "transport infrastructure" project has a low maturity score. The reason for this is related to the characteristics of transportation infrastructure projects such as long construction period, large number of involved professionals, many parties involved, obvious construction sequence, huge coordination workload, and unpredictable factors.

4.4.3 Analysis of BIM maturity in different Contracting Mode

The projects surveyed are classified into different contracting mode as Design-Build (DB), Engineering. Procurement and Construction (EPC) and Design-Bid-Build (DBB). The comprehensive scores of maturity and the scores of each area are shown in Table 4.19. Figure 4.20, Figure 4.21. It can be seen from this that the degree of BIM maturity shows a certain degree of difference depending on the contracting mode. From the perspective of comprehensive maturity scores, projects under the Design-Build (DB) and Engineering General Contracting (EPC) mode have higher scores and are all at Level 3 of maturity, "BIM Implementation Management Level (2.5-3.75 points)". The DBB mode project score is relatively low. From the perspective of various fields, Process area and organization area show great difference, in which the DBB score is low. However, the scores of other areas in each mode have little difference.

Table 4.16 Comparison of maturity score in different Contracting Modes

Project Contracting Mode	Quantity	Maturity score	Score of each area			
			Process Area	Technology Area	Organization Area	Human Area
Design-Build (DB)	13	3.793	3.789	3.775	3.812	3.829
Engineering General Contracting (EPC)	27	3.774	3.742	3.784	3.805	3.849
Design-Bid-Build (DBB)	23	3.555	3.383	3.730	3.583	3.844

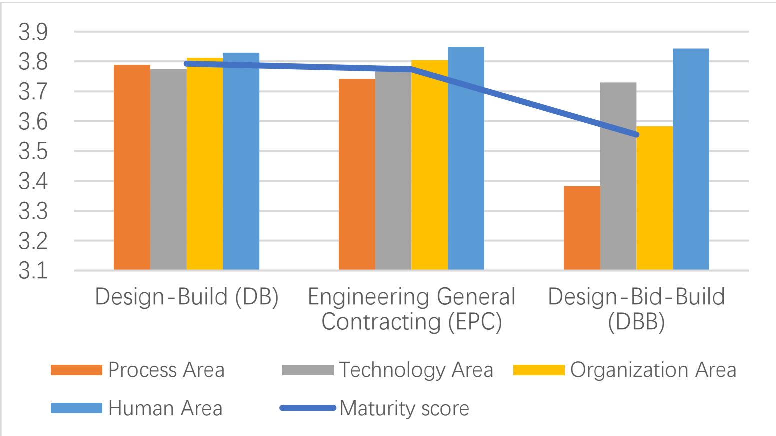

Figure 4.9 Comparison of maturity score in different Contracting Modes

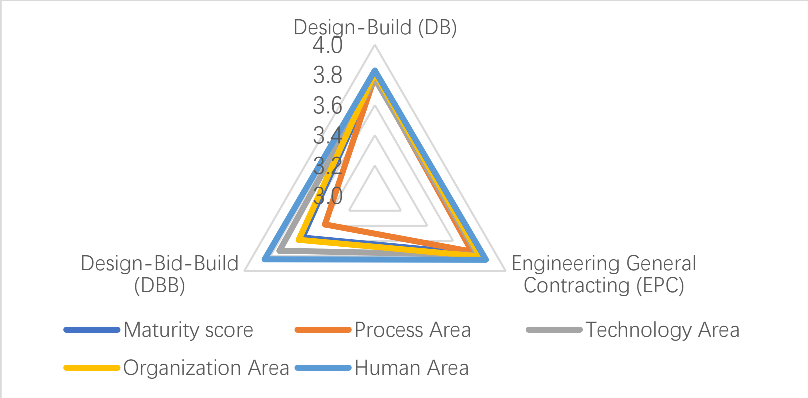

Figure 4.10 Comparison of maturity score in different Contracting Modes

According to the One-Way ANOVA analysis, the project contracting mode variables are significantly related to the P3 " Coordination and transmission of the models ", O1 " Development of Contracts of BIM Related Rewards and Risks Allocations" and O3 " BIM Team Stability " evaluation results. It is not difficult to find out why, in Design-Build (DB) and Engineering General Contracting (EPC) mode, design and construction are integrated and work together to improve the integration and efficiency of BIM at all stages of design and construction, and then improve the project BIM maturity.

4.4.4 Analysis of BIM maturity in different Project Investment Scale

The surveyed projects are categorized according to the scale of investment, with the investment amount of 100 million yuan and 1 billion yuan divided into extra large, large and medium-sized projects. After the classification, the comprehensive scores of BIM maturity and the scores of each area are shown in Table 4.20 and Figure 4.22 and Figure 4.23. It can be seen that BIM maturity is also different for construction projects with different investment scales. The comprehensive scores of maturity are ranked from extra large to large, large and then to medium-sized. The larger the scale, the more mature their BIM implementations are. The maturity score of extra large projects is 3.816 points, which is in the level 4 integration level of BIM maturity. The large-scale projects and medium-sized projects were 3.692 points and 3.599 points respectively, both at level 3. From the perspective of each area, the four areas have shown consistency, that is, the greater the scale of project investment, the higher the maturity score in each area.

Table 4.17 Comparison of maturity score in different Investment Scale

Investment	Quanti	Maturity	Score of each area

Scale	ty	score	Process Area	Technology Area	Organization Area	Human Area
Extra large	19	3.816	3.728	3.893	3.878	3.92
Large	23	3.692	3.622	3.746	3.705	3.852
Medium	21	3.599	3.523	3.665	3.612	3.758

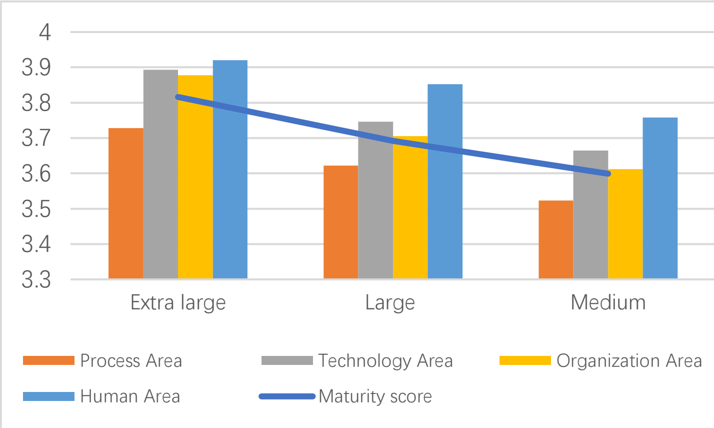

Figure 4.11 Comparison of maturity score in different Investment Scale

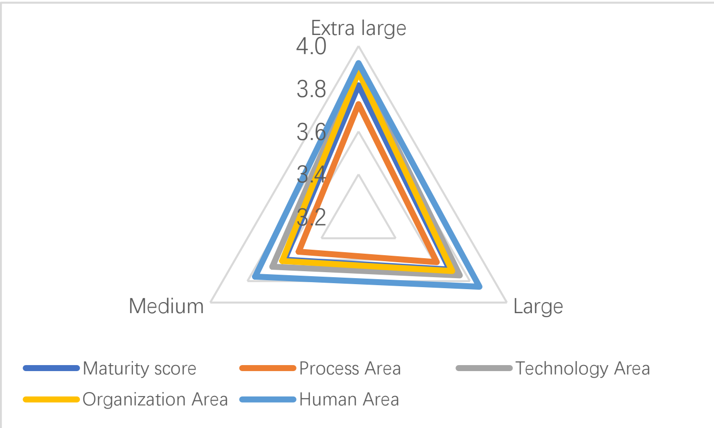

Figure 4.12 Comparison of maturity score in different Investment Scale

Through One-Way ANOVA analysis, the project investment scale variables are significantly related to the evaluation results of P1 " BIM Execution Plan", T1 " BIM Functions Adoption and Software Selections ", T2 " BIM Relating Hardware Implemented ", O2 "Senior Management Support", and H4 " BIM roles and Responsibilities". From this, it can be seen that the greater the investment scale of the project, the more attention it attaches to the formulation and implementation of the BIM plan and the overall layout. Moreover, we also see that the greater the project investment, the greater the investment in software and hardware, and the more management support, which has brought about an increase in the project BIM maturity score.

4.4.5 Analysis of BIM maturity in different BIM Implementation Mode

The surveyed projects are classified into the owner-driven and the non-owner-driven mode. The number of projecs, maturity score, and scores of each area are shown in Table 4.21 and Figure 4.24. According to the results, the maturity of the project BIM implementation under the owner- driven mode is slightly higher than that of the non-owner-led model, but the difference is not significant, and the difference mainly comes from the organizationarea. Other areas have similar scores and no significant differences.

Table 4.18 Comparison of maturity score in different BIM Implementation Mode

BIM Implementation Mode	Quantity	Maturity score	Score of each area			
			Process Area	Technology Area	Organization Area	Human Area
Owner-driven	40	3.714	3.632	3.773	3.767	3.85
Non-Owner-driven	23	3.671	3.599	3.746	3.655	3.832

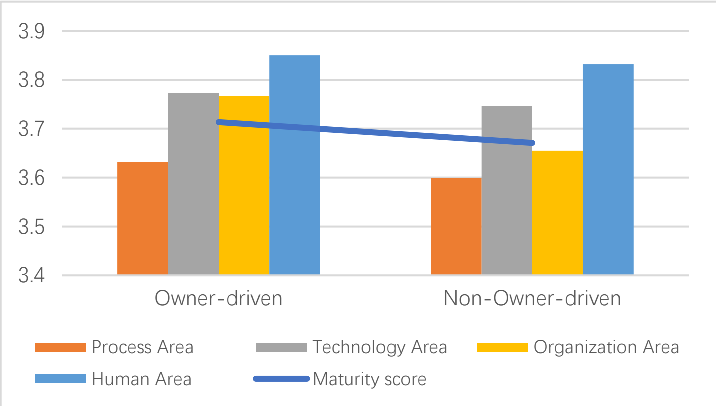

Figure 4.13 Comparison of maturity score in different BIM Implementation Mode

Through One-Way ANOVA analysis, the project BIM implementation model variables are significantly related to O1 " Development of Contracts of BIM Related Rewards and Risks Allocations " and O4 "BIM Communication " evaluation results. This shows that under the owner-driven mode, the owner can give more support in promoting BIM implementation cooperation among various participants of the project.

The owner-driven implementation mode can give full play to the maximum benefit and value of BIM technology. On the one hand, it is because this mode has played the main function of BIM, that is, it basically implements the implementation of BIM in the whole life cycle of the project. On the other hand, because the owner has absolute control over the entire project implementation process and may require the project parties to use BIM technology to assist the management of the project's entire process, this mode has greater scope for promotion. It is further verified that the owner side has been increasingly regarded as the most important beneficiary of project BIM implementations (Eadie et al. 2013; Lee et al., 2012).

5 Research Conclusions and Prospects

5.1 Research Conclusion

In this paper, based on the existing research results of BIM maturity evaluation and the Chinese context, the indicators for BIM maturity in Chinese construction projects are identified, and the weights and maturity ratings of each index are defined, and then BIM maturity evaluation model for Chinese construction projects is comprehensively constructed. Through investigating the construction projects of BIM technology applied in Shanghai, the empirical verification of the theoretical model was constructed. Descriptive and statistical data analysis methods were comprehensively used to analyze the empirical results. The main research work and conclusions are as follows:

(1) Literature research, theoretical deduction, and other research methodologies have been used to construct a theoretical model for evaluating BIM maturity in Chinese construction projects. The model includes four areas (Process area, Technology area, Organization area, and Human area) and 19 dimensions; Through Analytic Hierarchy Process, we determine the weight of each evaluation index by means of expert scoring; The maturity level is divided into five levels (Initial leve, Definable level, Management level, Integrated level, Optimization level. Through empirical research, it is verified that the theoretical model constructed in this paper is reasonable in structure, with good scientificity and operability.

(2) An empirical study of the appraisal of BIM maturity in Shanghai construction projects was conducted to verify the validity and reliability of the model. At the same time, the BIM implementation maturity status of the surveyed projects in different areas and dimensions was revealed, and then we compare the differences in project BIM maturity levels under different project types, different project contracting mode, different project investment scales, and different BIM implementation modes.

This study finds that the project type “Traffic Infrastructure” projects have low scores, which is related to the complex structure of such projects and the difficulty of uniform management. For the project contracting modes, the project BIM maturity scores are higher in the design-build (DB) and Engineering. Procurement and Construction (EPC) modes. Among them, the scores in Process area and Organization area are significantly higher than those in the Design-Bid-Build (DBB) mode, whileTechnology and Humman area did not show significant differences. This is in line with the design and construction are integrated and work together under DB and EPC modes, which can more effectively improve the coordination and transmission of BIM information. With regard to the scale of project investment, the study found that the larger the investment scale, the higher its BIM maturity level, and it has a better performance in the formulation and implementation of BIM planning and high-level management support. As for the implementation mode, owner-driven construction projects can more effectively improve BIM maturity, especially in the organizational area. Under the leadership of the owner, all participating parties can cooperate more effectively and positively.

(3) For the construction projects, the BIM implementation maturity evaluation model proposed in this paper can be used to make an objective and comprehensive assessment of the current BIM technology implementation status, and scores based on the maturity rating and each analysis factor. We can understand the actual BIM implementation situation of the project and then to identify the path and measures for the project to improve BIM maturity level. Moreover, the process of evaluation, whether for the government or the project participants, is a process of reviewing the current status of the various aspects of the project's BIM capabilities.

5.2 Research Innovation

(1) In terms of research ideas, this thesis starts with the project-level evaluation of BIM maturity, combining Chinese situation, and innovates the BIM maturity evaluation model for Chinese construction projects, making up for the deficiencies of existing research and proposing new, comprehensive, effective, accurate and practical BIM maturity evaluation model for Chinese construction projects, which will help to compensate for the current lack of a unified, scientifically-appraisal tool for BIM implementation construction projects. And at the same time, it will bring new development and enrichment in the field of construction industry.

(2) As for the construction project, the model can be used as the basis and benchmarking for self-assessment. Through the evaluation process and evaluation results, it helps the construction project to analyze the problems existing in the BIM implementation process, thereby helping to understand itself and strengthen its advantages. To make up for deficiencies, and to find ways and measures to improve BIM capacities and improve BIM effectiveness of construction projects, and gradually increase the level of BIM maturity

(3) In terms of research methodologies, this thesis has comprehensively used literature research, theoretical deduction, empirical analysis, qualitative and quantitative methods, and then choose field surveys, expert interviews, AHP, and correlation analysis, to provide support and foundation for the construction of theoretical model, acquisition of sample information, and analysis of data.

5.3 Research Prospects

The study of BIM maturity evaluation of Chinese construction projects is a continuous research process that combines actual analysis and theoretical analysis. Although that and it proposes a research framework for the evaluation of BIM maturity, it still has the following deficiencies:

(1) The improvement of capacity building and maturity is not static, it should be the long-term process of dynamic spiralling. However, due to the limited time span and effort of this study, it is impossible to track during the writing of the paper. Subsequent studies should continue to track each investigated project or select some key projects, so as to further explore and improve the path of continuous improvement of BIM maturity in Chinese construction projects.。

(2) The relevant data for the study on the maturity of BIM implementation in Chinese Construction Projects currently only comes from Shanghai. The applicability of related research conclusions in other areas in China still needs further investigation and verification. Subsequent studies can attempt cross-regional comparative analysis and explore the applicability of conclusions due to regional differences.

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Appendix A Chinese Construction Projects' BIM Implementation Maturity Evaluation Index Questionnaire

尊敬的专家，您好！

非常感谢您在百忙之中抽出宝贵的时间参加此项调查。

我是同济大学经济与管理学院工业工程专业的硕士研究生，目前正在进行关于**"中国建设工程项目BIM应用成熟度评估模型构建及实证分析"**的研究工作。**本调查旨在了解针对中国建设工程项目，各评价指标对于项目BIM应用成熟度评估的影响程度**。

本问卷调查数据仅作为本人的毕业论文学术研究之用，保证对您的反馈信息严格保密，绝不会对您及您所在的企业造成任何不利影响。

如您在问卷填写过程中有任何疑问，可通过以下方式随时与我联系：边桐，18817599335，biantong8888 @163.com，

完成本调查大约需要耽误您 5 分钟左右的宝贵时间，对您的合作表示衷心感谢！

1. 结合国内 BIM 应用情况，您认为以下五个领域的成熟度，对于评估中国建设工程项目 BIM 应用成熟度的影响程度如何？							
编号	名称	描述与解释	很重要	较重要	一般重要	不那么重要	完全不重要
P	流程领域	评估项目对 BIM 业务活动相关的资源、活动、工作流、服务模式等诸多相关内容进行管理、协调与改善的情况					
T	技术领域	评估项目在保持与提升软硬件配置、信息共享、信息准确、数据丰富、数据交换方式等方面的情况					
O	组织领域	评估项目各参建方组织层面的 BIM 战略部署情况，包括各参建方相互协调、领导力支持以及沟通方式和氛围					
H	人员领域	评估项目中 BIM 人员的技术经验、能力、对 BIM 的接受度以及工作中的分工安排、角色分配方面的情况					
2. **结合国内 BIM 应用情况**，您认为以下几项要素，对于评估国内建设工程项目 BIM 应用**流程领域**成熟度的影响程度如何？							

编号	名称	描述与解释	很重要	较重要	一般重要	不那么重要	完全不重要
P1	BIM 应用方案	项目制定 BIM 应用方案，明确 BIM 应用范围，确定 BIM 工作任务流程，确定各参与方之间的信息交换等内容的程度					
P2	BIM 全生命周期应用	BIM 在全生命周期各个阶段的应用情况，以及对实施规划要求的全部应用点的完成情况					
P3	模型的协调和传递	正向建模的程度，以及各阶段模型的衔接性程度，比如项目参建方能对各自的建设信息进行互联互通，实现共享					
P4	BIM 应用质量控制	项目中采取控制活动，以使 BIM 技术应用满足项目需求的程度					
P5	BIM 产品及服务的交付	项目按照模型等级深度（LOD）要求合理建模、完整交付的程度，以及是否制定 BIM 交付标准的程度，是否提供模拟分析报告、碰撞检查报告、工程量清单等各类 BIM 应用形成的其他成果文件的情况					
P6	BIM 政策响应和执行	项目响应及执行政策要求的程度，是否针对国内出台的一系列 BIM 政策比如标准制定、宣传培训和合同范本等进行积极响应和执行，以有效促进项目中的 BIM 应用推广					
3. **结合国内 BIM 应用情况，**您认为以下几项要素，对于评估国内建设工程项目 BIM 应用**技术领域**成熟度的影响程度如何？							
编号	名称	描述与解释	很重要	较重要	一般重要	不那么重要	完全不重要
T1	BIM 软件	BIM 软件符合标准与应用需求的程度，包括是否能满足设计、施工与运维的信息传递需求、是否能与其他 BIM 软件进行交互等。					
T2	BIM 硬件	硬件配置的程度，以及能实现实时的 BIM 信息访问+动态更新的程度					
T3	数据丰富性与准确性	BIM 应用过程中，数据和信息的准确度，模型深度是否符合要求					
T4	BIM 协同管理平台	项目对 BIM 协同管理平台的开发与应用程度，是否对协同方法作出定义，为各参建方提供了信息共享和传递的条件					
T5	基于 BIM 的研发	项目根据自身需求对现有 BIM 工具进行合理再开发的程度，包括 BIM 深度应用的软件平台的研发、BIM 相关软件功能的改进和完善					
4. **结合国内 BIM 应用情况，**您认为以下几项要素，对于评估国内建设工程项目 BIM 应用**组织领域**成熟度的影响程度如何？							
编号	名称	描述与解释	很重要	较重要	一般	不那么	完全

					重要	重要	不重要
01	合同与契约	项目组织方式明确，BIM 由建设单位主导，各参建方职责清晰，合同约束力强，各方严格按照合同执行，保证了 BIM 技术顺利实施并实现预期目标					
02	高层管理支持	项目高层管理者对 BIM 的认知及支持程度					
03	BIM 团队稳定性	项目灵活调整 BIM 团队组织架构，保证较高技术水平的 BIM 团队的程度					
04	BIM 业务沟通交流	项目根据需求，召开 BIM 相关的专项会议的频率和程度					
		项目根据需求，召开 BIM 相关的专项会议的频率和程度；项目成员的沟通方式全面性和多样性程度，比如面对面直接沟通、电话、微信 QQ 等社交软件、邮件、正式文件等					
5. **结合国内 BIM 应用情况，**您认为以下几项要素，对于评估国内建设工程项目 BIM 应用**人员领域**成熟度的影响程度如何？							
编号	名称	描述与解释	很重要	较重要	一般重要	不那么重要	完全不重要
H1	BIM 人员能力	BIM 人员经验、技术能力、知识丰富度等综合能力满足要求的程度					
H2	BIM 接受度	参建方对于 BIM 带来的工作方式、管理方式等变化的接受程度					
H3	教育培训	项目在开展过程中，人员定期接受 BIM 知识和技能培训的程度					
H4	BIM 角色和职责	项目设置了 BIM 技术负责人和技术工程师，且其建设管理和 BIM 技术应用经验，能保证 BIM 技术应用和项目实施结合的程度					

再次感谢您的大力支持！

如您认为指标体系有需要更改和完善的地方，请提出您宝贵的意见：

Appendix B Chinese Construction Projects' BIM Implementation Maturity Questionnaire

尊敬的先生/女士，您好！

我是同济大学经济与管理学院工业工程专业的硕士研究生，该调查问卷**旨在了解中国建设工程项目BIM应用方面的现状做法，同时为提出中国建设工程项目BIM应用成熟度评估模型的构建奠定基础**。请根据您所在项目的实际BIM应用情况，回答本问卷中的问题。

本问卷调查数据仅作为本人的毕业论文学术研究之用，保证对您的反馈信息严格保密，绝不会对您及您所在的企业造成任何不利影响。

如您在问卷填写过程中有任何疑问，可通过以下方式随时与我联系：边桐，18817599335，biantong8888@163.com

填写本问卷大约需要耽误您3-5分钟的宝贵时间，再次对您的合作表示衷心感谢！

一、项目基本信息	
1、您隶属于项目的：☐业主方 ☐设计方 ☐施工总包方 ☐.施工分包方 ☐咨询/监理方 ☐其他______	
2、**您在项目中担任的职位：**☐项目经理/总工程师 ☐BIM 经理 ☐BIM 工程师 ☐其他______	
3、项目名称	______
4、项目类型	☐住宅 ☐商业 ☐工业 ☐办公 ☐文化 ☐教育 ☐体育 ☐旅游 ☐医疗卫生 ☐交通基础设施 ☐保障性住房 ☐其他______
5、项目投资额	______
6、项目投资属性	☐公共项目(包括政府投资项目、公私合营项目) ☐私有项目
7、承发包模式	☐设计-建造（DB） ☐工程总承包（EPC） ☐平行发包（DBB） ☐施工总承包 ☐其他______
8、BIM 应用模式	☐业主方驱动模式（包括自行应用和委托第三方机构） ☐设计方驱动模式 ☐施工方驱动模式
9、BIM 管理方法	☐业主主导、专业咨询、各方参与模式 ☐业主牵头、各方参与模式 ☐BIM 总包实施、各方配合、项目使用模式 ☐参与方自主实施模式 ☐第三方咨询机构作为 BIM 总包 ☐第三方咨询机构协助业主开展相关 BIM 技术工作

<table>
<tr><td></td><td colspan="7">☐其他____________</td></tr>
<tr><td>10、BIM 应用阶段</td><td colspan="7">☐初步设计 ☐施工图设计 ☐施工准备 ☐施工实施 ☐运维</td></tr>
<tr><td colspan="8">二、BIM 应用成熟度情况调查表</td></tr>
<tr><td rowspan="2">BIM 应用领域</td><td rowspan="2">序号</td><td rowspan="2">请根据您的自身经历,给出项目中以下 BIM 应用情况的符合程度</td><td colspan="5">完全不符合←中立→非常符合</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td rowspan="12">流程领域</td><td>P1-1</td><td>项目建立了完整的 BIM 技术应用标准与实施规划，用以规范与指导项目整体的 BIM 应用</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>P1-2</td><td>项目在初期即设立了明确可行的 BIM 应用目标，比如通过 BIM 技术的应用，减少工程返工率 x%，实现成本降低 x 万元，加快设计进度 x 个月</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>P2-2</td><td>完成实施规划要求的全部应用点</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>P3-1</td><td>项目采用正向建模，即正向三维设计</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>P3-2</td><td>项目参建方各自的模型信息能够进行互联互通，实现共享，减少了模型传递间的的转化信息丢失。</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>P3-3</td><td>项目中对数据信息修改等信息请求做出及时响应和反馈</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>P4-1</td><td>各阶段 BIM 模型由各专业负责人进行初审，再由其他参与方对成果进行进一步确认；最后提交 BIM 总协调方进行最终审核，形成审核报告</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>P4-2</td><td>BIM 实施方按审核意见对模型进行调整，并对相关问题作出回复，直至通过最终审核</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>P5-1</td><td>各参建方了解 BIM 模型深度的要求，能够按照上海市建筑信息模型技术应用指南的规定与客户的深度要求进行建模，同时不过度建模</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>P5-2</td><td>项目对不同 BIM 应用点的交付成果、交付时间及文件要求作出了明确的规定</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>P5-3</td><td>BIM 产品和服务的交付成果达到质量要求和标准</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

	P5-4	项目提供模拟分析报告、碰撞检查报告、工程量清单等各类 BIM 应用形成的其他成果文件					
	P6-1	项目对 BIM 政策、标准与相关推广活动进行了积极的响应与执行					
技术领域	T1-1	项目各参建方给予 BIM 软件充足的投入，合理配置 BIM 软件					
	T1-2	项目有明确的数据格式标准，对所需的 BIM 建模、应用和协同管理软件进行选型					
	T1-3	软件功能充分满足建模需求					
	T2-1	给予 BIM 硬件充足的投入，合理配置 BIM 硬件设施设备					
	T2-2	硬件连通性强，能实现实时的 BIM 信息访问+动态更新					
	T3-1	BIM 应用过程中，项目参与者在对 BIM 模型提供信息时注意数据的权威可靠性					
	T4-1	项目采用了 BIM 协同管理平台，且对协同方法作出定义，为各参建方提供了信息共享和传递的条件					
	T5-1	项目根据自身需求，对现有 BIM 软件平台进行自主研发					
	T5-2	项目根据自身需求，对现有 BIM 软件功能进行改进和完善					
组织领域	O1-1	各参建方职责清晰，合同约束力强，各方严格按照合同执行，保证了 BIM 技术顺利实施并实现预期目标					
	O1-2	BIM 成果的产权和归属有明确的规定和划分					
	O1-3	在 BIM 模型传递和应用方面，各参建方间相互信任和配合					
	O2-1	各参建方高层管理人员对 BIM 有较深入的认知,对于 BIM 技术在项目中的推广应用持积极与支持态度					
	O3-1	项目减少 BIM 人员流动，同时灵活调整 BIM 团队组织架构，保证较高技术水平的 BIM 团队					

	O4-1	项目中定期召开专项例会，给予项目参与人员充足的沟通与交流					
	O4-2	项目成员的沟通方式较全面和多样，比如面对面直接沟通、电话、微信 QQ 等社交软件、邮件、正式文件等					
人员领域	H1-1	BIM 人员经验、技术能力、知识丰富度等综合能力能够满足项目需求					
	H2-1	项目中员工对于 BIM 理念与技术普遍能够乐观的接纳，抵触情绪较小					
	H3-1	项目 BIM 人员定期接受 BIM 知识和技能培训					
	H4-1	项目设置了 BIM 技术负责人和 BIM 技术工程师，他们对项目 BIM 相关的工作任务、决策、BIM 目标的控制与实现情况负责，拥有明确的岗位职责要求					