APPLICATION OF BIM IN BUILDING INDUSTRIALIZATION PROCESS IN CHINA

By

NAN XIE

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To my family and friends

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LIST OF ABBREVIATIONS

AEC	Architecture/Engineering/Construction.
BIM	Building Information Modeling
BIM	Building Information Modeling
CBIMS	Chinese Building Information Modeling System
GSA	General Services Administration
IFC	Industry Foundation Classes
PBS	Public Buildings Service
PBS-ITS	Public Buildings Information Technology Services
ROI	Return on Investment

Abstract of Thesis Presented to the Graduate School
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Nan Xie

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With the *Assessment Standard for Industrialized Building in China* issued and implemented on Jan. 1st, 2016, the speed of building industrialization in China will be accelerated and the traditional building construction method will be gradually substituted for a new industrialized method. Therefore, the new approach to building industrialization is a key for the whole process.

Industrialized building does not include only pre-fabrication but it is a wide scope of building methods. Pre-fabricated components, modular structure and off-site construction all belong to industrialized building. Industrialized buildings can bring many benefits to the building industry, such as high efficiency, high quality, pollution reduction and so forth.

Building information modeling (BIM) is a process involving the generation and management of digital representations of physical and functional characteristics of buildings. Based on the concept of life-cycle management, BIM can deliver information from architecture to engineering and construction through 3D modeling process. On the other hand, industrialized buildings have simple, modular, pre-fabricated features, the use of BIM technology can be relatively easy to create modular design and components library, which reduces the difficulty of BIM modeling work.

Building information modeling (BIM) was applied and developed very early in the US, and now is a main stream of information technology development in the construction industry, while BIM technology is at a starting point in China. Building construction with 2D drawings is still the most popular method, and 3D modeling is probably only applied on a small part of the whole project.

This research explored the future potential of BIM implementation in industrialized building, and in addition, focused on the benefits that BIM could bring in and the obstacles to BIM implementation, and evaluated the best approach to the application of BIM. The results indicated that BIM technology and building industrialization are both beginning to be implemented in China, and most people have the positive attitude to the potential development in future. BIM can bring many benefits, such as visualization, code review, clash detection, and so on. The key elements of implementing BIM in building industrialization consist of components standardization, technical guidance, governmental support, and coordination with different departments.

CHAPTER 1
INTRODUCTION

1.1 Overview

With rapid economic development, the pace of urbanization is also accelerating in China. But the housing supply and demand is out of balance, which has become a big issue in the urbanization process. According to the government new urbanization blueprint (2014-2020), the population will increase 10% in 2020, and low-rent housing and public rent housing will be strongly promoted. In order to meet the sustenance needs for people who will move in small towns or cities, more and more housing and public commercial buildings will be encouraged. Additionally, the environment pollution that traditional building construction methods brings in has caused many serious outcomes including worse air quality, polluted water resource, and even harmful noises from building construction. The best way to remove these obstacles in the urbanization process is to change the traditional building construction method to a new building model. Building industrialization will solve not only the fast-construction-needed problem but also the environmental pollution problem.

Industrial building does not include only pre-fabrication but also a wide scope of building methods including simple and even traditional prefabrication methods (Mirsaeedie 2009). Pre-fabricated components, modular structures and off-site construction all belong to industrialized building. Also from the economic perspective, the cost of industrial building is less than the traditional cast-in-place building construction, according to the comparative analysis from the life cycle building costs using mathematic modeling (Jing and Runze 2016).

Building information modeling (BIM) is a process involving the generation and management of digital representations of physical and functional characteristics of buildings. Based on the concept of life-cycle management, BIM can deliver information from architecture

to engineering and construction through 3D modeling process, ultimately help to make feasible design, reasonable schedule, efficient construction and effective management. BIM was applied and developed very early in US, and now is a main stream of information technology development in the construction industry, while BIM technology is at a starting point in China. Building construction with 2D drawings is still the most popular method, and 3D modeling is probably only applied on a small part of the whole project.

Industrialized building has simple, pre-fabricated, modular features; BIM technology can be relatively easy to implement modular design and to organize component libraries, which reduces the difficulty of BIM modeling work. Building industrialization also requires optimizing the whole industry chain, including upstream product development and downstream construction materials and even production sales, which can coincide with the feathers of BIM concept. In addition, BIM technology can bring many benefits during construction process, such as space optimization, reducing errors and omissions in collision, simulation of construction process and project cost control, and so forth.

1.2 Aim and Objectives

The aim of this study is to analyze the role of BIM in building industrialization in China as well as explore the future potential of BIM application in industrialized buildings. The following are the objectives for this paper: 1) Investigate the status of building industrialization and BIM technology in China; 2) Identify the benefits and the role of BIM technology in industrialized buildings; 3) Figure out the key elements that implement BIM in industrialized building projects; 4) Analyze the obstacles that are met in practice and find out how to remove them.

1.3 Research Method

The research methodology consists of two distinct phases which are survey and case study. The survey investigated the developing situation of building industrialization and BIM technology. The answers collected from the survey showed the direction of BIM application as well as the anticipated obstacles to future development.

After collecting data through the survey and analyzing the data, two case studies are conducted: a case study of comparing an industrialized project with a traditional project; another case study of analyzing a project with BIM assisted. The case study is analyzed from some key perspectives that summarized from the preceding survey.

1.4 Organization of Research

The study has six chapters. Chapter 1 overviews and outlines the purpose and background of the paper and states the research methodology. Chapter 2 provides a literature review that presents earlier research related to building industrialization and development of BIM in China, its history, limitations and potential solutions, as well as the concept of building industrialization and its benefits in building construction. Chapter 3 presents a discussion of the research objectives and methods and describes the specific methods and procedures followed in conducting the research. Chapter 4 analyzes the survey data and answers some questions in chapter 1. Chapter 5 studies two cases based on some key perspectives that summarized from the preceding survey. Chapter 6 summarizes the conclusion of this research in the application of BIM in building industrialization and puts forward to the potential marketing and gives the recommendations to future research.

CHAPTER 2
LITERATURE REVIEW

2.1 Overview

This literature review introduces an overview of building information modeling (BIM) in United States, and in China and then identifies the purposes and features of building industrialization and presents a brief history of building industrialization development in China. The obstacles that impede BIM application in industrialized buildings as well as the benefits that combine BIM with building industrialization are discussed subsequently. Finally, new direction and approaches that make use of BIM technology in building industrialization in China are proposed.

2.2 The Implementation of BIM in the US

BIM is a technology that leads the building industry to a higher level and is a technology revolution that follows the transformation from hand drawing to computer drawing. BIM is a specific application of information modeling and a method that can create and take advantage of digitalization technology to design, build, and operate building construction through the whole life cycle.

BIM technology went through many phases from being proposed to being improved gradually, then to be generally accepted in construction industry. The application of BIM was initially led by a couple of developed countries, such as Finland, Norway, Singapore and United States (Laiserin and Wang 2013). After many years' of development, BIM is now in the main stream of information technology development in the US construction industry.

2.2.1 Political Support for BIM

In United States, the General Services Administration (GSA) established the National 3D-4D-BIM Program in 2003 through the Public Buildings Service (PBS). Since then, this

program has developed into a cooperative relationship between the Public Buildings Information Technology Services (PB-ITS) and PBS, through its Governance Board (GSA 2016). According to GSA (2016), the following are the focused areas of the GSA National 3D-4D-BIM Program:

- Requiring all major projects and GSA business lines to adopt BIM as their main technology by establishing policies.
- Providing expertise support and resources for ongoing pilot projects to incorporate 3D, 4D, and BIM technologies
- Giving help and guidance for subsequent use of BIM data in maintenance and facility management
- Evaluating industry readiness and technology maturity
- Developing solicitation and contractual language for 3D-4D-BIM services
- Cooperating with BIM vendors, other federal agencies, professional associations, open standard organizations, and academic/research institutions
- Establishing a relationship between BIM Champions and GSA
- Issuing the BIM Guide Series: BIM Guide 01- 08

2.2.2 Research and Construction Practices in BIM

The 3D-4D-BIM program provided a base foundation for the development of BIM in political support and guidelines manual. Apart from the political encouragement, research in BIM as well as the associated construction practices both promoted BIM use in US. Through the collection of data from 32 major projects, Stanford University's Center for Integrated Facilities Engineering reported the following benefits of BIM (CRC Construction Innovation 2007):

- Up to 40% elimination of unbudgeted change,
- Cost estimation accuracy within 3% as compared to traditional estimates,
- Up to 80% reduction in time taken to generate a cost estimate,
- A savings of up to 10% of the contract value through clash detections
- Up to 7% reduction in project time.

The return on investment (ROI) analysis is also an important factor to evaluate the application of BIM. ROI indicates the gain anticipated through earning revenue against the cost of the investment.

$$ROI = Earning/Cost \qquad \text{(Equation 1-1)}$$

ROI is used to assess many types of corporate investments, from research and development projects to training programs to fixed asset purchases (Autodesk 2007). In general, ROI analysis focus on six main areas in building industry: 1) improved project achievement such as reduced RFIs (request for information); 2) better communication between different departments due to 3D visualization; 3) increased personnel productivity; 4) higher possibility to win projects; 5) lifecycle management trough BIM; 6) initial investment such as update software and staff training (McGraw-Hill Construction 2008).

According to a case study by Azhar (2011) who collected the detailed cost data for 10 projects from Holder Construction Company, Atlanta, GA to analyze the ROI of using BIM on construction projects (see Table 2-1).

As shown in the Table 2-1, the BIM ROI for different projects varied from 140% to 39,900%. On average, it was 1,633% for all projects and 634% for projects without a planning or value analysis phase. The probable reason for the large data spread is the varying scope of BIM in different projects (Azhar 2011). However, the case study can prove that all the 10 observed projects saved money due to BIM.

In order to further compare projects with BIM and without BIM, Giel and Issa (2013) conducted case studies and collected the correlated data. Six projects were selected from Company X and were divided into three sets. Each set consisted of a BIM-assisted project and a

similar project constructed without BIM. The comparison of project parameters are shown in Table 2-2, and ROIs are shown in Table 2-3.

Table 2-1. Building Information Modeling Return on Investment Analysis (Adapted from Azhar 2011)

Year	Cost ($M)	Project	BIM cost ($)	Direct saving	Net BIM saving BIM ($)	BIM ROI
2005	30	Ashley Overlook	5,000	(135,000)	(130,000)	2600
2006	54	Progressive Data Center	120,000	(395,000)	(232,000)	140
2006	47	Raleigh Marriott	4,288	(500,000)	(495,712)	11560
2006	16	GSU Library	10,000	(74,120)	(64,120)	640
2006	88	Mansion on Peachtree	1,440	(15,000)	(6,850)	940
2007	47	Aquarium Hilton	90,000	(800,000)	(710,000)	780
2007	58	1515 Wynkoop	3,800	(200,000)	(196,200)	5160
2007	82	HP Data Center	20,000	(67,500)	(47,500)	240
2007	14	Savannah State	5,000	(2,000,000)	(1,995,000)	39900
2007	32	NAU Sciences Lab	1,000	(330,000)	(329,000)	32900
Total all types			260,528	4,516,620	4,256,092	1633%
Total without planning/VA phase			247,440	1,816,620	1,569,180	634%

Note: CD = construction documentation; D = design; F = feasibility analysis; FM = facilities management; GSU = Georgia State University; NAU = Northern Arizona University; P = planning; PC = preconstruction services; ROI = return on investment; VA = value analysis.

Table 2-2 shows the numbers of change orders and RFIs for the projects. Table 2-3 shows the estimated ROI of Project A, C, E, and the anticipated ROI of Project B, D, F. The ROI for using BIM on Project A, C, and E can be estimated through calculating the saving cost of change orders and RFIs, and then the ROI of indirect savings for Project B, D, and F can be anticipated

by using the previously calculated ROI as a model rubric. The case study confirmed the high return on investment of BIM in a midsized general contracting company (Giel and Issa 2013).

Table 2-2. Project Parameters Comparisons (Adapted from Giel and Issa 2013)

Project parameter	Case Study One		Case Study Two		Case Study Three	
	Project A (Pre-BIM)	Project B (BIM)	Project C (Pre-BIM)	Project D (BIM)	Project E (Pre-BIM)	Project F (BIM)
Total number of change orders	10	6	21	11	49	31
Total number of change orders preventable by BIM	3	0	4	1	11	2
Total number of RFIs	79	52	350	112	651	369
Number of VDC discovered during conversion of plans to BIM	__	9	__	17	__	57
Number of field RFIs discoverable by using BIM during construction	23	13	142	49	210	86

Note: VDC=Virtual Design and Construction

Table 2-3. ROI Comparisons (Adapted from Giel and Issa 2013)

	Project A (BIM ROI)	Project B (ROI of Indirect Savings)	Project C (BIM ROI)	Project D (ROI of Indirect Savings)	Project E (BIM ROI)	Project F (ROI of Indirect Savings)
Total estimated savings	$48,723	$51,365	$254,635	$123,330	$3,662,009	$887,700
Cost of BIM	$35,640	$44,220	$53,510	$58,995	$208,788	$222,000
Net BIM savings	$13,083	$7,145	$201,125	$64,335	$3,453,221	$665,700
ROI	36.7%	16.2%	376%	109%	1,653.9%	299.9%

2.2.3 BIM Adoption in AEC Industry in the US

Many factors can influence the adoption of BIM in AEC industry. The top factors are top management support, perceived benefits and external forces (Liu et al. 2012). The attitude of top managers determines whether BIM can be adopted by companies from the perspective of internal

readiness. Perceived benefits, such as quality improvement, improved accuracy, improved access to information, promote BIM to be applied in AEC industry from the economic perspective. External forces from cooperating parties as well as competitors compel to adopt BIM for the future development to some extent.

The benefit of clash detection through BIM has been recognized by the whole building industry. In addition, managing multiple works from different trades' model can be also coordinated by BIM technology (Giel et al. 2016). Piles of files generated during the process of coordination with different trades can be replaced by the automation tool of BIM, which helps general contractor select subcontractor more effectively as well as encourages subcontractors to compete more healthily.

With the rapid adoption of BIM in AEC industry, the concept of cloud-based BIM performance score system was proposed (Liu et al. 2016). Based on the concept, BIM users can share BIM data in one cloud-based space and assess BIM performance from 6 parameters as well as compare BIM performance with industry peers. From the aspect of BIM model, BIM performance can be evaluated on quality, accuracy, usefulness and economy; from the aspect of BIM process, the cloud-base system consists of productivity and effectiveness.

2.3 Status of BIM Technology in China

The current situation of BIM development in China can be discussed from many aspects including government, design team, construction contractor, operation and maintenance, software development, and technology research, (Zhang 2011) as follows:

- Government: Rules and regulations are blank.
- Designing team: 3D modeling is only used in a few irregularly shaped and complicated building structures.
- Construction contractor: Lack of technical employees and high-configuration devices.

- Operation and Maintenance: BIM cannot be applied and used.
- Software development: Promoting BIM at a large-scale range and cooperating with Autodesk
- Technology research: Tsinghua University's research on Chinese Building Information Modeling System (CBIMS); building modeling transition based on Industry Foundation Classes (IFC) standards.

In terms of building industrialization, BIM application is still focused on the design phase and a few special projects, and sitting on the fence. According to the report from Vanke Corporation (2012), Vanke had built a total of 7,010,000 square meters of industrialized buildings up till 2012, and the area of new industrial projects using BIM in 2012 is 2,722,900 square meters, accounting for 18.5% out of all the construction areas. Compared with the traditional construction, industrialized building reduces energy use per square meter by 20%, cut water consumption down by 62%, formwork and building waste decreased by 87% and 91% respectively. The results of Vanke's report stems from the accurate data management through BIM, therefore, BIM can push the real estate and even the whole building industry forward by translating building production into digital content. Nowadays, BIM technology has become the successful path to developing building industrialization in China.

2.4 Building Industrialization

Building industrialization is the process of reforming and improving traditional design, production, construction, installation, and operation management with the help of concurrent industry fabrication methods as well as to facilitate intensive integration and achieve the development of quality and maximum benefits (Wang et al. 2014). According to Hossein et al. (2013), Massive usages of prefabricated components that are produced and finished in a factory as well as the continuous assembly process are both part of building industrialization.

2.4.1 Purpose of Building Industrialization

The industrialization of construction has several purposes: increasing labor productivity, replacing manual labor with machines, accelerating the pace of construction, putting new projects into operation more quickly, reducing costs, and improving quality (The Great Soviet Encyclopedia 1979).

Industrialization is based on high capacity for reducing price and increasing quality and granting further accessing to more and more products for a wide scope of people. The main trend of building construction is industrialization, which can save time and cost as well as reduce the impacts on environment.

2.4.2 Features of Industrialized Building

Generally, industrialized buildings can be classified into six features (Wang et al. 2014): 1) continuity during producing; 2): components standardization; 3): process centralization; 4): organization highly informatization; 5): production assembly mechanization; 6) integration in fabrication and management. The fourth one, organization highly informatization, requires some technologies that can help transfer building practices into digital information and in reverse the digital information can guide building practices in right the direction.

2.4.3 Building Industrialization Development in China

1. The Beginning of Industrialization (1970's). In the 1970's, China cooperated with many developed countries including Japan. With the establishment of international relationships, China's foreign economic and technological exchanges began to perk up. After the end of the *Cultural Revolution* and the *Great Leap Forward* in 1976 that severely influenced the economic, culture and construction, a large number of residential buildings were in demand, and this demand had become one of the most urgent problems that needed to be solved. Therefore, the China Academy of Building Research referred to more than 100 building industrialization

standards in developed countries and then expanded and applied these standards to building construction in China (Building Committee 2014).

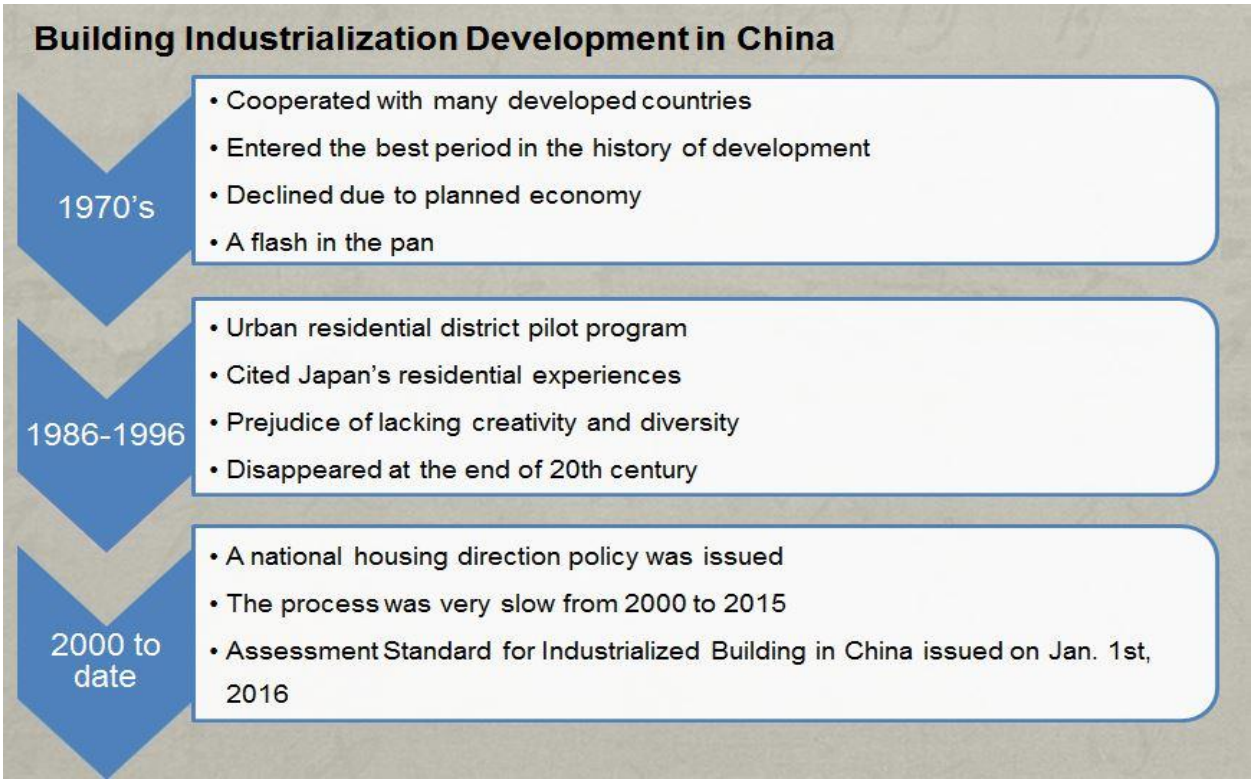

Figure 2-1. Building Industrialization Development in China. Created by Nan Xie on 09/30/2016.

The approach that a large number of repetitive components were prefabricated in factory accelerated the pace of development and was commonly thought the best way to provide better and more economical housing. During 1978 building construction set off a decade long industrialization movement, and proposed "three industrializations and one transformation" that is "design standardization, components factorization, construction mechanization and wall material transformation". During the movement, prefabricated big plate, light floor plate in framework, large-scale CMU took the place of the traditional brick and concrete structure building (Lang 2009). Chinese industrial buildings entered the best period in the history of development. However, due to China's strict implementation of the planned economy, industrialization mostly depended on the political guide rather than the free marketing economy.

The new building system cost much more than the traditional method, and government also did not establish the relevant encouraging policies to support building industrialization. The industrialization event was just a flash in the pan. As shown in Figure 2-1.

2. Trial model housing period (1986-1996). The Ministry of Building Construction in China started to carry out urban residential district pilot program during 1986 to 1996. The program adopted new technology, new system, and new production to build trial housing in appointed district. The research of urban housing situation led to the development of building industrialization during 1990 to 1993. The program cited Japan's residential experiences and focused on making new design theory, modular coordination and product integration as well as performance evaluation in pilot project, which provided theoretical foundation and created sufficient condition for the building industrialization. Unfortunately, the program did not last too long due to the prejudice against building industrialization. Many real estate companies misunderstood the concept of industrialization and thought it as "out-of-date" production that lacked creativity and diversity. The industrialization program gradually disappeared until the end of 20th century in China (Zhang 2004).

3. Recent building industrialization trend (2000 to date). At the beginning of the 21st century, a national housing direction policy was issued. However, from 2000 to 2015, the progress of industrial development of housing was very slow because technology and standards were lagging and backward. More importantly, building construction and design companies did not like to take part in the industrialization. However, with the "the evaluation standards of building industrialization" issued and applied in January in 2016, more and more relevant building companies and individuals began to pay attention to the new building methods. The standards firstly mentioned the terms of "prefabricated rate" and "assembly rate" as well as the

minimum requirements for the relevant rates. The process will embrace the best opportunity as well as experience a tough time and come across many obstacles during the implementation process (China News 2014).

2.5 The Obstacles of Impeding BIM Application in Building Industrialization

2.5.1 Building Industrialization Starts Late

With the restriction of production mode, technology level and promotion policy, prefabricated components were not produced in China until the 1970's. However, the industrial buildings that were composed of prefabricated floor plates were characterized by poor production and construction which resulted in the withdrawal of prefabrication technology from the building market. Generally speaking, the premise of building industrialization was unstable and weak, and additionally the building system and technology level in China lagged way behind other countries. (Xue 2015)

2.5.2 The Imbalance of Industrialization and BIM Development

One of most important prerequisite for building industrialization is large-scale production that depends on powerful industrialization support. The process of industrialization can be divided into three parts: initial, middle and advanced period (Hollis 1969). According to this standard, the United States completed industrialization and entered post-industrialization in 1955. Comparably, the GDP per capita in 2013 in China was around $ 6767 (National Bureau of Statistics of China), which means that China was still in the middle period of industrialization. The industrialization level could not support the development of BIM technology before the year of 2013.

2.5.3 The Contradiction between Enough Workforce and Deficient Technology Laborers

The building industrialization process in developed countries is usually influenced by human resources whatever the workforce deficiency at the beginning of the process or the

population restriction. In Australia, the building industry is pushed forward by the salary level of construction workers, building industrialization will help to reduce workforce cost and then reduce the total cost, finally improving market competition. The components that can be installed in construction sites all can be fabricated and assembled in factory in order to relieve work strength, to reduce construction time and to improve the production quality. However, the burden of workforce cost does not exist most of the time in China because of enough human resources, by contrast, the cost of developing BIM technology is relatively very high (Xue 2015).

2.5.4 Lack of Standards System Support

During the industrialization process BIM technology not only provides technical support for one single organization, but more importantly also collects the information from many groups and makes a seamless connection between these related groups. The seamless connection needs to be completed though a standard system. However, the standard system has not been established so far, and different standards of BIM are applied in different departments, which caused the disconnection between each individual phase. This situation easily results in disorder of the whole building industry and is harmful to the industrialization process.

2.6 Benefits of Applying BIM to Building Industrialization

Building industrialization is meaningful to the economic boom in China. The industrialization not only changed the traditional building construction method, but also reduced building cost as well as improved the production efficiency and quality. The benefits that applying BIM to building industrialization generates are as follows:

2.6.1 Unit Apartment Design System.

Most residential buildings in China are simple unit repetitive and every unit shape has the modular characteristic that is created by standards and then combined by the designer. The unit apartment can make BIM work easier and shop drawings faster. For instance, a real estate

developer required four different main unit types in one group of high-rise residential buildings. The designer just needed to establish four standard units in Revit and then combined the four units into different separate buildings (Ji *et al* 2013).

2.6.2 The Establishment of Components Pool in BIM.

Designer can make use of the material pool, prefabricated components pool and furniture pool that already in BIM to build a model, or even can establish a specific components library that is needed in one project and will be needed in the future projects. The characteristics of components pool are standardization, generalization, systemization, modularization and industrialization (Ji et al 2013).

2.6.3 BIM Professional Shop Drawing System.

Architectural design, structural design and MEP (mechanical, electrical and plumbing) design can use BIM technology. In addition, building performance analysis also can use BIM technology, such as day lighting analysis, energy consumption analysis, structure performance analysis and so forth. The best advantage of BIM design is that BIM can check components clashes to avoid future conflicts in the field. The BIM model can generate section plan automatically, which not only help to gets rid of rework but also avoid many probable mistakes as well (Urban Construction Theory 2014).

2.6.4 Construction Process Simulation.

The BIM model is a virtual building, in which the real building structure can be modeled and analyzed; the problems that may come out in the real site will be solved in advance, which will avoid rework and resource waste. Construction procedure also can be simulated in a 4D model with the time dimension added and to validate the order of construction process (Xiong 2012).

2.6.5 Construction Quantity Takeoff.

The quantity takeoff will be calculated once the model is completed, if the cost of every item in the BIM model can be added in the database, the accurate estimating of the building will be calculated with a fast rate and an accurate quality (Xiong 2012).

CHAPTER 3
RESEARCH METHOD

3.1 Overview

The purpose of this study is to investigate the status of building industrialization and BIM technology in China as well as to promote the industrialization process and application of BIM in China. In addition, the benefits of BIM use needs to be identified and the obstacles that could be met in practice need to be analyzed. As long as the benefits of BIM are known by public, more and more companies will adopt BIM technology; likewise, the application of BIM could avoid difficulties and straightforward development if the obstacles were clear. In order to achieve the objectives, a thorough investigation and wealthy data support are necessary.

The study consists of two distinct phases which are survey and case study. The survey questionnaire that was distributed to many companies related to the building industry investigates the status of building industrialization and BIM technology in China. The answers collected from the survey show the direction of BIM implementation as well as the anticipated obstacles to future development. After collecting data through the survey and analyzing the data, two case studies are conducted: a case study of comparing an industrialized project with a traditional project; another case study of analyzing a project with BIM assisted. The case study is analyzed from some key perspectives that summarized from the preceding survey. The role of BIM technology in building industrialization and the solution to removing obstacles are analyzed through the case study. The research process is shown in Figure 3-1.

3.2 Phase 1: Survey Questionnaire Design

The survey was distributed to employees who are working in building related companies, such as owners, design companies, contractors, and suppliers. The survey is electronic edition and was distributed by email. Preceding the survey questions, a concept description of BIM and

building industrialization and a brief introduction to the development situation are given in order to give participants a basic understanding of the subject matter. Then the demographic and background and the technical questions are listed. The demographic and background questions was designed for collecting personal and company information, and consisted of five questions. The subsequent technical questionnaire was designed for collecting the responses to BIM and industrialized buildings related questions, and consisted of 12 questions. Each question is described in detail in the next section of this study. The survey questions consisted of multiple choice and open-ended questions. In the multiple choices section, a few of options were given and when respondents selected the "other" option, a brief explanation was required, while in the open-ended answer questions, each participant was allowed to express their opinion. The process of collecting responses from participants lasted about one month.

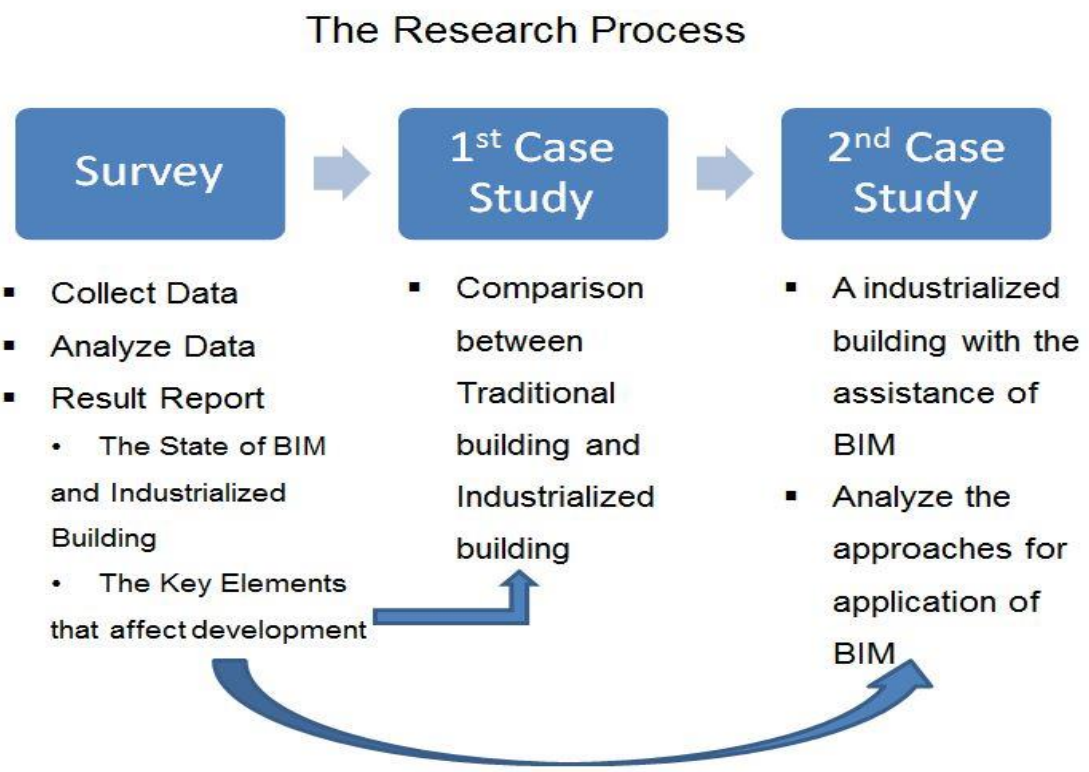

Figure 3-1. The Research Process. Created by Nan Xie on 09/30/2016.

3.2.1 Demographic and Background Questionnaire

The respondents had various backgrounds based on work experience, work location and job title as well as the differences in company size, type and project which can affect their subsequent technical answers. The compared results from the group with same characteristics are reliable. Therefore, identifying these characteristics of respondents can be necessary and useful.

Question 1.1: What is the business type of the company you work in? – Five response options were given: a. real estate developer; b. design company; c. construction company; d. supplier; and e. others. The purpose of this question was to identify in which type of company BIM is prevalent and to guide stratification of groups.

Question 1.2: How many employees are there in your company? – Six response options were given ranging from 1 to above 500. The purpose of this question was to identify the company scale which allows for determining whether there is a positive correlation between BIM application and company scale.

Question 1.3: Which city are you working in? – Salary and technical level vary in different cities. The responses to this question can reflect the regional popularity of BIM and the potential for future development.

Question 1.4: What is the orientation of the projects in your company? – Five response options were given including residential, commercial, industrial, civil and others. The answers for this question can yield which fields focus more on the application of BIM and what type of projects are more suitable to new construction methods.

Question 1.5: What is your job title? – There were six response options: technical engineer, designer, project manager, estimator, office administrator, and others. The objective of this question was to analyze the range of application of BIM in China and identify which occupation is likely to use BIM.

3.2.2 Technical Questionnaire

The technical questionnaire was designed for the purpose of obtaining specialized opinions about BIM development and building industrialization in China. These questions were organized from four aspects. The first section focused on investigating the popularity of BIM and industrialized buildings in China from Question 2.1 to 2.4; the subsequent section asked about the advantages and obstacles of implementing BIM and industrialized buildings in the context of government-oriented market (Question 2.5-7); the scope, approach and role of BIM applied in building industry were reflected in question 2.8-10; the last section (Question 2.11-12) mainly focused on the discussion about the elements that can affect BIM implementation in China. The questions in the technical section consisted of multiple choice and open-ended questions. The results from multiple choice questions can be used for quantitative statistical analysis while the explanative open-ended answers can provide directive factors for the subsequent case study.

Question 2.1 Have you heard of building information modeling (BIM)?

Question 2.2 Have you heard of Building Industrialization?

– The purpose of Questions 2.1 and 2.2 was to identify whether the respondents have a basic understanding about the concept of the subjective matter.

Question 2.3 Have you participated in any projects assisted by BIM technology?

Question 2.4 Have you participated in any projects incorporating industrialized building? – The purpose of Questions 2.3 and 2.4 was to verify if participants have any work experience related the subject of this study.

Question 2.5 In comparing industrialized buildings with conventional buildings, what are the advantages and challenges of industrialized buildings? – The responses of this question provide the recognitions and opinions about industrialized buildings from different walks of building industry.

Question 2.6 What benefits do you think BIM will bring to building projects? – This question help collect as many benefits as possible from a variety of perspectives.

Question 2.7 What do you think are the most significant obstacles to BIM implementation in your company? – The responses to this question summarize the main obstacles to BIM implementation and avoid unexpected problems in the future.

Question 2.8 Which group among owner, designer, contractor or facility operator do you think BIM will bring most benefits to? – Four options were given: owner, designer, contractor, facility operator. Participants could select more than one option. The most common use of BIM and potential implementation in the future can be assessed.

Question 2.9 What kind of building structure do you prefer to use BIM on? – Four options were given: masonry, concrete, steel, complicated structure. Respondents could select many options based on their opinions. The purpose of this question was to evaluate the potential of BIM implementation in different structures and provide an orientation to companies.

Question 2.10 What effect do you think BIM will have on building Industrialization? – This question asked their opinion of the impact of BIM on industrialized buildings and encouraged participants to consider the interaction with each other.

Question 2.11 What do you think are the key elements in implementing BIM in industrialized building projects? – The responses to this question reflect which incentives can stimulate the application of BIM in industrialized buildings.

Question 2.12 How many years do you think before BIM will be popular in whole building industry? – The responses from the respondents reflect their speculation and expectation for the potential application of BIM in China.

The opening questions in this survey can not only encourage respondents to give their own opinions, but provide more angles for the subsequent case study as well.

3.3 Phase 2: Case Study

3.3.1 Case Study 1: Comparative Case Study

The case study phase consists of two project cases. The first case is a comparison of construction cost between two similar projects. The reason for comparing construction cost is that construction cost is one of the most important factors in impeding industrialized building development according to previous survey results. The two comparable projects are both high-rise residential buildings located in Wuhan that is the capital of Hubei province in China. The construction data was collected from the archived documentation of a mid-sized construction company. One practical project of the set is a new residential apartment with 34 stories above ground and 1 story underground. The stories 1-5 used a traditional construction cast-in-place method, while the stories 6-34 adopted an industrialized construction method, a prefabricated and assembled on site method. The total floor areas are up to 15,016 square meters; however the actual areas used for subsequent comparison are the 6-34 stories, 13,127 square meters. The contrast sample project is a residential apartment with 33 stories, and the construction method is a conventional cast-in-place method. The data of this sample project was from a historical documentation two years old. The construction costs of the two similar projects were compared from four aspects: labor cost, material cost, equipment cost and miscellaneous fees. The purpose of the comparison is to identify which construction method is more economical, and to analyze reasons for the differences between the two construction methods, and to assess which parts among the five aspects can be improved in the future.

3.3.2 Case Study 2: A BIM Assisted Project

The second case study is also a high-rise residential apartment project. However, the buildings this case study focused on were built in an industrialized, BIM-assisted construction method. The data of this project was provided by a large-scale real estate company. The project is located in Beijing and is comprised of 6 buildings with 21 stories and 6 buildings with 11 stories, and of which Buildings #7, #8 and #9 adopted an industrialized, BIM assisted construction method. Figure 3-2 is an aerial view rendering picture. Figure 3-3 is a picture of completed project which is provided by the real estate company V.

Figure 3-2. Aerial View Rendering, August 20, 2016. Courtesy of Company V.

In order to figure out how BIM technology can assist industrialized building procedure and what can be improved during the design, prefabrication, and construction processes through BIM assistance, this case study was conducted. Additionally, this case study also can provide a method to solve the cost problem in Case Study 1. The case study kept a record of the whole process from the beginning design to the construction close-out, and was divided into three phases based on time sequence. The approaches that BIM is implemented into practice were

analyzed from three perspectives, design, prefabrication, and construction respectively. One story of BIM model is showed in Figure 3-4.

Figure 3-3. Completed Project Rendering, August 20, 2016. Courtesy of Company V.

3.4 Limitations of Methodology

The research methodology consisted of two phases: a survey and case studies. The survey was to investigate the state of building industrialization and BIM as well as to summarize the key elements affecting its adoption. However, the survey could not be distributed to a large population due to the limitation in availability of respondents and the time limit, and all respondents were from a few cities, which limited regional diversity. Besides, the survey did not consider the perspective influence of people who worked in different job positions on its subject matter.

The purpose of the case studies was to verify the result of the preceding survey and to solve problems in the previously collected results. The first case study only focused on one of the most important factors, the other factors need to be analyzed in future research. Additionally, the

second case study focused on a residential building project, for other types of buildings, the analyzed results probably do not apply in the same way.

Figure 3-4. Standard Floor in BIM Model, August 20, 2016. Courtesy of Company V.

CHAPTER 4
ANALYSIS OF SURVEY RESULTS

The survey was distributed to 55 prospective participants who were working on various jobs related to the building industry in China. Fifty-Two (95%) out of the 55 participants completed the survey questions and replied by email. The results of the questions are listed in the following section, and are shown in tables or graphs, followed by a brief analysis of each question. The purpose of this survey is to investigate the status of building industrialization and BIM technology in China as well as to figure out the key elements that affect the implementation of BIM in industrialized buildings.

4.1 Demographic and Background Questionnaire

The respondents had various backgrounds based on work experience, work location and job title as well as the differences in company size, type and project which can affect their subsequent technical answers.

Question 1.1: What is the business type of the company you work in?

The purpose of this question was to identify in which type of company BIM is prevalent and to guide the stratification of groups for analysis purposes. The distribution of company types is shown in Figure 4-1. The most respondents (23, 44%) were from design companies; 11 (21%) respondents worked for construction companies; 9 (17%) respondents and 6 (12%) respondents were from real estate developer and supplier respectively; just 3 (6%) respondents were from other companies, one was from a building inspection institute and the other two were from building consulting companies.

Question 1.2: How many employees are there in your company?

Six response options were given ranging from 1 to above 500. As shown in Figure 4-2, 19 respondents (37%) were from large-scale companies with more than 500 employees; 15

respondents (29%) were from mid-sized companies with 100-500 employees; 18 respondents (34%) were from small-sized companies with less than 100 employees.

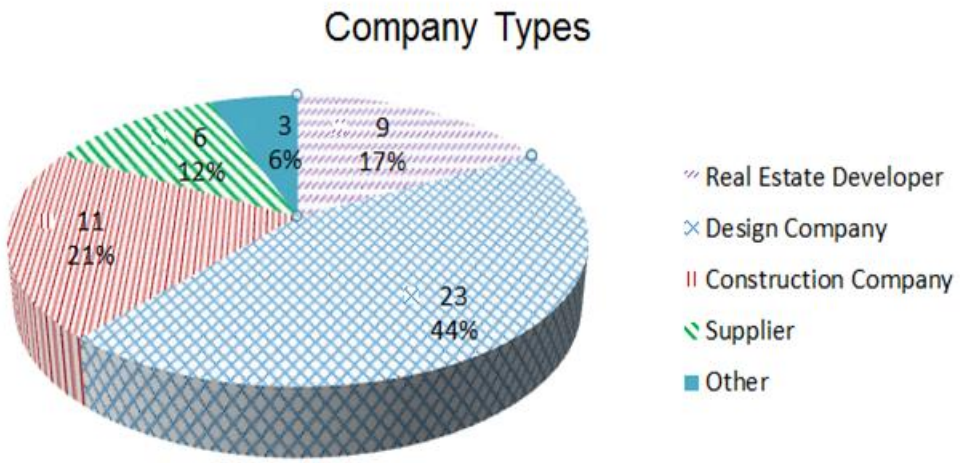

Figure 4-1. Distribution of Company Types

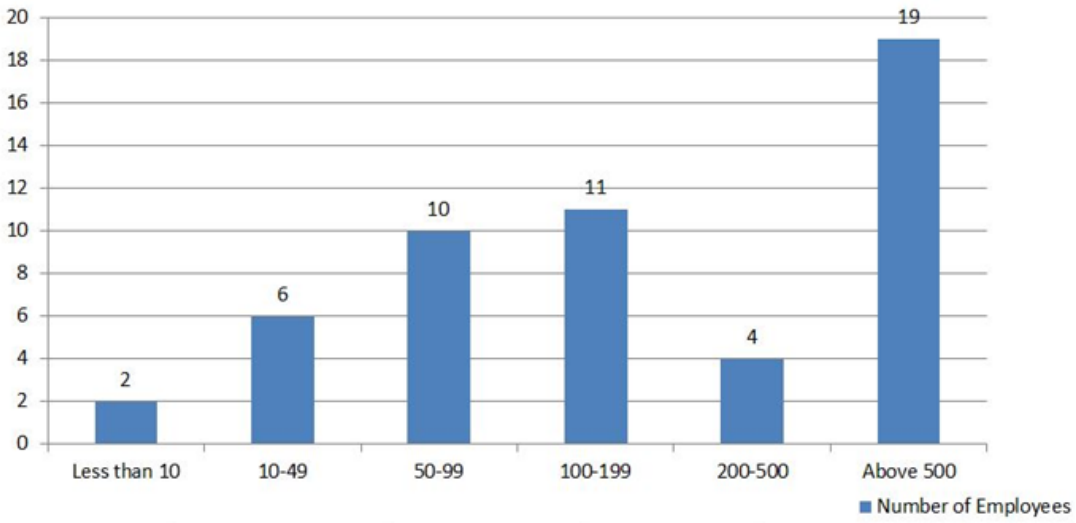

Figure 4-2. Number of Employees in Different Scale of Companies

Question 1.3: Which city are you working in?

The 52 respondents were distributed in 9 cities in China. 20 respondents (38%) worked in Shijiazhuang; 20 respondents (38%) worked in Beijing; 3 respondents (6%) worked in Kunming; the number of respondents who work in Tianjin, Zhengzhou and Tangshan was two (6%) each;

and the number of respondents who worked in Xi'an, Huhhot and Taian was one (2%) each. According to the report of City Classification in China (2016), the journal of CBNweekly divided cities in China into 5 grading levels, Grade1 to Grade5 corresponding with the most developed cities to the least developed cities. For instance, Beijing, Shanghai, Shenzhen were attributed to the Grade1, Grade2 included Fuzhou, Hefei, and so on. Based on the grading levels, Beijing and Tianjin were in Grade1, Shijiazhuang, Kunming, Zhengzhou, Xi'an, and Tangshan belonged to Grade2, and Huhhot and Taian tower rated as Grade4. Figure 4-3 shows the city distribution on different grades.

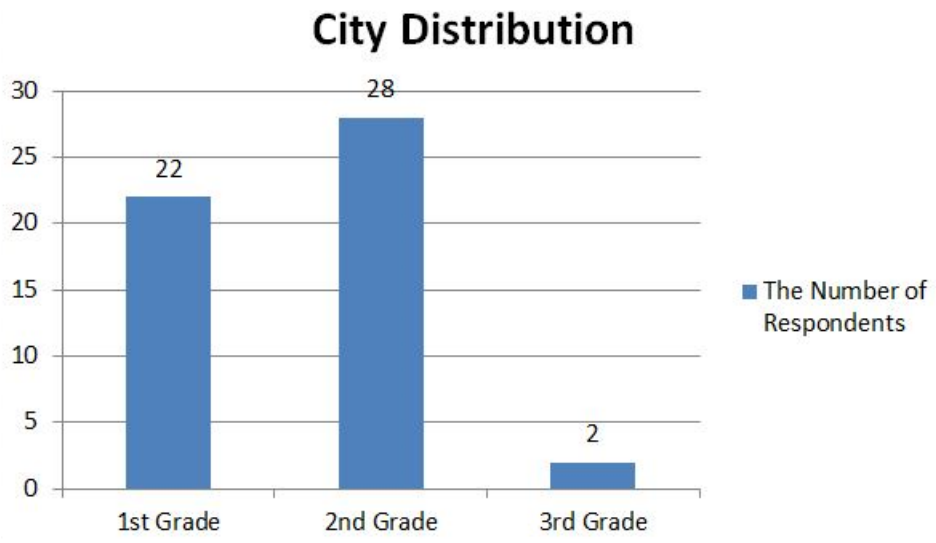

Figure 4-3. City Distribution

Question 1.4: What is type of projects does your company work on?

Five response options were given including residential, commercial, industrial, civil and others. As shown in Figure 4-4, 43 companies (51%) worked on residential buildings; 24 companies (29%) worked on commercial buildings; 11 companies (13%) were involved in industrial projects; 5 companies (6%) were involved in civil projects; and one respondent (1%) selected the other option without explanation. All the companies the respondents worked in had the business of residential or commercial projects, in other words, not any companies were

specialized in civil or industrial projects. For example, Company X worked on civil projects as well as residential projects. As shown in Figure 4-4, residential projects were the most popular type.

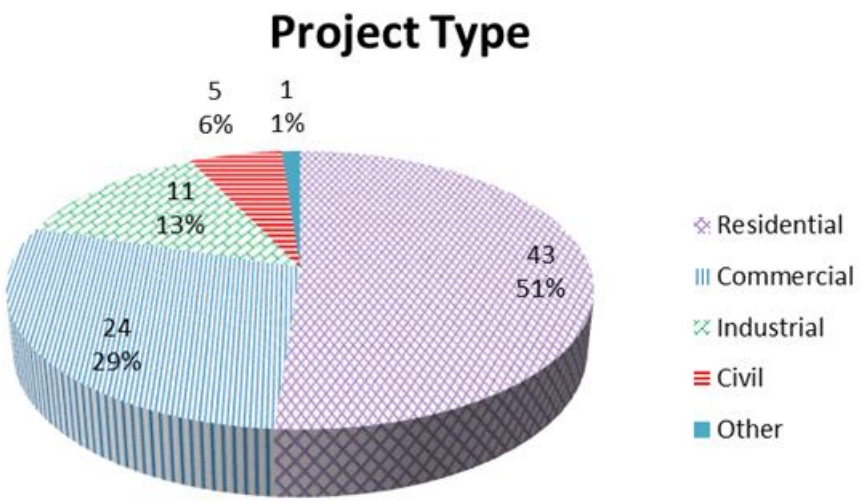

Figure 4-4. Project Type

4.2 Technical Questionnaire

The technical questionnaire was designed for the purpose of obtaining specialized opinions about BIM development and building industrialization in China.

Question 2.1: Have you heard of building information modeling (BIM)?

Question 2.2: Have you heard of building industrialization?

Question 2.3: Have you participated in any projects assisted by BIM technology?

Question 2.4: Have you participated in any projects incorporating industrialized building?

The four questions focused on investigating the popularity of BIM and industrialized buildings in China. As shown in Table 4-1, in terms of the development of BIM, the majority of the respondents, 96% (50) of total, had heard of BIM while only 44% (23) of total respondents had participated in projects assisted by BIM. The data indicated that the development of BIM is

standing at a beginning stage, most people who work in the construction industry have a basic knowledge on BIM, however just a few people (less than half) have the work experience with BIM. In terms of building industrialization, 92% (48) respondents had heard of this concept while 31% (16) had participated in projects incorporating industrialized building. The majority of construction employees knew the new construction method, and around one third of the respondents had taken part in industrialized building projects. In contrast, the two proportions of respondents who had heard of BIM and industrialized building were close, and both of the proportions were more than 90%. The percentage of people who had heard of BIM to people who have participated in BIM related work is 23/50 (46%), however, the percentage of people who have participated in industrialized building projects out of people who had heard of building industrialization is 16/48(33%), which means the development of industrialized buildings lagged behind the development of BIM technology to some extent.

Table 4-1. Popularity of BIM and Industrialized Buildings

Questions	Yes	No	Total	% Yes of Total
Have you heard of BIM?	50	2	52	96%
Have you participated in any projects assisted by BIM technology?	23	29	52	44%
Have you heard of Building Industrialization?	48	4	52	92%
Have you participated in any projects incorporating industrialized building?	16	36	52	31%

Question 2.5: In comparing industrialized buildings with conventional buildings, what are the advantages and challenges of industrialized buildings?

In term of the advantages, most of the points that 52 respondents mentioned are high efficiency, high quality, pollution reduction, and mechanization. Based on the collected data, the most advantages of industrialized buildings are high efficiency and high quality, listed by 42 (81%) and 39 respondents (75%), and then followed by pollution reduction (30 respondents,

58%) and mechanization (21 respondents, 40%) (See Figure 4-5). Responses to the challenges mainly focus on five aspects (most respondents listed): construction cost, technology barrier, production difficulty, delivery, and market promotion. As shown in Figure 4-6, 45 respondents (87%) regarded construction cost as the most challenging for the construction method, 40 respondents (77%) considered that high quality is one of the advantages, and production difficulty, delivery and market promotion were listed by 32 (62%), 20(38%) and 20 (38%) respondents respectively.

Question 2.6: What benefits do you think BIM will bring to building projects?

Question 2.7: What do you think are the most significant obstacles to BIM implementation in your company?

The purpose of Questions 2.6 and 2.7 was to collect as many benefits as possible from a variety of perspectives, and summarize the main obstacles to BIM implementation. According to the responses from all sectors of construction industry, most people perceived visualization, code review, clash detection, communication and cost estimating are the most benefits BIM can bring to construction industry. As shown in Figure 4-7, visualization, code review and clash detection were the top three benefits selected by 39 (75%), 37 (71%) and 36 (63%) respondents respectively; BIM was also perceived to increase the communication among different departments by 24 respondents (45%) and to be used in making cost estimating more accurate and faster by 22 respondents (42%). In terms of obstacles to BIM implementation (see Figure 4-8), the lack of standards and technical expertise were selected by 33 (63%) and 31 (60%) respondents respectively as the most obstacles while short construction period and investment cost are the other two obstacles listed by 28 (54%) and 25 (48%) respondents respectively. Twenty-one (40%) respondents also perceived that BIM has a wide range to be implemented

from upstream to downstream of the whole building industry. The wide range was a main reason for impeding the implementation of BIM, as long as BIM was applied to the whole life-cycle of buildings, the benefits of BIM could be maximized.

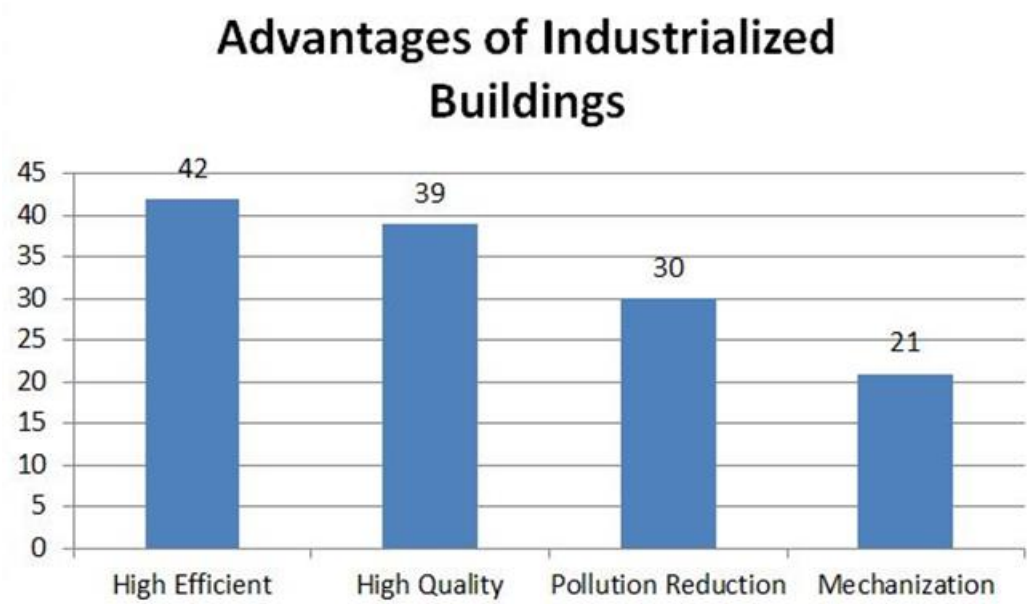

Figure 4-5. Advantages of Industrialized Buildings (n=52, all responses that applied were selected)

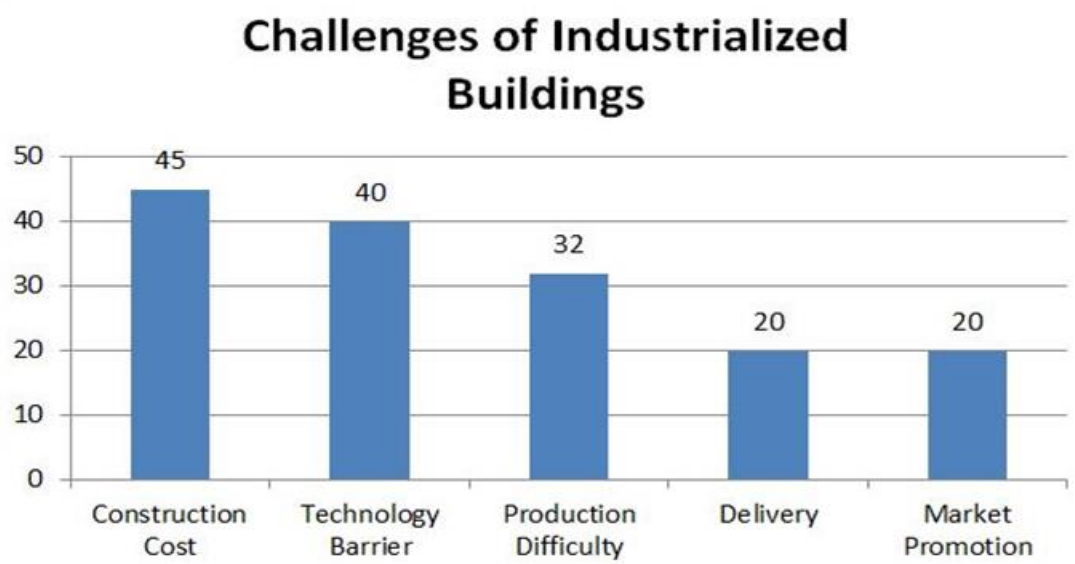

Figure 4-6. Challenges of Industrialized Buildings (n=52, all responses that applied were selected)

Question 2.8: Which group among owner, designer, constructor or facility operator do you think BIM will bring most benefits to?

Four options were given: owner, designer, constructor, facility operator. Participants can select more than one option. As shown in Figure 4-9, 31 respondents (60%) selected owner as the party who can obtain most benefits from BIM technology. Designer and construction companies (40% each) were deemed to derive the next most benefit. Thirteen respondents (25%) advocated that facility maintenance companies also can obtain benefits form BIM. The result indicates that encouraging more and more owners to adopt BIM is an effective beginning for the development of BIM in the future.

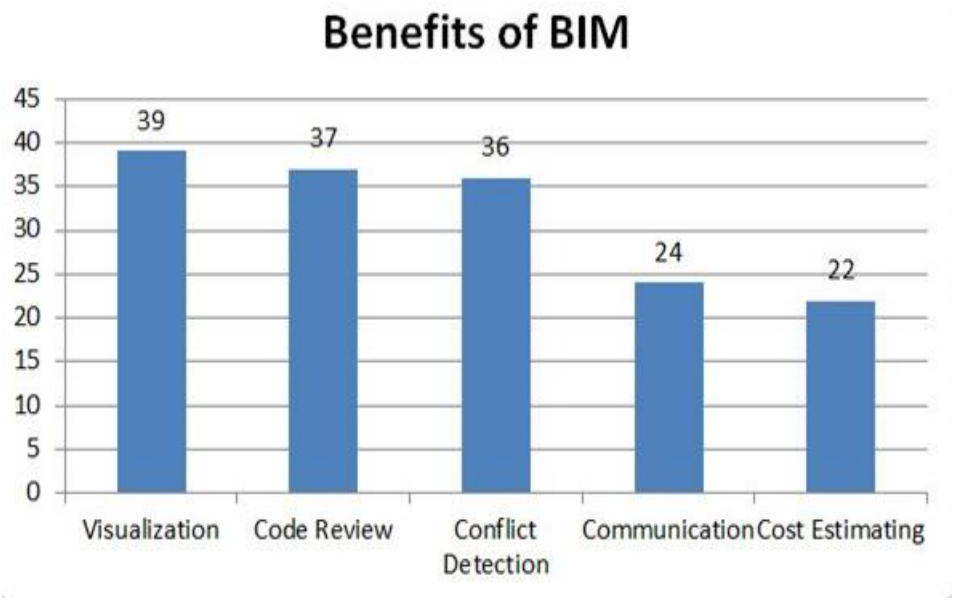

Figure 4-7. Benefits of BIM (n=52, all responses that applied were selected)

Question 2.9: What kind of building structure do you prefer to use BIM on?

Four options were given: masonry, concrete, steel, and complicated structure. The purpose of this question was to evaluate the potential of BIM implementation in different structures and provide an orientation to companies. As shown in Figure 4-10, 48 respondents

(92%) preferred to use BIM on complicated structure buildings while masonry, concrete and steel gained close support at the rate of 46% (24/52), 50% (26/52) and 54% (28/52) respectively.

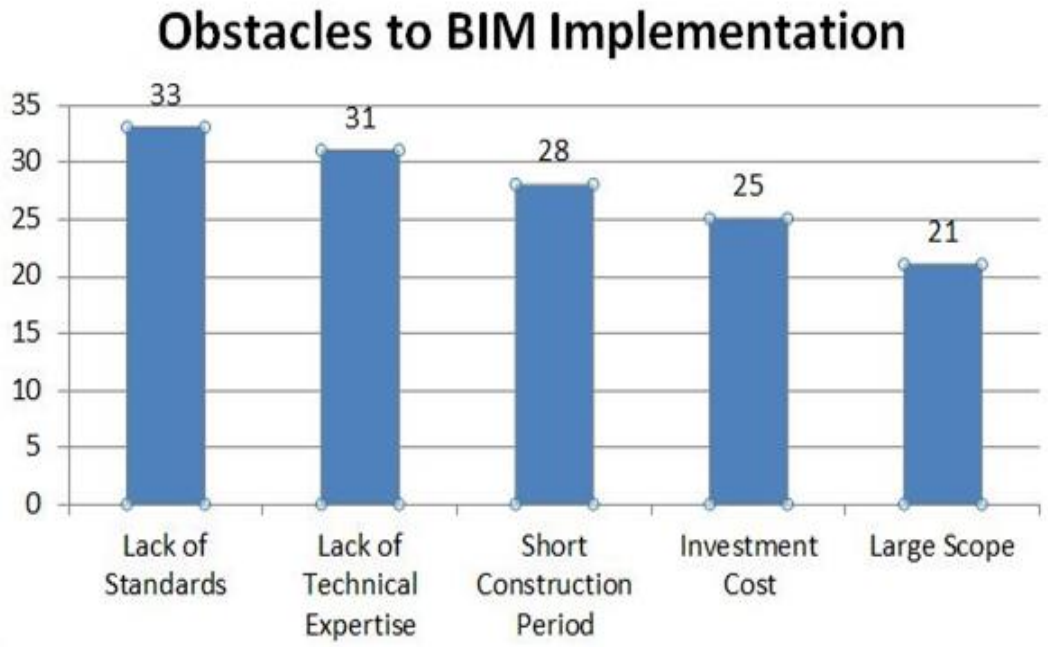

Figure 4-8. Obstacles to BIM Implementation (n=52, all responses that applied were selected)

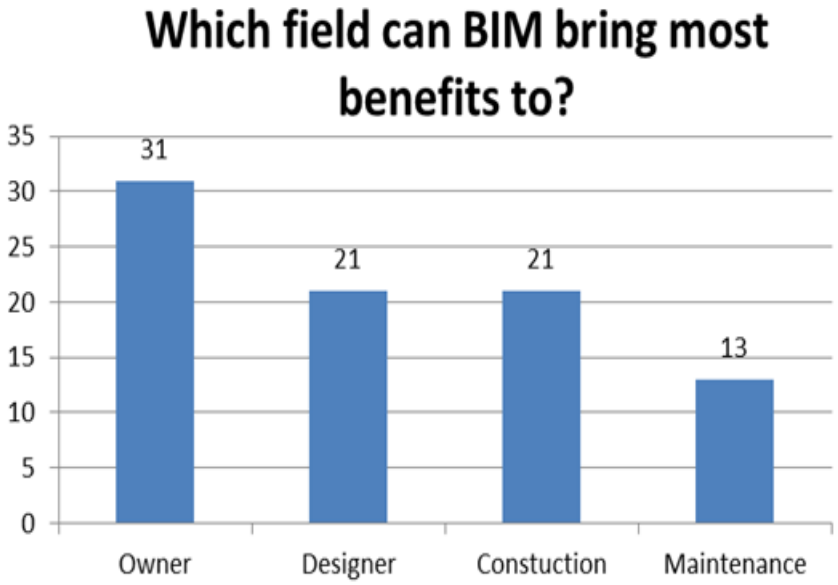

Figure 4-9. Which field can BIM Bring Most Benefits to? (n=52, all responses that applied were selected)

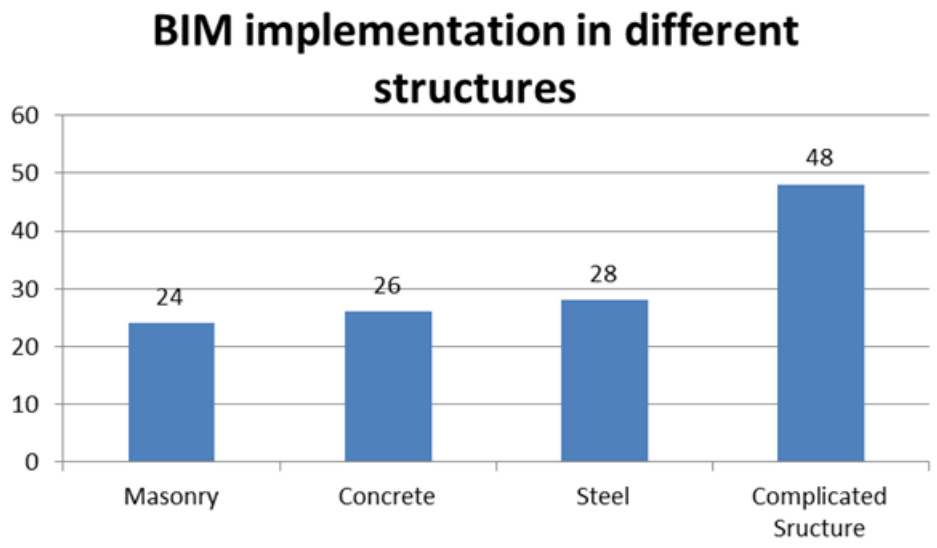

Figure 4-10. BIM Implementation in Different Structures (n=52, all responses that applied were selected)

Question 2.10: What effect do you think BIM will bring to building Industrialization?

Three options were given: positive, negative and unknown. As shown in Figure 4-11. Up to 90% of total respondents supposed that BIM will bring positive effect to building industrialization while not any respondents had the negative attitude to the subjective matter. Five (10%) respondents had no opinion on the influence of BIM on building industrialization.

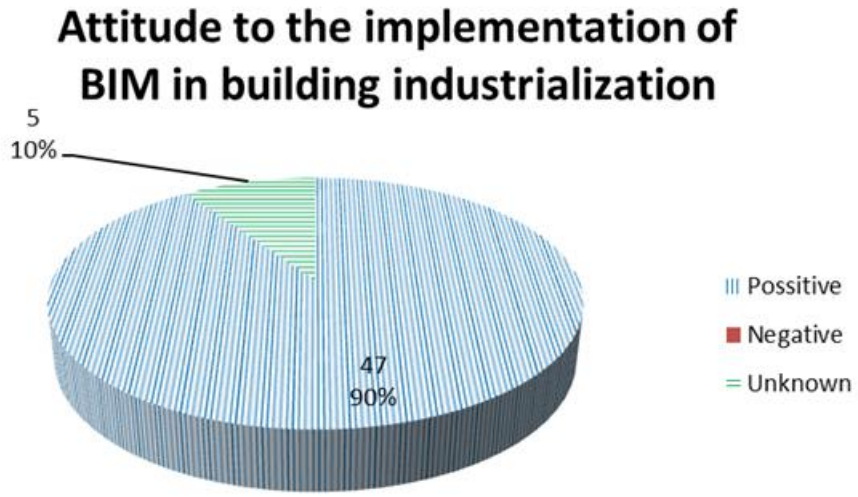

Figure 4-11. Attitude to The Implementation of BIM in Building Industrialization

Question 2.11: What do you think are the key elements to implementing BIM in industrialized building projects?

As shown in Figure 4-12, most responses to this question focused on four key elements: components standardization, technical guidance, governmental support and coordination. Based on the opinions from 33 respondents (63%), shared components standards applied both in BIM and industrialized buildings are necessary, since they can increase production quality and construction speed. Thirty respondents (58%) agreed that technical guidance went through the whole life-cycle is also essential. Apart from the technically support, 29 respondents (56%) thought government should make some related policies to encourage the development of BIM in building industrialization. The element of coordinating with different departments in construction industry was listed by 21 respondents (40%).

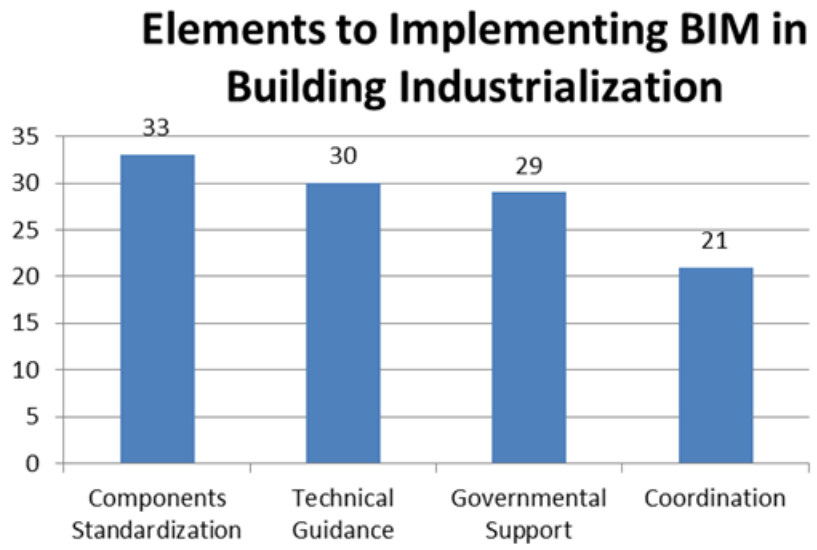

Figure 4-12. Elements to Implementing BIM in Building Industrialization (n=52, all responses that applied were selected)

Question 2.12: How many years do you think before BIM will be popular in the whole building industry?

The purpose of this question was to reflect respondents' speculation and expectation for the potential application of BIM in China. The responses were distributed in four durations (see Figure 4-13): 1-5 years (15 respondents), 5-10 years (14 respondents), 15-20 years (13 respondents), and 20-25 years (10 respondents). According to the explanation by each respondent, BIM will be applied in a small scope during the first five years, such as in economically developed cities like Beijing, Shanghai, Shenzhen, and in large-scale companies; and then BIM technology will have a steady development; finally, BIM is expected to be applied in a large scope within twenty-five years in China.

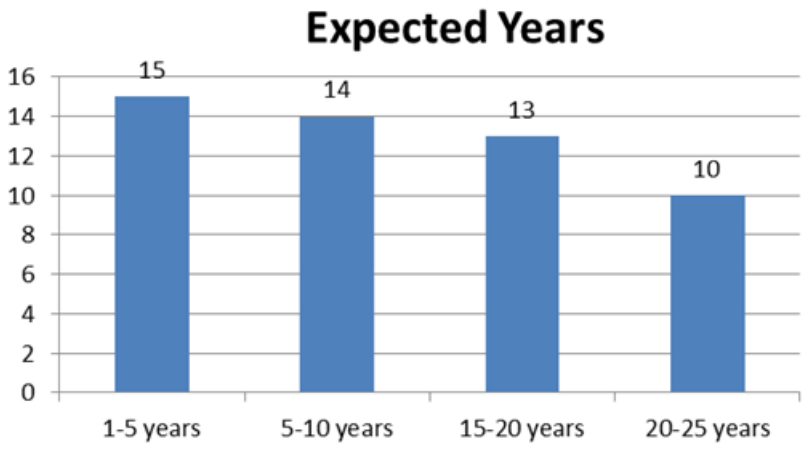

Figure 4-13. Expected Years

4.3 Summary

The survey investigated the status of building industrialization and BIM technology in China, and identified the benefits and the role of BIM technology in industrialized buildings, and figured out the key elements that implement BIM in industrialized building projects. Through the analysis of the survey result, BIM technology and building industrialization are both at a starting point in China; BIM can bring many benefits to building projects, such as visualization, code review, clash detection and so on; most people had positive attitude to the development of BIM

in industrialized buildings as well as perceived that components standardization, technical guidance, government support and coordination with different departments were the four key elements that implement BIM in industrialized buildings; construction cost was the biggest challenge for industrialized buildings; lack of standards and lack of technical support were two main obstacles .

CHAPTER 5
CASE STUDY

5.1 Case Study 1: Comparative Case Study

According to the survey results (Question 2.5), one of the main obstacles that impede development of industrialized buildings is construction cost. Construction companies do not like to adopt a new construction method at the cost of reducing profits, namely, no construction companies will invest money and time in a challenge until the challenge has been proven to be beneficial. Therefore, in order to identify the cost difference between the two construction methods, a comparative case study was conducted. The construction cost compared between the two projects only consisted of labor cost, primary material cost, equipment cost and miscellaneous fees while land lot cost, permit fees, designing cost, decoration and maintenance cost were not included.

Based on the result of Question 1.4 in the survey, residential buildings were perceived to be the most popular building type in China. Therefore, the first case selected two high-rise residential buildings with two different construction methods as the objects of the study. The two comparable projects are located in Wuhan that is the capital of Hubei province in China. One practical project is a new residential apartment with 34 stories above ground and 1 story underground. Stories 1-5 used a traditional construction cast-in-place method, while stories 6-34 adopted an industrialized construction method, a prefabricated and assembled on site method. The total floor areas added up to 15,016 square meters; however the actual areas used for subsequent comparison are the 6-34 stories, 13,127 square meters. The contrast sample project is a residential apartment building with 33 stories, and its construction method is a conventional cast-in-place method. The construction costs of the two similar projects were compared from four aspects: labor cost, material cost, equipment cost and miscellaneous fees.

Labor Cost. Labor cost was mainly spent on formwork, steel, cast-in-place concrete, components installation, wall installation, finishes and insulation. As shown in Table 5-1, the new construction method totally saved ¥1,976,565 in labor cost compared with the traditional method, the saving rate is approximately 46% (1,976,565/4,307,025). The labor cost of the assembled construction is less than the cost of traditional cast-in-place construction in formwork, steel, cast-in-place concrete, finishes and insulation while more was spent on components installation and wall installation. The reasons for the savings are that the installation of finishes and insulation is less than before and formwork needed in assembled construction is also less than in the traditional method.

Table 5-1. Labor Cost in Two Projects

Items	CIP Cost (¥)	Assembled Cost (¥)	Differences (¥)
Formwork	1,735,910	620,399	1,115,511
Steel	389,880	10,140	379,740
CIP concrete	154,665	3,605	151,060
Components installation	0	1,365,208	-1,365,208
Wall installation	0	95,430	-95,430
Finishes and insulation	2,026,570	235,678	1,790,892
Total	4,307,025	2330460	1,976,565

CIP= Cast-in-place.

Material Cost. As shown in Table 5-2, the traditional method is more economical (¥7,042,109 less) than the new method in material cost. The total cost of the assembled construction is almost triple in material cost than cast-in-place construction. The increased costs

are all spent on prefabricated components fee, which contributed to the material cost being much more than traditional method.

Table 5-2. Material Cost in Two Projects

Items	CIP Cost (¥)	Assembled Cost (¥)	Differences (¥)
Steel	1,505,840	185,541	1,320,299
Concrete	1,652,700	620,200	1,032,500
Prefab. Interior wall	0	4,312,000	-4,312,000
Prefab. Exterior wall	0	2,037,075	-2,037,075
Prefab. Board	0	3,356,342	-3,356,342
Prefab Stairs	0	143,140	-143,140
Grouting	0	292,500	-292,500
Finishes	956,399	210,250	746,149
Total	4,114,939	11,157,048	-7,042,109

CIP= Cast-in-place, Prefab. = Prefabricated.

Equipment Cost. As shown in Table 5-3, the equipment cost of the new method increased approximately 52% (356,000/680,000) compared with the traditional method. The reason is that in order to meet the requirements of installing prefabricated components, the project construction method used a TC7035B tower crane which is larger than the traditional TC5610 tower crane. Although the installation time is shorter than before, total cost is still expensive.

Miscellaneous Fees. The total miscellaneous cost of the new construction method is less than the traditional method, with an approximate savings of 40% (916,270/2,282,192). The only item that cost more is the management fee (shown in Table 5-4). Lack of related management method and experience in new assembled construction is the main reason for this higher fee.

Table 5-3. Equipment Cost in Two Projects

Items	CIP Cost (¥)	Assembled Cost (¥)	Differences (¥)
Tower crane	351,000	630,000	-279,000
Basic fees of tower crane	63,000	140,000	-77,000
Elevator	216,000	216,000	0
Basic fees of elevator	50,000	50,000	0
Total	680,000	1,036,000	-356,000

Table 5-4. Miscellaneous Fees in Two Projects

Items	CIP Cost (¥)	Assembled Cost (¥)	Differences (¥)
Scaffold and others	708,858	47,055	661,803
Formwork	261,720	246,840	14,880
Formwork support	97,125	9,520	87,605
Utility fees	545,012	314,268	230,744
Management fee	459,445	538,207	-78,762
Safety fee	210,032	210,032	0
Total	2,282,192	1,365,922	916,270

Summary

According to the comparison of the four parameters between a new project with industrialized construction method and an old project with traditional construction method, the total construction cost and the cost per square meter were calculated as shown in Table 5-5. In spite of the advantages of industrialized buildings in high efficiency, high quality, pollution reduction and mechanization, the average cost of the new construction method is more than the traditional method, and is approximately increased by 38%. Therefore, construction cost is the

main obstacle impeding the development of industrialized buildings. Based on the case study, the most effective approach to solving this problem is to decrease the material and equipment costs.

Table 5-5. Total Construction Cost in Two Projects

Project	Total Cost (¥)	Total area (m^2)	Average Cost (¥/m^2)
Cast-in-place project	11,384,156	13,010	875
Assembled project	15,889,430	13,127	1,210

5.2 Case Study 2: A BIM Assisted Project

The responses to Question 2.9 from survey questionnaire indicated that 92% of the respondents preferred to use BIM on complicated structures. BIM technology now is at its infancy in China, and the usage of BIM is just concentrated on a few large-scale companies and has not been deployed in the whole construction industry. However, BIM is tools that can help people complete building projects accurately and efficiently, once BIM is implemented in whole building industry, all types of structures can use BIM to solve problems. The second case study selected a similar high-rise residential building with general concrete structure. The main difference between the two cases is that the project in case study 2 was assisted by BIM. The purpose of the second study was to find out approaches to removing the perceived obstacles found in previous survey.

The project is located in Beijing and is comprised of 6 buildings with 21 stories and 6 buildings with 11 stories, with Buildings #7, #8 and #9 having adopted an industrialized, BIM assisted construction method. This case study used Building #7. Figure 5-1 shows the floor plan and Figure 5-2 shows the BIM modeling of one floor.

According to the responses to Question 2.7 in the previous survey, the main obstacles to using BIM in industrialized construction are lack of standards and technical support, short construction period, high investment cost and large scope. Strictly to speak, the first two obstacles are the direct reasons for the last three obstacles, in other words, if there were agreed

upon standards and sufficient technical support, BIM would be applied in the whole building industry, and then the construction period would be reduced and return on investment would be increased. Therefore, this case study just focused on solving the two problems of the lack of standards and technical support.

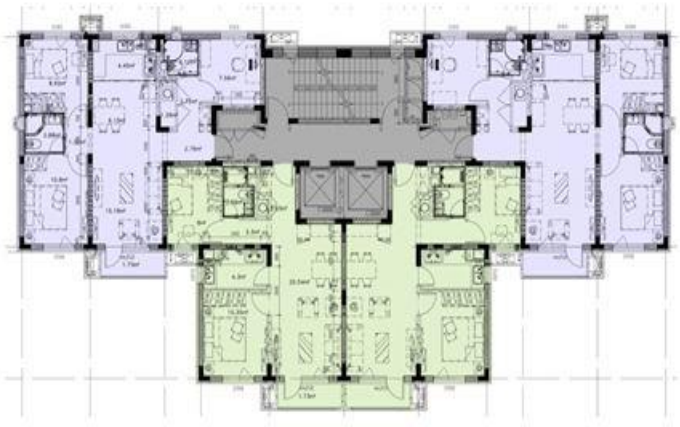

Figure 5-1. Standard Floor Plan, August 20, 2016. Courtesy of Company V.

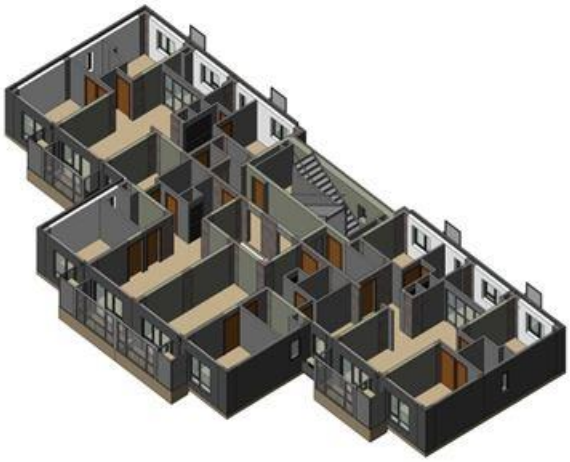

Figure 5-2. BIM Modeling of One Floor, August 20, 2016. Courtesy of Company V.

5.2.1 BIM Standard Design

The purpose of standardization is to make individual components be used on different projects. Massive production of standard components under the same standard can guarantee quality and decrease cost and encourage a positive cycle in the building industry.

In order to establish a standard library, the project divided building components into two types based on orientation: horizontal components (slabs, balconies, stairs and so on) and vertical components, such as walls. And then the standard library with all components was created in BIM related software, as shown in Figure 5-3. Figure 5-4 shows the components with different shapes and types with their respective names. Figure 5-5 shows the installed prefabricated components.

Once the standard components library was established, same components in different locations can be repeatedly used, which can save time not just for other locations in the same project, but also for subsequent projects in future. If component libraries in different building projects can be shared with one another, the components in the big library will meet more and more projects' requirements, and then promote the development of BIM implementation.

5.2.2 Technical Support on Using BIM to Support Industrialized Building

Technical support on using BIM for industrialized building was analyzed from two aspects: production off-site and construction on-site. The project used BIM from the beginning phase of components production in the factory. A few complicated components could not be shown in clear detail and the factory also lacked previous experience of special components. In order to make accurate components, BIM was used to model 3D detailed components to assist factory production, as shown in Figure 5-6.

Additionally, BIM can guide the construction process on site. This project took advantage of the animation feature to simulate the construction site and organize the construction sequence, which can help detect mistakes in advance as well as control construction status and process. Figure 5-7 shows the computer simulation on-site practice.

Summary

The case study 2 provided approaches to solving the two problems of the lack of standards and technical support from the view of practical projects. BIM standard design showed how to take components apart and how to organize different components as well as presented suggestions for potential usage. Technical support introduced and demonstrated the approach to fabricating complicated components off-site and to directing construction on-site.

Figure 5-3. Disassembled Components, August 20, 2016. Courtesy of Company V.

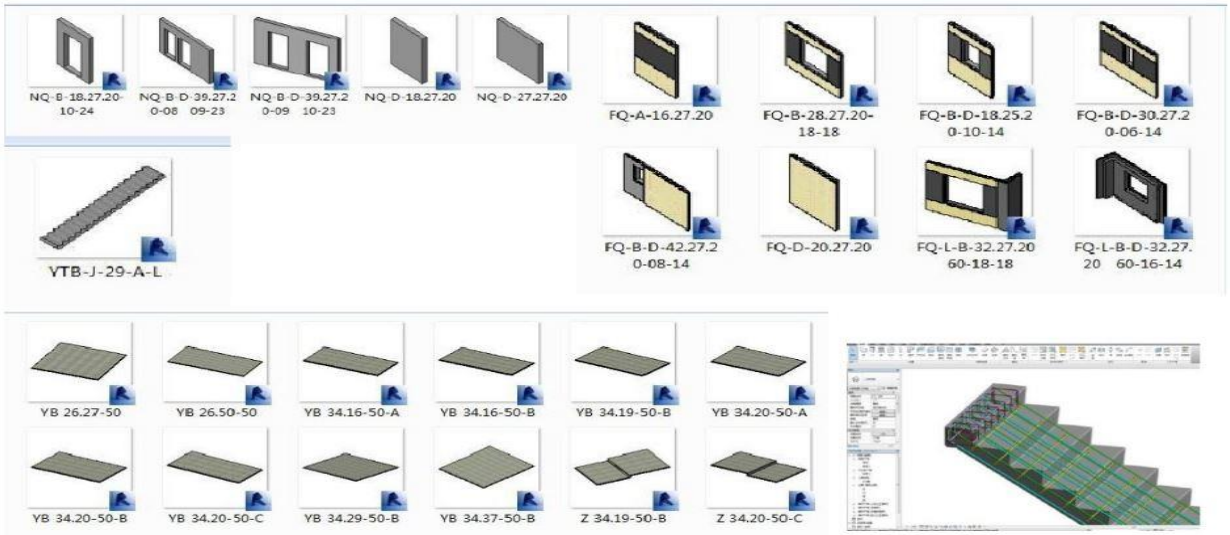

Figure 5-4. Components Library in BIM Related Software, August 20, 2016. Courtesy of Company V.

Figure 5-5. Prefabricated Slab, Balcony, Stair and Wall, August 20, 2016. Courtesy of Company V.

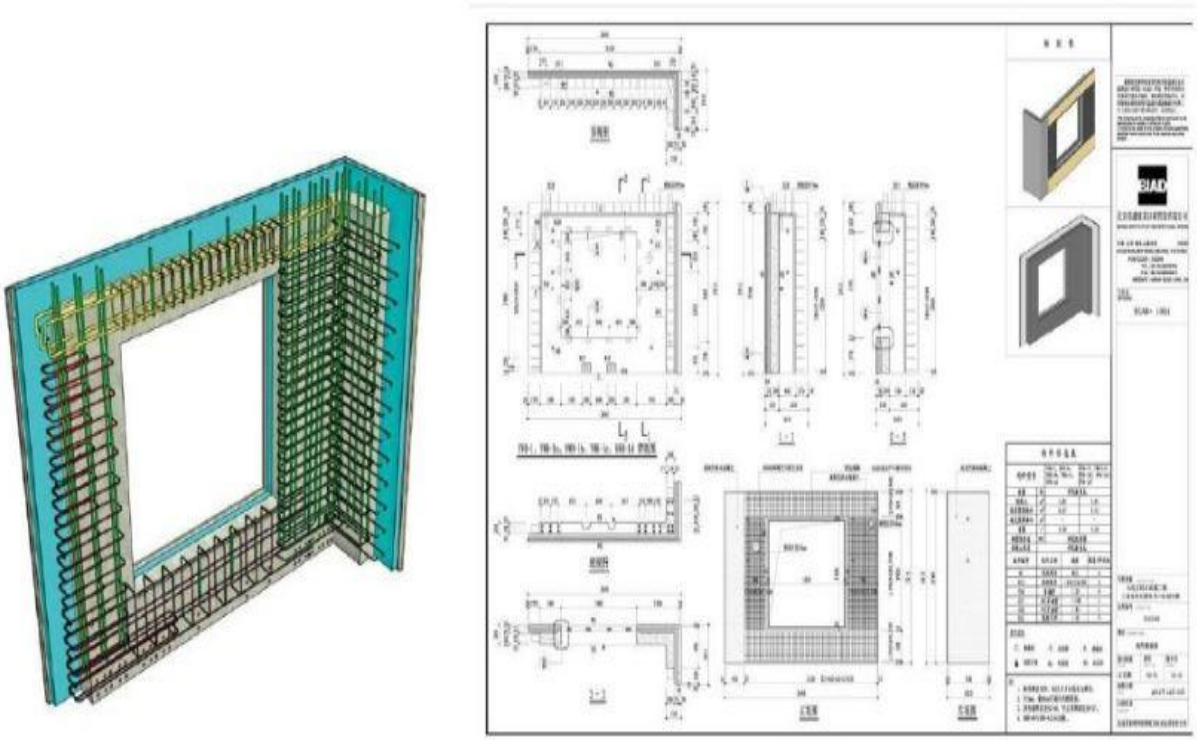

Figure 5-6. BIM Assisted Components Production, August 20, 2016. Courtesy of Company V.

Figure 5-7. Computer Simulation and On-Site Practice, August 20, 2016. Courtesy of Company V.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

BIM is a tool that directly represents building projects in practice by digital technology, which can be applied in the whole building industry from the beginning proposal phase to maintenance process. BIM can assist a project not only to improve quality and save time, but also to control the whole construction process. Building industrialization requires optimizing the whole building industry chain, including upstream product development and downstream construction materials and even production sales. To be specific, industrialized buildings consist of prefabricated components, modular structures and off-site construction. With more and more supportive policies in relation to building industrialization issued by the government, construction methods in China are changing from the traditional cast-in-place method to the new assembled method.

The purposes of building industrialization were to save money and time as well as decrease environmental pollution, and BIM technology has the features of controlling project time and cost. Therefore, the application of BIM in building industrialization process can be promoted and developed in China.

The purposes of this study were to analyze the role of BIM in building industrialization in China as well as to explore the future potential of BIM application in industrialized buildings. Through the data analysis from a survey and a study of two project cases in practice, this study has achieved four objectives: 1) Investigate the status of building industrialization and BIM technology in China; 2) Identify the benefits and the role of BIM technology in industrialized buildings; 3) Figure out the key elements that implement BIM in industrialized building projects; 4) Analyze the obstacles that are met in practice and find out how to remove them.

Objective 1: Investigate the status of building industrialization and BIM technology in China.

As indicated by the results of the survey questions, BIM technology and building industrialization are both beginning to be implemented in China. Most people in relation to building industry know the concept of BIM and building industrialization while only a few of people have participated in practice. The development of industrialized buildings lagged behind that of BIM and both of them have the potential to be developed in future.

Objective 2: Identify the benefits and the role of BIM technology in industrialized buildings.

The advantages of industrialized buildings consist of high efficiency and quality, pollution reduction and mechanical production while the benefits that BIM can bring to building industry are visualization, code review, conflict detection, communication with different departments and accurate and fast cost estimating. Additionally, the owner is one of the most important party to promote the development of BIM due to owner being able to obtain maximum benefits from BIM, meanwhile, BIM can be applied initially to complicated structures, and then be promoted to all types of structures. Most people had a positive attitude to the effect of BIM on industrialized buildings and supposed that BIM will be applied in a large scope within two decades in China.

Objective 3: Figure out the key elements that implement BIM in industrialized building projects.

Three most important key elements are components standardization, technical guidance and governmental support. Governmental support can guide more companies to adopt new technology, and technical guidance can provide a best approach during the development process,

lastly components standardization can standardize the whole building industry. Besides, inter-departmental coordination is also an essential element of implementing BIM in industrialized buildings.

Objective 4: Analyze the obstacles that are met in practice and find out how to remove them.

The biggest challenge for changing the traditional construction method to the industrialized method is construction cost. According to analysis of the comparative case study, the construction cost of the industrialized method is more than that of traditional cast-in-place method. The highest cost differentials in expenses are prefabricated components and equipment usage. Industrialized building is not popular in China, and one of the reasons is market-driven because not many factories produce building components, which increased the cost of related materials. The new construction method requires larger tower cranes to lift building components, which also increases equipment cost. In order to mitigate the total construction cost of the industrialized method, the best approach should begin with decreasing the cost of material and equipment.

Lack of standards and technical support are the main obstacles that impede the application of BIM in industrialized buildings. First of all, making standards based on projects in practice, namely, collecting data from experience and extracting common used standards are essential. Case Study 2 demonstrated the approach to establishing components library in BIM and to making use of BIM to guide construction in practice, and then proposed the suggestion of sharing BIM library between different projects. Secondly, Case Study 2 introduced two types of technical support: production off-site and construction on-site. Making 3D models of complicated components can assist factories to produce building components accurately and fast

and simulating the construction process can predict construction difficulties and solve them in time.

6.2 Recommendation

This study investigated the status of BIM and building industrialization, and determined the main elements that implement BIM in industrialized building, and summarized the obstacles in practice as well as the approaches to removing them. However, additional research on analyzing each detailed aspect is needed in future. For instance, Case Study 1 compared the construction cost of two projects with distinct construction methods. The repetitive use of aluminum formwork was not calculated in the cost, and the study also did not consider the economic benefits caused by pollution reduction. Additionally, specific methods of decreasing the cost of prefabricated components and equipment rent can be researched in future studies. In terms of the survey, future researchers should attempt to attract a large number of respondents, and focus on other perspectives, such as: comparing answers from people who work in different job positions on this subject matter and investigating development status based on distinct locations.

6.3 Future Development

BIM technology application and building industrialization both are in the beginning phase in China. The development of BIM technology needs not only BIM researchers' technical support but also market economical support. Building industrialization will be not carried on smoothly without government's policy guide and participation of most building companies. In terms of the relationship of BIM technology and building industrialization, both of them are strongly mutually supportive. For the future development, the establishment of BIM in developing modular components will be a new research direction and help to lead industrialized

building construction to a fast and accurate path as well as expand the application of BIM in China.

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BIOGRAPHICAL SKETCH

Nan Xie was born in Shi Jiazhuang, China. She lived there a long time until she went to Bao Ding, China in 2005 to start her undergraduate studies. In 2009, she received her Bachelor of Science in Civil Engineering from the Agricultural University of Hebei in China. After her four years' study, she had an internship experience as an assistant estimator in the summer and then worked in Hebei Academy of Building Research as a structural designer.

In January 2015, she traveled to United States for the purpose of pursuing her graduate studies at the M.E. Rinker, Sr. School of Construction Management, University of Florida. She received her Master of Science in Construction Management from the University of Florida in December 2016. She hopes to start her career in the construction industry.