CRITICAL BARRIER FACTORS OF APPLYING BUILDING INFORMATION MODELING (BIM) TECHNOLOGY IN CHENGDU'S MEDICAL BUILDING CONSTRUCTION PROJECTS (MBCPS)

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ABSTRACT IN ENGLISH

The COVID-19 pandemic and the aging population in Chengdu have had profound impacts on the medical industry, particularly in terms of the demand and construction of hospital treatment facilities. Therefore, exploring BIM technologies in Chengdu's MBCPs is crucial. This mixed-method study examines Chengdu's MBCPs primary BIM technology adoption barrier factors using literature reviews, expert interviews, questionnaire surveys, and the Relative Importance Index (RII) method. The study preliminarily identified 12 potential barrier factors to the application of BIM, categorized into four main groups: Cost Factor (CF), People Factor (PF), Technical Factor (TF), and Organizational Factor (OF). The study uses non-parametric rank sum analysis to compare the perceptions of these barrier characteristics among BIM technology users and their industry roles (e.g., managers, designers, engineers). This study not only identifies the Top six critical barrier factors affecting the application of BIM in Chengdu's MBCPs but also proposes targeted strategies to overcome these barriers; it will help to strengthen the wide application of BIM technology in Chengdu's MBCPs. These findings offer valuable insights and guidance for construction industry professionals, helping them to implement and utilize BIM technology more effectively in the face of current challenges and propagate wider acceptance and significant use of BIM in MBCPs and the Construction Industry (CI).

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Jiahao Chen

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LIST OF ABBREVIATIONS AND SYMBOLS

AECO	Architecture, Engineering, Construction, and Operations
AEC	Architecture, Engineering, and Construction
AECI	Architecture, Engineering, and Construction Industry
AM	Asset Management
BIM	Building Information Modeling
BDA	Big Data Analysis
CI	Construction Industry
CCI	Chengdu Construction Industry
FM	Facility Management
K-W H	Kruskal-Wallis H
PPIs	Key Performance Indicators
HVAC	Heating Ventilation and Air Conditioning
BURDB	Housing and Urban-Rural Development Bureau
BURDBC	Housing and Urban-Rural Development Bureau of Chengdu
M	Mean
MBCPs	Medical Building Construction Projects
MI	Medical Industry
MEP	Mechanical, Electrical, and Plumbing
M-W U	Mann-Whitney U
ICU	Intensive Care Unit
IOC	Item-Objective Congruence
ICT	Information and Communication Technology
RII	Relative Importance Index
SD	Standard Deviation

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Since the global outbreak of the COVID-19 pandemic in early 2020, its impact on the Medical Industry (MI) has become increasingly significant, particularly in terms of the surging demand for specific treatment facilities in hospitals (Lin et al., 2021). The pandemic has not only highlighted the limitations of traditional hospital physical structures, such as the difficulty in rapidly converting to negative pressure isolation wards to cope with the outbreak but also exposed the inadequacies of existing medical information systems in meeting the special needs during the pandemic (Jin et al., 2021). Moreover, the challenges posed by the large and aging population are worsening in China (He, 2021), and many problems have become increasingly prominent contradictions, such as insufficient total health resources, unreasonable structure, uneven distribution, and weak basic service capabilities (Zhu et al., 2020). Despite transitioning into the post-pandemic era now, according to the "Operational Guidelines for the Prevention and Control of Novel Coronavirus Infection Epidemic" issued by the Joint Prevention and Control Mechanism of the State Council (JPCMSC) on January 19, 2023, there is still a need to build and remodel the Intensive Care Units (ICU) to standard and to ensure that the units are ready for use (JPCMSC, 2023), and highlight the following contents of the guidelines as shown in Table 1.1.

Based on the measures outlined, it is clear that higher requirements and more project construction needs have been set for the design, construction, and remold of Medical Building Construction Projects (MBCPs). MBCPs are professionally characterized as initiatives to design and construct medical facilities that deliver comprehensive medical services (Soliman-Junior et al., 2021), as shown in Figure 1.1. MBCPs are one of the fastest-growing and largest industries (Cheng Lim & Tang, 2000). Furthermore, the complexity and challenges of such projects are progressively intensifying from the perspective of facilities management (Mohammadpour et al., 2017). Due to their specialized character, intricate processes, profound design intricacies, and interdisciplinary interactions, MBCPs exhibit high complexity (Kahn, 2009; Enache-

Pommer et al., 2010), as shown in Figure 1.2. In MBCPs, the complexity of project requirements is often even more significant (Cysneiros, 2002). This increased complexity is caused by the various functional requirements that hospitals need to fulfill (Doulabi & Asnaashari, 2016), including inpatient and outpatient services, diagnostics and treatment, administration, emergency, teaching and research, and reception functions. Additionally, modern hospitals utilize a vast array of diagnostic and therapeutic specialized equipment, adding another layer of technical complexity on top of standard building services such as Heating Ventilation and Air Conditioning (HVAC), Mechanical, Electrical, and Plumbing (MEP), Information and Communication Technology (ICT) and safety and security systems (Alnaggar & Papadonikolaki, 2019).

Table 1.1 The important element of the "Operational Guidelines for the Prevention and Control of Novel Coronavirus Infection Epidemic."

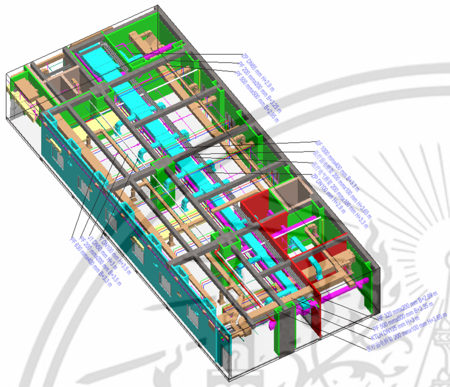
Measure	Concrete Content
Strengthening the critical care resource pool in Level II hospitals	Secondary general hospitals should independently set up departments of critical care medicine, while secondary infectious disease hospitals and pediatric specialty hospitals should establish Intensive Care Units (ICU).
Enhanced preparation of critical care resources for tertiary hospitals	Rapidly transform other specialty ICU beds. Hospitals should immediately initiate the expansion and transformation of other specialty critical care beds in addition to the general ICU. Reserve a batch of "convertible ICU beds" to ensure that they can be transformed into intensive care units within 24 hours if needed. The number of "convertible ICU" beds should be no less than 4% of the total number of actual beds opened by the hospital.
Ensuring the readiness of medical resources in sentinel hospitals	The number of ICU beds in designated hospitals should not be less than 10% of the total number of beds, and the convertible ICU beds set up in combination with emergency situations should not be less than 10% of the total number of beds, ensuring that the capacity of various ICU can be expanded to 20% of the total number of beds when needed.
Upgrading of the Square Cabin Hospital.	Upgrade and transform square cabin hospitals into sub-designated hospitals at the prefecture-level city, based on the population size, and set up monitoring beds at 10% of the total number of beds to ensure sufficient medical resources.

Note: Adopted from JPCMSC (2023).

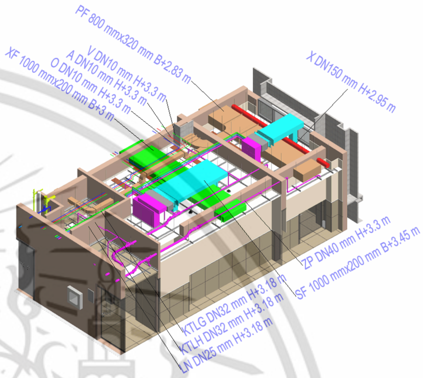
(a) Side view map

(b) Bird's eye view map

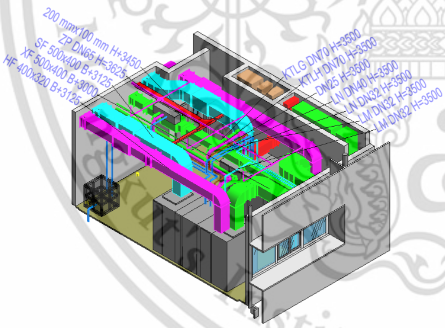
Figure 1.1 Rendering of MBCPs.



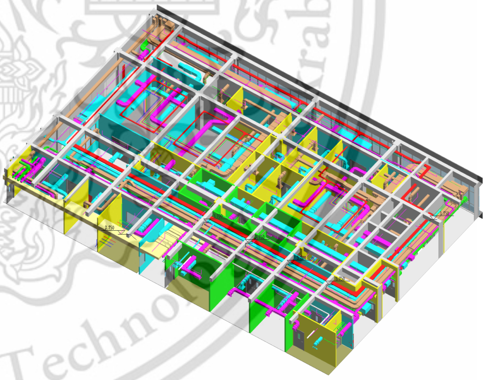
(a) 3D view of the complex area of the ICU lobby



(b) 3D view of the complex area of the ward



(c) 3D map of the complex area of the operating room equipment room



(d) 3D map of the complex area of the operating room

Figure 1.2 Part of the complexity of the MBCPs.

Moreover, the lifecycle of MBCPs encompasses four stages: conceptualization, design, construction, and operation, necessitating specialized information and knowledge among participants and stakeholders (Lin et al., 2018). The design of the medical building is critical to the success of a project, as it greatly affects the satisfaction of stakeholders and medical staff (doctors, nurses, and physician assistants)

(Lin et al., 2018). Furthermore, the architectural and functional design of MBCPs impacts the energy consumption of hospitals, the productivity of medical staff, and patient's physical and mental recovery (Hareide et al., 2016; Mackrill et al., 2017). In traditional design methodologies, design teams rely on two-dimensional (2D) CAD drawings and related materials to communicate medical design intentions to medical professionals and stakeholders (Eastman, 2011; Somboonwit & Sahachaisaeree, 2012), as shown in Figure 1.3. However, due to a lack of engineering expertise and experience, comprehending the concepts and content depicted in these two-dimensional drawings poses a challenge for medical professionals and stakeholder engagement (Okada et al., 2017). Poor communication may lead to errors such as design errors during construction, non-updating of drawings, delays, cost overruns, poor quality of work, and design conflicts.

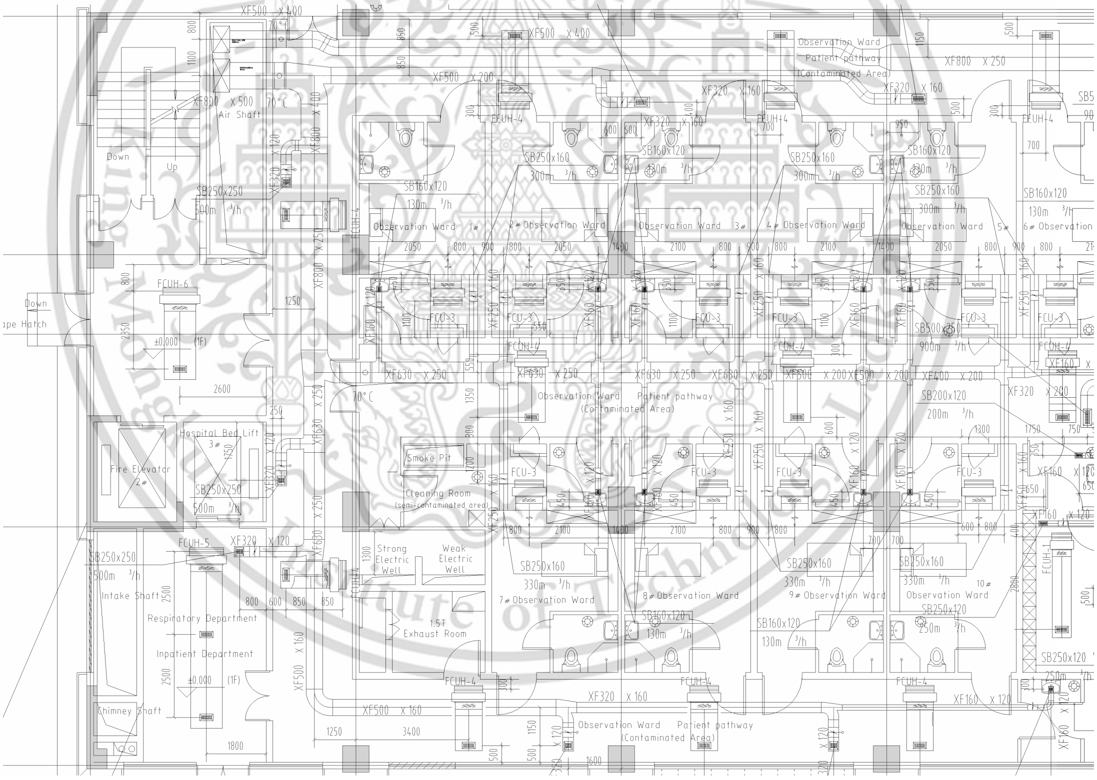


Figure 1.3 2D CAD drawings.

Furthermore, Facility Management (FM) and Asset Management (AM) have become focal points within the Architecture, Engineering, Construction, and Operations (AECO) industry due to their undeniable economic significance (Alnaggar & Pitt, 2019). Meanwhile, the FM stage is also the costliest stage in the life cycle of a medical building (Demirdöğen et al., 2023). Research on FM and AM has indicated that operational expenditures account for approximately 80% of the total lifecycle costs of a building (Thabet & Lucas, 2017). Data management activities in FM are crucial, as FM/AM encompasses a collection of information-intensive activities where facility managers gather, analyze, document, exchange, and manage vast amounts of facility information (Alnaggar & Pitt, 2019; Brunet et al., 2019). Chen et al. (2018) have highlighted that the data retrieval process results in significant waste, consuming about 80% of FM time. Consequently, the efficacy of FM decision-making processes is paramount in mitigating cost and time-related concerns within FM operations. Therefore, based on the above background, traditional construction models can no longer meet modern sustainable construction requirements. To adapt to this change, the Construction Industry's (CI) development philosophy must integrate with the concept of green environmental protection (Anderson, 2019; Wu, He, Chen, et al., 2021; Wu, He, Yang, et al., 2021). This requires the China CI to explore an innovative transformation and upgrade path to ensure its long-term competitiveness in environmental sustainability.

In order to respond effectively to these challenges, building experts are constantly looking for innovative methods and tools. Meanwhile, the application of Building Information Modeling (BIM) has attracted significant attention, as it can visualize the project's companion from design to construction to operation (Mesároš et al., 2020), as shown in Figure 1.5. The concept of BIM was first introduced by Dr. Chuck Eastman in 1975 (Peterson et al., 2011). According to the National BIM Standard of the United States, BIM is a digital representation of a project's physical and functional characteristics and a shared knowledge resource, providing a reliable scientific basis for all decision-making throughout the project lifecycle (Wu et al., 2019). The concept of BIM is based on object-oriented technology and a three-dimensional model with a single database, utilized to assist in the design and construction of projects (Lin et al., 2018), as shown in Figure 1.4. Such visual content favors the construction project participants' communication and decision-making (X. Zhang, 2022). BIM technology allows efficient information sharing among each project stakeholder and is a platform that facilitates collaboration among all project parties (Chen et al., 2020). The latest demand for construction enterprises has been combining BIM technology to improve information and construction cost management (Li, 2022). Implementing BIM technology in MBCP management has demonstrated its immense potential for

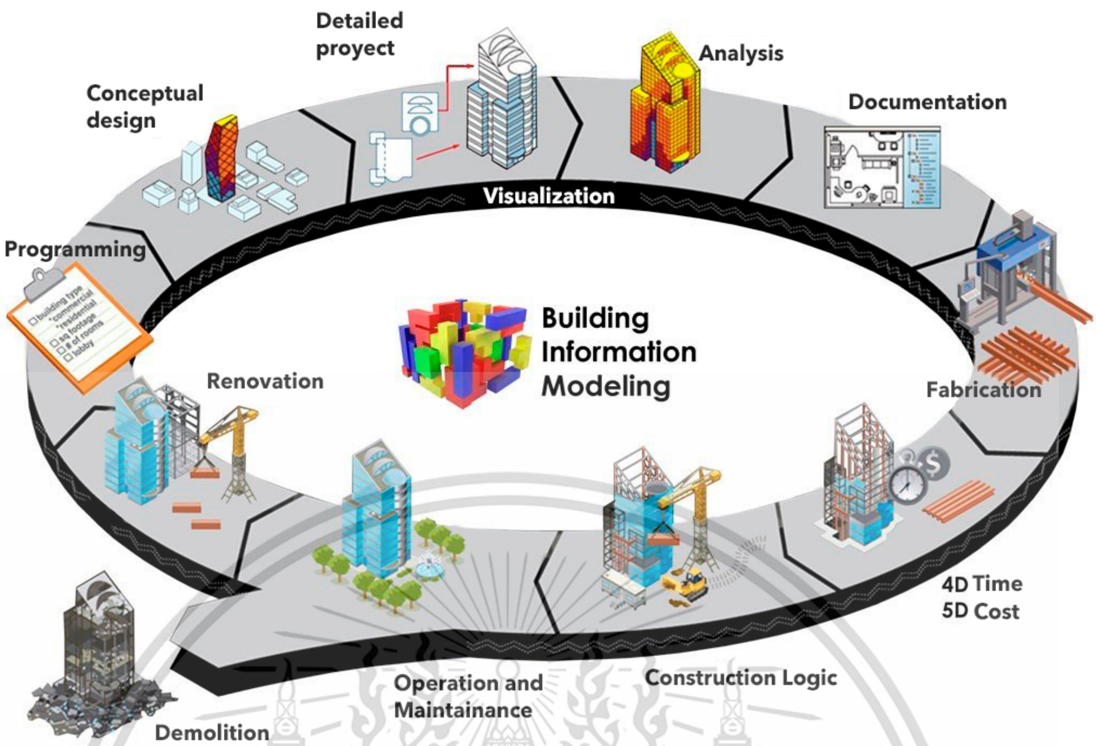


Figure 1.5 Full life cycle application of BIM technology (Source: IpsaBIM, 2018).

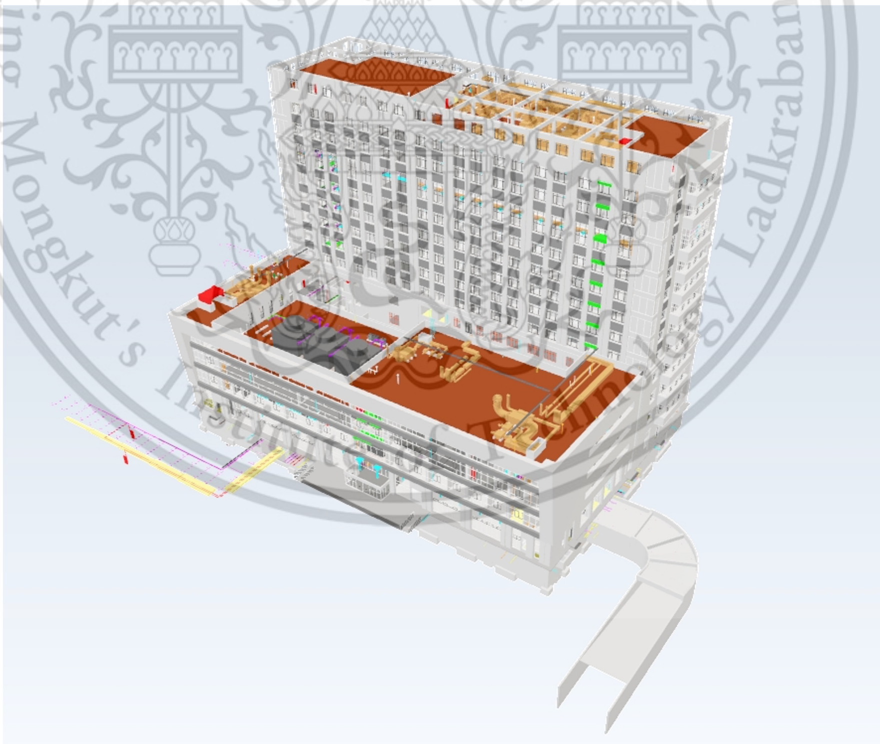


Figure 1.4 Lightweight BIM model of BMCPs.

enhancing project efficiency and quality, particularly during the planning and design phases. BIM technology fosters collaboration and communication among project teams, optimizing overall performance (Zhan et al., 2022). Simultaneously, BIM technology building design and construction processes can be applied in many ways, particularly in the case of highly complex Architecture Under construction (Manning & Messner, 2008; Merschbrock & Munkvold, 2015). Construction work typically has three goals: to complete the project on time, within the budgeted dollar amount, and to meet quality requirements (Elhusseiny et al., 2021). Balancing these three aims by extending BIM technology in the construction companion would improve the market competitiveness in the construction business and the employees' coordination capacity (Schimanski et al., 2020). This is because BIM technology enhances project management's intelligence level and significantly improves construction engineering quality (Du & Usman, 2021). Besides, BIM technology is used in construction cost control and design because it optimizes the construction engineering design and information processing and covers the entire life cycle of engineering project design and construction and resource information sharing and transmission (Kaiyang Wang et al., 2022). Additionally, BIM technology enables key designers and management professionals to respond correctly and efficiently to varied construction information, offering a reliable basis for the construction quality of subsequent construction projects and playing a vital role in the project's quality and cost savings (Toan et al., 2022). Some researchers developed a medical FM system based on Big Data Analysis (BDA), BIM, and NoSQL (Not Only SQL) databases, which enables the querying of FM information and the visualization of Key Performance Indicators (FM-KPIs) (Demirdöğen et al., 2023). Moreover, the system effectively facilitates the retrieval and analysis of FM data for management personnel in medical institutions. Therefore, in this context, MBCPs are more suited for applying BIM technology throughout their entire lifecycle than other types of construction projects (Choi et al., 2020). This fully leverages the significant advantages of BIM technology in enhancing project management efficiency, optimizing building performance, and improving resource utilization efficiency. Although there is a growing body of research related to BIM technology and MBCPs, few researchers have examined the potential barrier factors and challenges that affect BIM adoption in MBCPs.

Moreover, Even though BIM technology has reached a relatively mature level in developed countries such as the USA, UK, and Australia and has been widely used in the CI (Abdalla et al., 2023), however, in developing countries, particularly in China, the application and development of BIM technology are still at a more rudimentary stage. For instance, in October 2019, the China Construction Industry Association (CCIA) released the "Analysis Report on BIM Applications in China Construction Enterprises," pointing out that the current level of industrialization and informatization in China's CI is relatively low, and there is still a large prospect of progress and development (CCIA, 2019). Meanwhile, some studies state that in China in 2021, the percentage of BIM implementation in the construction phase, the percentage of the level of BIM model quality, and the percentage of construction organizations that have clearly defined BIM workflows are very low, as shown in Table 1.2 (Tu et al., 2023). There are still significant gaps compared to developed countries, particularly the case in MBCPs, where the in-depth application of BIM technology is relatively lacking. Therefore, identifying critical barrier factors and challenges is of great significance for promoting the widespread application of BIM technology and the industry's overall progress.

Table 1.2 Application of BIM technology in the construction phase in China in 2021.

Different Perspective	Percentage
The percentage of BIM implementation.	48.8%
The level of BIM model quality.	27.6%
The construction organizations have clearly defined BIM workflows.	18.5%

Note: Adopted from Tu et al. (2023).

Chengdu, located in Sichuan Province, China, is the national center city of China, and the city is also the country's sixth largest megacity, with a total population of 21.192 million (Cheng, 2022). According to the China Ministry of Housing and Urban-Rural Development (MOHURD), as the core cities of China, national central cities have the two characteristics of centrality and internationality (MOHURD, 2010), and play an important central role in culture, finance, and management and at the same time promote China's international economic development and transnational cultural exchanges (Zhao & Cheng, 2017). Likewise, the city is renowned for its abundant high-quality medical resources, featuring 96 tertiary general and specialized hospitals (Xin & Ren, 2022). High-quality medical resources refer to the superior-quality assets within the healthcare service system, encompassing highly skilled medical professionals and technologies, top-quality instruments and equipment, and advanced medical information systems (An, 2011). Notably, At the first session of the 18th People's Congress of Chengdu Municipal on February 21, 2023, the report on the work of the Government emphasized the focus on improving quality to create a happy Chengdu, and it aims to accelerate the development of high-quality, livable areas. That is, Chengdu started the construction of the city center hospital, the city's brain science hospital, and 27 other major projects in medical to create 10 high-level clinical key specialties, as well as new districts (counties) medical sub-centers 15 in 2023 (General Office of the Municipal Government, 2023). Meanwhile, the Housing and Urban-Rural Development Bureau of Chengdu (BURDBC) has vigorously issued some policies to promote the use of BIM technology. Notably, on June 15, 2022, "the notice of the BURDBC to the Application of BIM Technology in the Design and Review Stages of Housing Construction and Municipal Infrastructure Projects" promulgated by the BURDBC mandates the application of BIM technology during the construction drawing and review stages for the following types of projects within the city (BURDBC, 2022), as shown in Table 1.3. Moreover, on February 27, 2023, the bureau also organized the preparation and promulgation of the "Technical Provisions for BIM Construction in Chengdu Housing Construction Projects (Trial Version)," "Technical Provisions for BIM Construction in Chengdu Municipal Projects (Trial Version)," "Technical Provisions for BIM Operation and Maintenance in Chengdu Municipal Housing Construction Projects (Trial Version)" and "Technical Provisions for BIM Operation and Maintenance in Chengdu Municipal Projects (Trial Version) (BURDBC, 2023)." In recent years, a number of positive policies have been introduced, highlighting the determination of the Chengdu Construction Industry (CCI) to reform, innovate, and develop. Given these multifaceted strengths, Chengdu emerges as an exemplary research site for this study, reflecting its dynamic integration of cultural, economic, technological, and medical advancements and more MBCP construction and renovation needs.

Table 1.3 Notices issued by BURDBC on BIM technology in 2022.

Items	Project Type	Provisions
Scope of Application	New construction projects for residential buildings.	Public and industrial building projects with a single building area greater ≥ 5,000 square meters or a building height greater than 24 meters.

Table 1.3 Continued.

Items	Project Type	Provisions
		Residential buildings exceeding 12 floors or with a total calculated building area greater ≥ 50,000 square meters.
	New (or expansion/improvement) municipal infrastructure projects.	Construction projects such as roads (excluding roads alone), bridges, tunnels, rail transit, comprehensive utility tunnels, and municipal pipelines.
Items	**Organization**	**Provisions**
Responsible Body	The construction unit has the main responsibility.	The construction unit is the main body responsible for the application of BIM technology, BIM technology service fees should be included in the project construction costs.
	The design unit is responsible for quality.	The design unit is the implementation of the BIM technology application of the main body, according to the contract agreement and the requirements of this notice application of BIM technology, and the quality of the BIM model and the consistency of the model is responsible for.
	The construction plan review organization is responsible for the review.	The construction plan review organization shall review the BIM model of the project in accordance with the requirements of this Notice and relevant regulations and shall not issue a certificate of conformity for the review of construction plan design documents if it is unqualified.
Items	**Type of requirement**	**Provisions**
Application Requirements	During the design phase of the construction drawings.	The BIM model, referred to as the "construction drawing BIM model", shall comply with the requirements of the "Chengdu BIM Design Technical Regulations (Trial Version)".
	When applying for a review of construction design documents.	The review is accompanied by the submission of 2D construction drawing design documents and construction drawing BIM models, which will be retained by the reviewing organization after passing the review.
	Specialty type requirements for BIM models.	The BIM model of the construction drawings of the building construction project shall be submitted separately for the building, structure, water supply and drainage, HVAC, and electrical specialties; the municipal infrastructure project shall be submitted for the integration of the BIM model of each specialty.

Note: Adopted from BURDBC (2022).

Table 1.3 Continued.

Items	Type of requirement	Provisions
	During the Review of construction drawings.	The construction plan reviewer shall review the construction plan BIM model for elements such as coordinates, elevation, project base, content, accuracy, and plan model consistency.

Note: Adopted from BURDBC (2022).

Although BIM technology has been widely recognized globally as a key technology for enhancing the efficiency of construction projects (Ghaffarianhoseini et al., 2017), and many governments have actively promoted its application (Z. Liu et al., 2019; Zhou et al., 2019), the in-depth application of BIM technology in China's MBCPs is still relatively limited. This phenomenon is mainly attributed to the high costs, complexity, and other factors of implementing BIM technology (Ahmed, 2018), coupled with the fact that most projects remain in the initial stages of applying BIM technology, which involves merely constructing simple BIM models. Additionally, most MBCPs adopt BIM technology at only a specific stage of the project, and cases of full-process application of BIM are extremely rare (Ren, 2018). As a result, the potential of BIM technology to enhance the design efficiency, construction management, and operation and maintenance of MBCPs has not been fully exploited (Wu et al., 2017). Furthermore, although the application and research of BIM technology in the healthcare sector are gradually increasing, there is still a lack of in-depth academic discussion on the barriers to the widespread application of BIM technology in MBCPs to date. However, given the significant market demand in China for new and renovated MBCPs and the notable advantages of BIM technology in guiding the management of complex construction projects, this technology has become an indispensable management tool in the CI and MBCPs, showing significant transformative potential in the field. Therefore, exploring the barriers to the widespread application of BIM technology in Chengdu's MBCPs is of great research significance. This study, through an in-depth analysis of MBCPs in the Chengdu area combined with online survey questionnaires targeting the management personnel, designers, and engineers involved in these projects, aims to identify the main barriers to the application of BIM technology in local MBCPs using the Relative Importance Index (RII) method. Additionally, this study will use non-parametric tests to explore whether there is a statistically significant difference in the perception of the importance of these barriers among used BIM or not used BIM, as well as different professional identities (such as managers, designers, and engineers). Finally, the study will propose targeted solutions to guide the promotion and in-depth application of BIM technology in MBCPs and the broader Architecture, Engineering, and Construction Industry (AECI) and CI, thereby promoting the digital transformation and industrial upgrading of the AECI and CI.

1.2 PROBLEM STATEMENT

With the advent of the 21st century, technological innovations have greatly propelled the evolution of the architectural physiognomy of public infrastructure. While the appearance of public infrastructure has become increasingly aesthetically pleasing, its construction techniques have also become more complex (Evangelinos & Tscharaktschiew, 2021). This trend has rendered traditional project management tools, such as two-dimensional CAD drawings and conventional quantity surveying methods, increasingly inadequate (Shen, 2018). Additionally, the "13th Five-Year Plan" period is a crucial phase for China in building a comprehensively well-off society (Commentary Department of the People's Daily, 2020), thereby placing higher demands on the construction of the healthcare system. The nation is committed to improving the basic medical system, aiming at the rational allocation of medical resources and optimizing the design of medical buildings. With the improvement of people's living standards and the enhanced pursuit of medicine, facing the challenges of a large population and intensifying aging, China's medical resources are confronted with issues of insufficient total quantity, irrational structure, uneven distribution, and weak basic service capabilities (He, 2021). Moreover, the new normal of China's economic development, accelerated industrialization and urbanization, the generalization of diseases, changes in the ecological environment and lifestyles, and innovations in medical technology, all pose higher demands for medical reform. On the other hand, the outbreak of the COVID-19 pandemic in early 2020 further exacerbated these challenges (Kaye et al., 2021).

Although it has entered the post-pandemic era, local areas still need to strengthen epidemic prevention and control, especially in constructing and renovating hospital ICUs to meet emergency needs (JPCMSC, 2023). MBCPs are typically characterized by complex functions, diverse professional systems (as shown in Figure 1.6), and property and medical facility maintenance complexity (Kahn, 2009; Enache-Pommer et al., 2010). Feasibility studies on design and construction reveal that for healthcare projects to be successful, project managers must consider many complex factors (Doulabi & Asnaashari, 2016). The diverse building components and systems, varied stakeholder demands, advanced medical technologies, specialized functionalities, different financing methods, and specific building regulations make managing the construction of medical facilities a challenging task for project managers. In the later stages of project operation and maintenance, it may be necessary to reorganize functions, rebuild, and expand according to changing needs, which requires exploring new models of information management for design, construction, and operation and maintenance that suit the characteristics of medical projects. On the other hand, in traditional design methodologies, design teams use 2D CAD drawings and related materials to convey medical design ideas to medical professionals and stakeholders. However, the lack of engineering expertise and experience makes it difficult for medical professionals and stakeholders to understand the concepts and content presented in these 2D drawings (Okada et al., 2017). In this context, the application of BIM technology has become one of the main solutions. By applying BIM technology throughout the entire lifecycle of MBCPs (Mesároš et al., 2020), it is possible not only to achieve cost control and improve construction efficiency but also to promote sustainable development, reduce energy consumption during the operation and maintenance phase, and optimize medical building service functions (Zhan et al., 2022), as shown in Figure 1.7. Therefore, BIM technology is gradually becoming a key tool and means for the management of MBCPs. However, China still has a significant gap compared to developed countries such as the USA, the UK, and Australia in the application rate of BIM technology in CI (Abdalla et al., 2023). Meanwhile, research on the potential barriers to implementing BIM technology in MBCPs remains unexplored, highlighting the importance of this research field.

Chengdu, as one of China's national central cities and its sixth largest city, also faces challenges such as population aging, disequilibrium of medical resources, and low usage rates of BIM technology (He, 2021). Therefore, in response to national policies, Chengdu has taken proactive measures to construct or reconstruct MBCPs to prepare medical resources for public health emergencies (General Office of the Municipal Government, 2023). Meanwhile, to promote the CI's digital transformation and industrial upgrading, Chengdu has also introduced several policies to encourage the application of BIM technology, as shown in Table 1.3. Therefore, this study aims to provide theoretical support and practical guidance for policy formulation and practice by conducting a thorough investigation into the critical barrier factors and challenges to the application of BIM technology in Chengdu's MBCPs through the systematic review of the literature, expert interviews, and survey questionnaires.

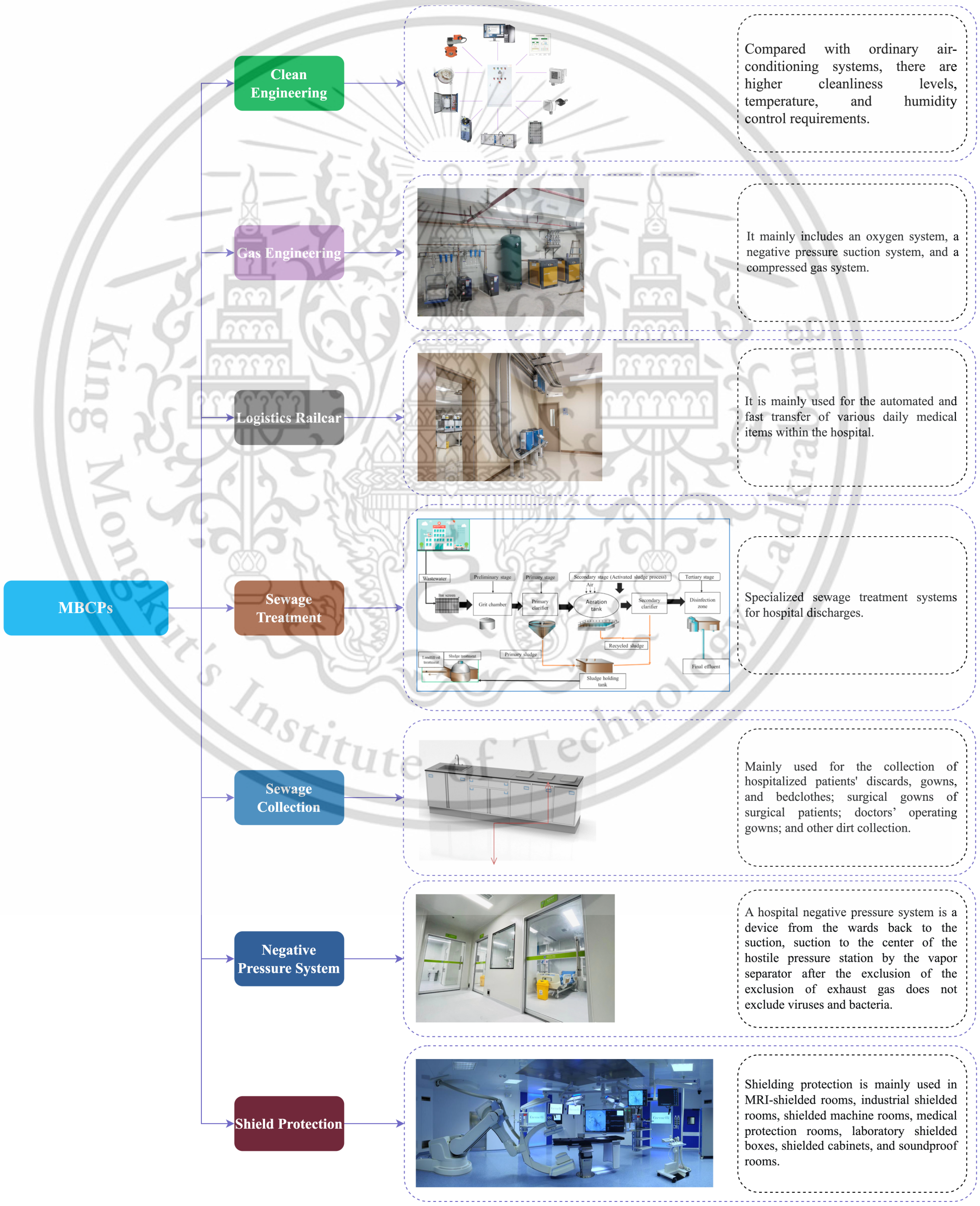


Figure 1.6 MBCPs' seven specialized systems.

Detailed list of ward wall tiles

<Detailed list of ward wall tiles>

A	B	C	D
Type	Width	Height	Area
Wall Tiles (1)	35. 000 mm	185. 000 mm	0. 006 m²
Wall Tiles (1)	35. 000 mm	185. 000 mm	0. 006 m²
Wall Tiles (1)	35. 000 mm	285. 000 mm	0. 010 m²
Wall Tiles (1)	35. 000 mm	285. 000 mm	0. 010 m²
Wall Tiles (1)	35. 000 mm	290. 000 mm	0. 010 m²
Wall Tiles (1)	35. 000 mm	290. 000 mm	0. 010 m²
Wall Tiles (1)	35. 000 mm	290. 000 mm	0. 010 m²
Wall Tiles (1)	35. 000 mm	290. 000 mm	0. 010 m²
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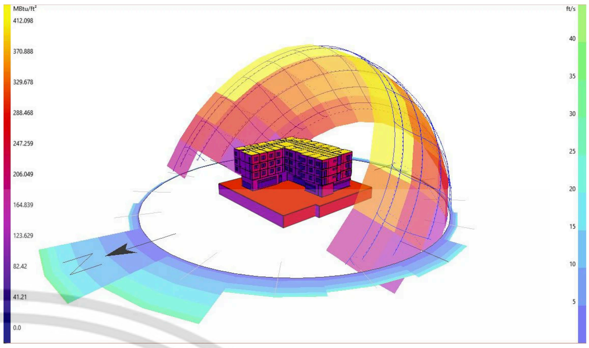
Wall Tiles (1)	35. 000 mm	290. 000 mm	0. 010 m²
Wall Tiles (1)	35. 000 mm	290. 000 mm	0. 010 m²
Wall Tiles (1)	35. 000 mm	290. 000 mm	0. 010 m²
Wall Tiles (1)	145. 000 mm	85. 000 mm	0. 012 m²
Wall Tiles (1)	145. 000 mm	85. 000 mm	0. 012 m²
Wall Tiles (1)	185. 000 mm	84. 977 mm	0. 016 m²
Wall Tiles (1)	185. 000 mm	84. 977 mm	0. 016 m²
Wall Tiles (1)	185. 000 mm	85. 000 mm	0. 016 m²
Wall Tiles (1)	185. 000 mm	85. 000 mm	0. 016 m²
Wall Tiles (1)	290. 000 mm	55. 064 mm	0. 016 m²
Wall Tiles (1)	290. 000 mm	55. 064 mm	0. 016 m²
Wall Tiles (1)	290. 000 mm	74. 988 mm	0. 022 m²
Wall Tiles (1)	300. 000 mm	74. 988 mm	0. 022 m²
Wall Tiles (1)	245. 000 mm	95. 000 mm	0. 023 m²
Wall Tiles (1)	245. 000 mm	95. 000 mm	0. 023 m²
Wall Tiles (1)	285. 000 mm	85. 000 mm	0. 024 m²
Wall Tiles (1)	285. 000 mm	85. 000 mm	0. 024 m²
Wall Tiles (1)	290. 000 mm	85. 000 mm	0. 025 m²
Wall Tiles (1)	290. 000 mm	85. 000 mm	0. 025 m²
Wall Tiles (1)	290. 000 mm	85. 000 mm	0. 025 m²
Wall Tiles (1)	135. 000 mm	190. 000 mm	0. 026 m²



(a) BIM model bill of quantities (b) BIM model energy consumption analysis

(Source: Thet (2022))

Figure 1.7 Benefits of cost control and reduced energy consumption.

1.3 RESEARCH QUESTIONS

Within the context of MBCPs in Chengdu, this study, through the systematic review of the literature, expert interviews, questionnaire surveys, and the RII method aims to deeply explore the potential, critical barrier factors, and challenges to the widespread adoption of BIM technology within Chengdu's MBCPs. The specific questions set forth by this study are as follows:

Q1: What potential factors contribute to the low utilization rate of BIM technology in Chengdu's MBCPs?

Q2: Among these factors, which are the critical barrier factors and challenges that have the greatest impact on the low utilization rate of BIM technology?

Q3: In response to the low utilization rate of BIM technology in Chengdu's MBCPs, what measures should be taken to improve the status quo the situation?

Q4: Is there a statistically significant difference in respondents' perceptions of the importance of these barriers depending on whether they have used

BIM technology in the past?

Q5: Is there a statistically significant difference in respondents' perceptions importance of these barriers by different professional status (e.g., manager, designer, and engineer)?

1.4 RESEARCH OBJECTIVES

The primary goal of this study is to identify the critical barrier factors that hinder the widespread application of BIM technology in Chengdu's MBCPs and make sound recommendations to overcome critical barrier factors. The specific research objectives are as follows:

1. Gain an in-depth understanding of the current research status of BIM technology in Chengdu's MBCPs.
2. Identify potential barrier factors hindering the widespread application of BIM technology in Chengdu's MBCPs through the systematic review of the literature and expert interviews.
3. Through questionnaire surveys and the RII method, the top six critical barrier factors and challenges to the widespread application of BIM technology in Chengdu's MBCPs are identified.
4. Analyze whether statistical significance difference in respondents' perceptions of the importance of these barriers based on whether or not they had used BIM technology in the past.
5. Analyze whether statistical significance exists on the importance of various barrier factors among different professional identities, such as managers, designers, and engineers.
6. The important objective is to formulate and offer strategic recommendations that are pragmatically oriented for the effective integration of BIM technology in Chengdu's MBCPs. This will encompass strategies tailored to overcome identified challenges and capitalize on the technology's benefits, thus paving the way for its successful implementation.

1.5 SCOPE OF STUDY

1.5.1 Include

This study, grounded in the systematic review of the literature and expert interviews, meticulously developed an online survey questionnaire to delve into the current state of BIM technology application and critical barrier factors and challenges in Chengdu's MBCPs. The survey targeted managers, designers, and engineers from 48 construction companies that have undertaken MBCPs in Chengdu; details are shown in Table 1.4.

Table 1.4 The object, location, population, and time of this study.

Radius	Specific Content
Research Object	Medical Building Construction Projects (MBCPs)
Scope of Location	Chengdu, Sichuan Province, China.
Scope of Population	Managers, designers, and engineers of construction companies that had undertaken MBCPs in Chengdu.
Scope of Time	Data was collected between August and December 2023.

1.5.2 Not Include

This study does not include related matters that are not related to MBCPs, as detailed below.

1. Non-Chengdu MBCPs: This study will not consider the application of BIM technology in non-Chengdu MBCPs, nor will it involve construction projects in other industries or fields.
2. Construction enterprises in other countries or regions: This study only focuses on 48 construction companies that have undertaken MBCPs in Chengdu and will not investigate the application of BIM technology by construction enterprises in other countries or regions.
3. Participants who are not managers, designers, and engineers: This study only targets management, designers, and engineers who have undertaken MBCPs in Chengdu, excluding employees in other positions or external stakeholders.

1.6 RESEARCH METHODOLOGY

This study fully combines qualitative and quantitative research, and the research framework is shown in Figure 1.8.

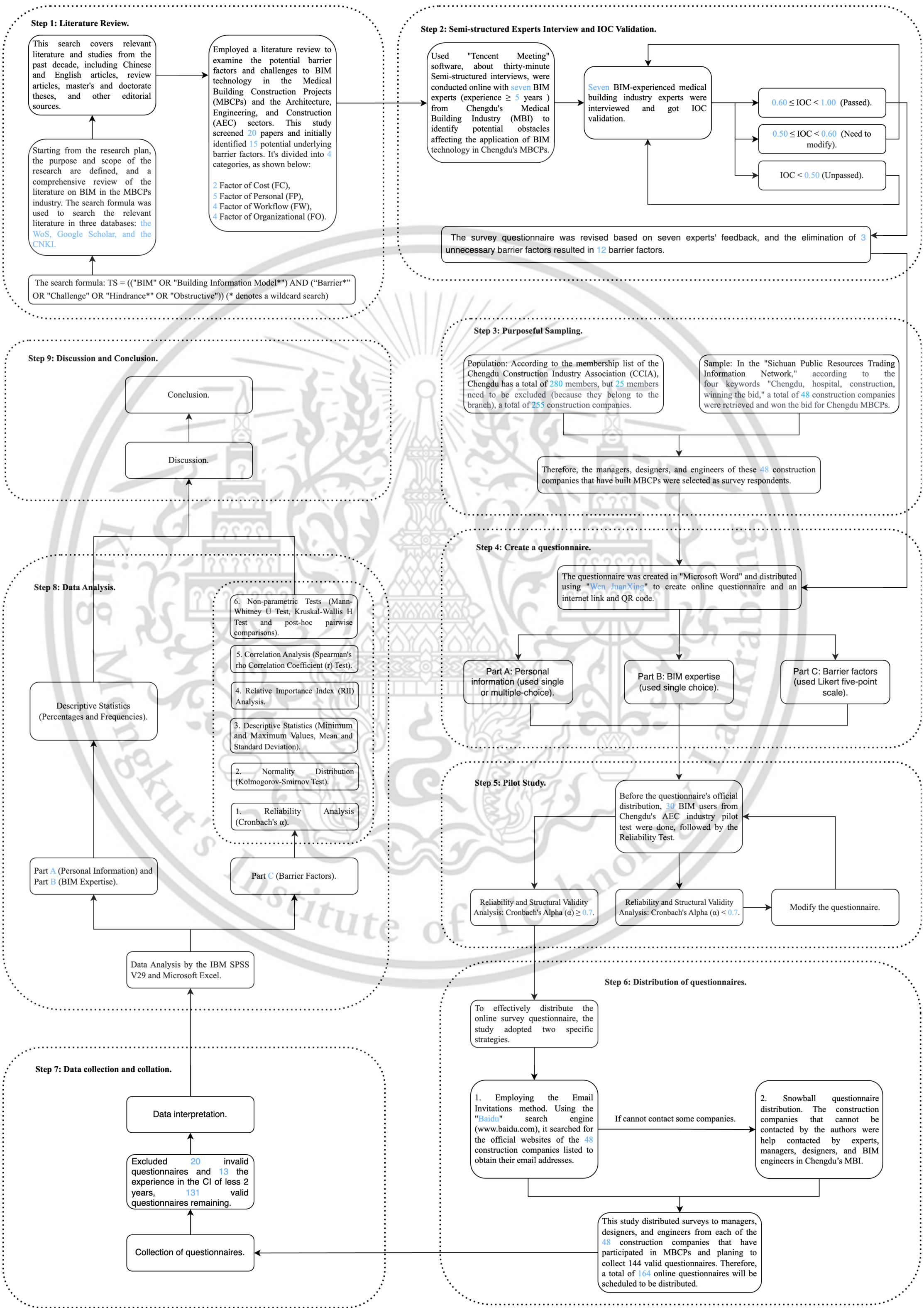


Figure 1.8 Research framework of this study.

This study aims to explore the barrier factors and challenges to the widespread application of BIM technology in MBCPs in Chengdu, employing a mixed-methods approach, namely (1) qualitative research and (2) quantitative research. This section introduces the research methods adopted to achieve the objectives of the study and addresses the research questions. Details are shown below.

Step 1: The systematic review of the literature and hypothesis formulation. The study begins with a clear definition of its objectives and scope. The study used three databases to search for the relevant literature: the Web of Science (WoS), Google Scholar, and the China National Knowledge Infrastructure (CNKI). A comprehensive review of the literature on BIM in the MBCPs domain helps identify and categorize barrier factors and challenges to BIM implementation, which are further developed into survey questions.

Step 2: Semi-structured expert interviews and Item-Objective Congruence (IOC) validation. This study used "Tencent Meeting" software, about thirty-minute online Interviews, and IOC validation conducted with seven BIM experts from Chengdu's MBCPs. The survey questionnaire was revised based on their feedback, and the elimination of 3 unnecessary barrier factors resulted in 12 barrier factors. In addition, these barrier factors were divided into four categories: Cost Factor (CF), People Factor (PF), Technical Factor (TF), and Organizational Factor (OF).

Step 3: Purposive sampling. Based on the member list of the Chengdu Construction Industry Association (CCIA), there are 280 members in total, excluding 25 members (as they belong to a sub-association), leaving 255 construction companies. Using the "Sichuan Public Resources Trading Information Network" and the keywords "Chengdu, hospital, construction, winning bid," 48 construction companies winning bids for Chengdu MBCPs are identified. Hence, managers, designers, and engineers from these 48 construction companies are selected as survey participants.

Step 4: Online survey questionnaire development. The questionnaire was initially created in Microsoft Word and then developed into an online survey using the China online survey platform "Wen Juanxing," which facilitates data collection via web pages and QR codes. The online questionnaire survey mainly includes three parts: Part A: Personal information (Single or multiple-choice), Part B: BIM expertise (Single choice), and Part C: Barrier factors (Using a five-point Likert scale).

Step 5: Pilot study. A pilot study was conducted with 30 BIM users in Chengdu with extensive experience in the AECI, followed by a reliability and validity analysis. The next step proceeds only if Cronbach's Alpha > 0.7; otherwise, the survey questionnaire is revised.

Step 6: Distribution of online survey questionnaires. For effective distribution, the study employs email invitations and a snowballing approach to disseminate QR codes and web links of the online survey. Email invitations are first sent out after obtaining contact information and emails from the official websites of the 48 construction companies via the popular China search engine website "Baidu." The snowballing distribution method is used for companies that could not be contacted directly, with assistance from experts, managers, designers, and engineers in the Chengdu medical construction field.

Step 7: Data collection. This step aims to exclude invalid questionnaires.

Step 8: Data analysis. The study uses the Statistical Package for the Social Sciences (SPSS) V29 in conjunction with Microsoft Excel for data processing and calculation. The quality of the questionnaire is measured through validity and reliability. Cronbach's alpha coefficient is used to assess reliability, and descriptive statistics such as mean, standard deviation, and percentage are used to analyze descriptive data. The Kolmogorov-Smirnov (K-S) test was conducted to assess the normality of the data. Furthermore, the RII is used to rank the barriers in the questionnaire, and the Mann-Whitney U (M-W U) Test is employed to determine whether there is a statistically significant difference in the respondents' perceptions of the importance of these barrier factors by whether they have used BIM technology in the past or not, and the Kruskal-Wallis H (K-W H) Test is explored whether there are statistically significant differences in the perception of the importance of these barriers among different professional identities (such as managers, designers, and engineers), and after identifying significant differences, post-hoc Dunn-Bonferroni pairwise comparisons will be conducted to elucidate the specific group differences further.

Step 9: Discussion and conclusion. The research will provide targeted recommendations for these critical barrier factors, challenges, and improvement strategies for future applications, which will promote the effective use and widespread adoption of BIM technology in Chengdu and other regions or other the CI.

1.7 EXPECTED RESULT

This research aims to make significant contributions to the field of BIM technology application, particularly within Chengdu's MBCPs, by addressing several key objectives. The expected outcomes of this study can be categorized as follows:

1. To understand the current state of research and the advantages associated with the application of BIM technology in Chengdu's CI and MBCPs.
2. Identify potential barrier factors affecting the widespread application of BIM technology in Chengdu's MBCPs.
3. The top six critical barrier factors and challenges affecting the widespread application of BIM technology in MBCPs in Chengdu are clearly identified.
4. There was a statistically significant difference in the respondents' perceptions of the barrier factors of the different impediments, whether or not they had used BIM technology in the past.
5. There were also statistically significant differences in the respondents' different occupational statuses (e.g., manager, design, and engineer) perceptions of the importance of different barrier factors.
6. Based on the identified critical barrier factors and challenges and the insights gained from the comparative analysis, this study will provide some feasible recommendations for overcoming the key impediments to promote higher BIM adoption rates in Chengdu's CI and MBCPs.
7. It provides reference and encouragement for actively promoting the wider application of BIM technology in other regions and in AECIs and CIs, thereby facilitating industry-wide industrial upgrading and digital transformation.

In summary, this research is poised to offer valuable insights and solutions that could significantly impact the application of BIM technology in Chengdu's MBCPs and beyond. By addressing both the theoretical and practical aspects of BIM adoption, the study has the potential to facilitate a greater understanding and utilization of BIM, contributing to the advancement and digital transformation of the AECI and the CI sectors.

CHAPTER 2

RELEVANT THEORY

2.1 BUILDING INFORMATION MODELING (BIM)

2.1.1 Conceit of BIM

The application of digitization in the AEC sector is increasingly being recognized as an emergent technological means to address the complexity of the industry (Shi et al.; Bryde et al., 2013). Currently, the workflow in this sector involves multiple parallel operations that require proper management to tackle a range of challenges including low productivity, poor quality, increased costs, construction waste, project delays, and insufficient information sharing (Ullah et al., 2019a; Hire et al., 2022). BIM technology is considered to aid in the effective management of business processes, thereby addressing challenges in the AEC sector and improving the overall industry performance (Abanda & Byers, 2016; Santos et al., 2019). As BIM technology gradually replaces CAD software, its application in the industry is becoming more widespread, potentially serving as a key factor in driving deeper digital adoption (Salamak et al., 2018; Begić & Galić, 2021).

In 1975, Professor Chuck Eastman of Georgia Institute of Technology, known as the "Father of BIM," established the concept of BIM (Sun et al., 2017). The enlightenment of the BIM concept was influenced by the global oil crisis in 1973, which necessitated the entire American industry to consider improving industrial efficiency. Therefore, in 1975, the "Father of BIM," Professor Eastman, proposed "a computer-based description of a building" in his research project "Building Description System" to facilitate the visualization and quantitative analysis of construction projects, thereby enhancing construction efficiency (Reddy, 2011; Mohd & Ahmad Latiffi, 2013). However, the dissemination of this concept was slow until 2002, when Autodesk officially released the "BIM White Paper," and the term "Building Information Model" was first popularized (Borkowski, 2023a). Moreover, Jerry Laiserin, the godfather of BIM, defined the connotation and extension of BIM and promoted its widespread adoption in April 2003 (Howell & Batcheler, 2005). The concept of BIM is rapidly gaining popularity and acceptance (Xiaolin et al., 2014). Following its gradual promotion abroad, China also joined the international ranks of BIM research.

In the initial encounter with BIM, the key lies in clearly defining the essence of BIM and its non-essential elements. BIM is not merely a software application, as some perspectives have pointed out. The core of the BIM process is not just about creating impressive three-dimensional models or achieving realistic visual effects; it represents a thorough transformation of the current state of the CI, signifying the emergence of a new paradigm of working methods. Throughout the entire architectural project process, BIM offers a new way of organizing work. Moreover, the BIM model represents a system of knowledge and information about the architectural object, supporting decisions throughout its entire lifecycle.

However, the concept of BIM is understood and defined in various ways. Eastman and his team define BIM as a collaborative method for storing, sharing, exchanging, and managing multidisciplinary information throughout the entire lifecycle of a construction project (including planning, design, construction, operation, maintenance, and demolition stages) (Eastman, 2011). Eastman emphasizes that BIM is a human activity, not just a constructed model. Moreover, the National Institute of Building Sciences (NIBS) in the United States defines BIM as "a digital representation of the physical and functional characteristics of a facility, serving as a knowledge resource for information sharing (NIBS, 2023)." Isikdag and Underwood (2010) view BIM as an information management process throughout the entire lifecycle of construction, focusing on the collaborative use of semantically rich three-dimensional BIM. Azhar et al. (2012) note that BIM extends far beyond software and technology; it involves significant changes to the workflow and delivery processes of design and construction. Moreover, researcher Borkowski (2023b) has suggested that the definition of BIM can also be understood from each of three different perspectives, as shown in Figure 2.1 follow.

Therefore, this study defines BIM technology as a process based on intelligent 3D models designed to integrate digital information, enabling professionals in architecture, engineering, and management to plan, design, construct, and manage buildings and infrastructure more efficiently. It not only facilitates collaboration and information sharing among project teams but also optimizes design and construction plans by supporting visualization, simulation, and analysis, enhancing building performance and the sustainability of the project.

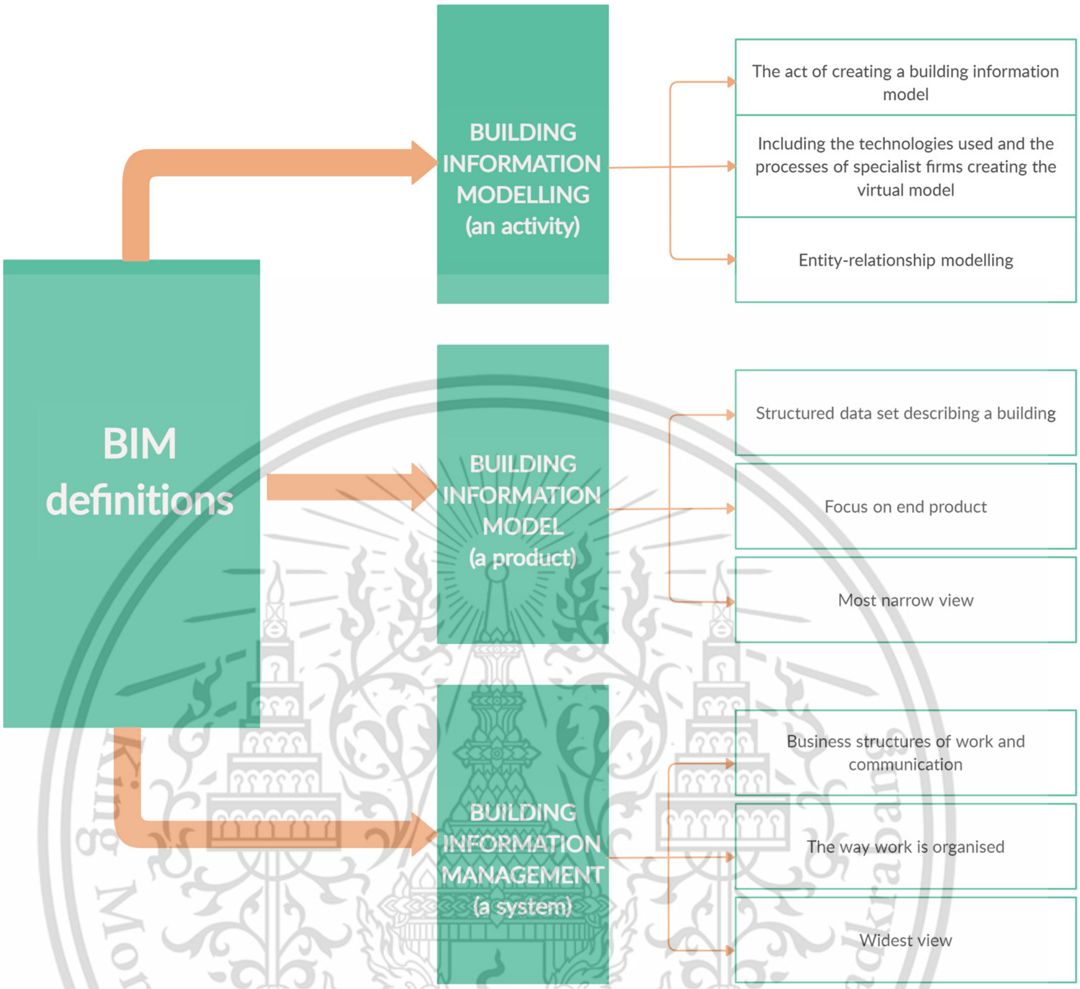


Figure 2.1 Variations in perspectives on BIM definitions (Source: Borkowski, 2023b).

2.1.2 History of BIM

Building Information Modeling (BIM) technology, as a revolutionary digital tool, has profoundly changed the design, construction, and management methods of the architecture industry. Since its inception in the early 1970s, BIM technology has undergone a long development process from concept introduction to widespread application.

In the 1970s, with the initial development of computer technology, the architecture industry began to explore digital design methods. The earliest attempts included simple two-dimensional drawing and calculation programs, which can be considered the embryonic form of BIM technology (Eastman, 1975). Eastman, one of the pioneers of the BIM concept, proposed a method to create and manage architectural project information using CAD systems.

Entering the 1980s and 1990s, with the rapid development of computer hardware and software technologies, BIM technology began to take shape gradually. During this period, the concept of multidimensional modeling emerged, allowing designers to handle spatial geometric information and related property information of projects in an integrated environment (Lee et al., 2006). This marked a key step in the transformation of BIM from a simple drawing tool to a comprehensive project information management tool.

In the early 21st century, BIM technology entered a stage of rapid development and widespread application. The International Organization for Standardization (ISO) and other bodies began to develop relevant standards and protocols to promote the international application and data exchange of BIM technology (British Standards Institution, 2019). Meanwhile, the introduction of BIM software such as Revit and ArchiCAD greatly promoted the application of BIM technology in architectural design, construction management, and facility operation.

In recent years, with the integration of advanced technologies such as cloud computing, big data, and artificial intelligence, BIM technology is developing in a more intelligent and efficient direction. The combination of these technologies not only enhances BIM's computational power and data processing capabilities but also makes it possible to achieve full lifecycle management of buildings (Succar, 2009).

In summary, the development of BIM technology is closely linked to the advancement of computer technology and the changing demands of the architecture industry. From the initial two-dimensional drawing to the current intelligent building information management, BIM technology has become an indispensable tool in the modern architecture industry. In the future, with continuous technological advancements, BIM is expected to play a greater role in improving the efficiency of architectural projects, reducing costs, and promoting sustainable development. Moreover, researcher Borkowski (2023b) summarized the timeline of major events and various conceptual developments in the field of BIM as shown Figure 2.2 below.

2.1.3 Levels Maturity of Application of BIM

Another approach to describing the characteristics of BIM involves defining the maturity levels of information technology applications in the construction sector. This

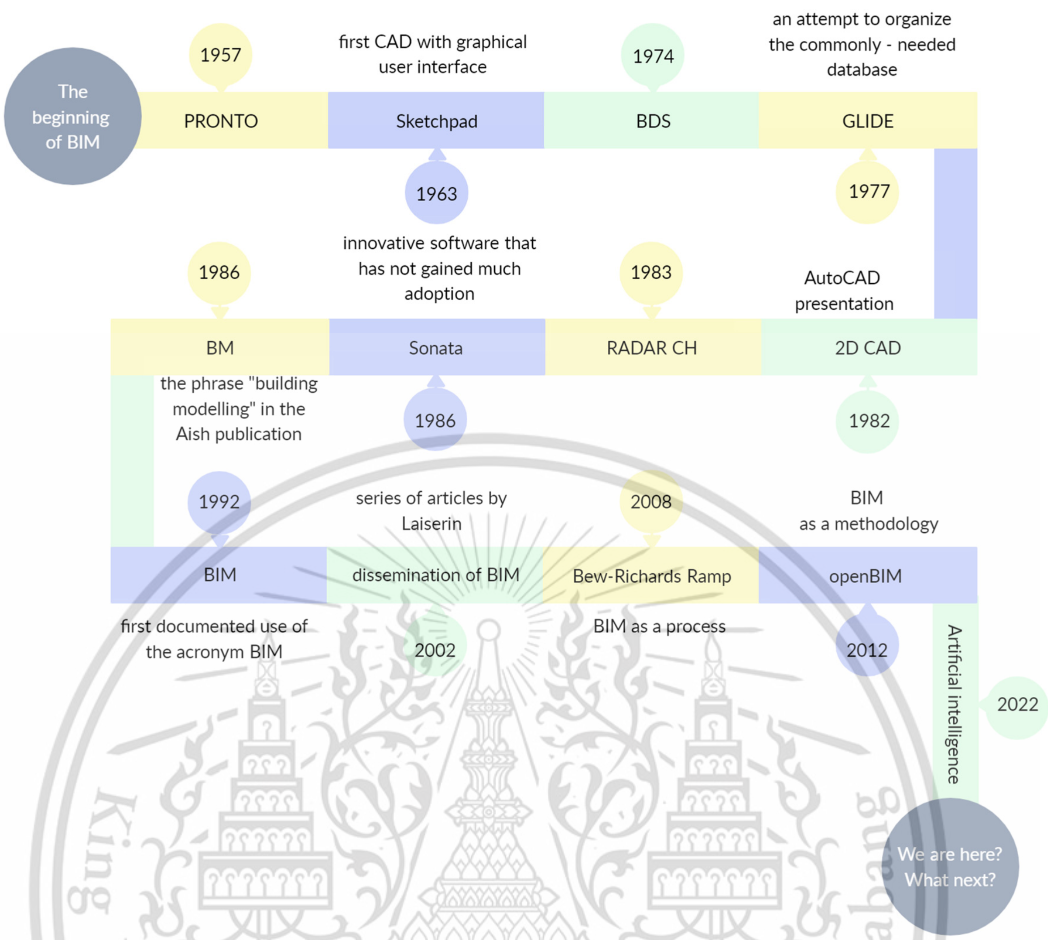


Figure 2.2 The timeline of the progression of numerous concepts and significant events (Source: Borkowski, 2023b).

not only reflects the degree of collaboration but also encompasses the complexity of tool usage. From this perspective, BIM is considered a multi-stage process that starts with CAD, leading the industry into the digital era. Since the UK government's BIM Task Group introduced the concept of "BIM Levels," the following figure and its definition of four levels (Level 0 to Level 3) have been widely accepted as the basic definition of whether a project complies with BIM standards (Sacks et al., 2018). In Figure 2.3, "BS Standard Number" refers to the standards set by the British Standards Institution, and the description of each level is defined according to the BS Standards. The four BIM levels are defined as follows:

Level 0 BIM is characterized by unmanaged CAD processes, predominantly in 2D formats, with information dissemination primarily through traditional paper drawings or digital PDFs, representing isolated data sources that cover basic asset details. The industry has largely surpassed this stage.

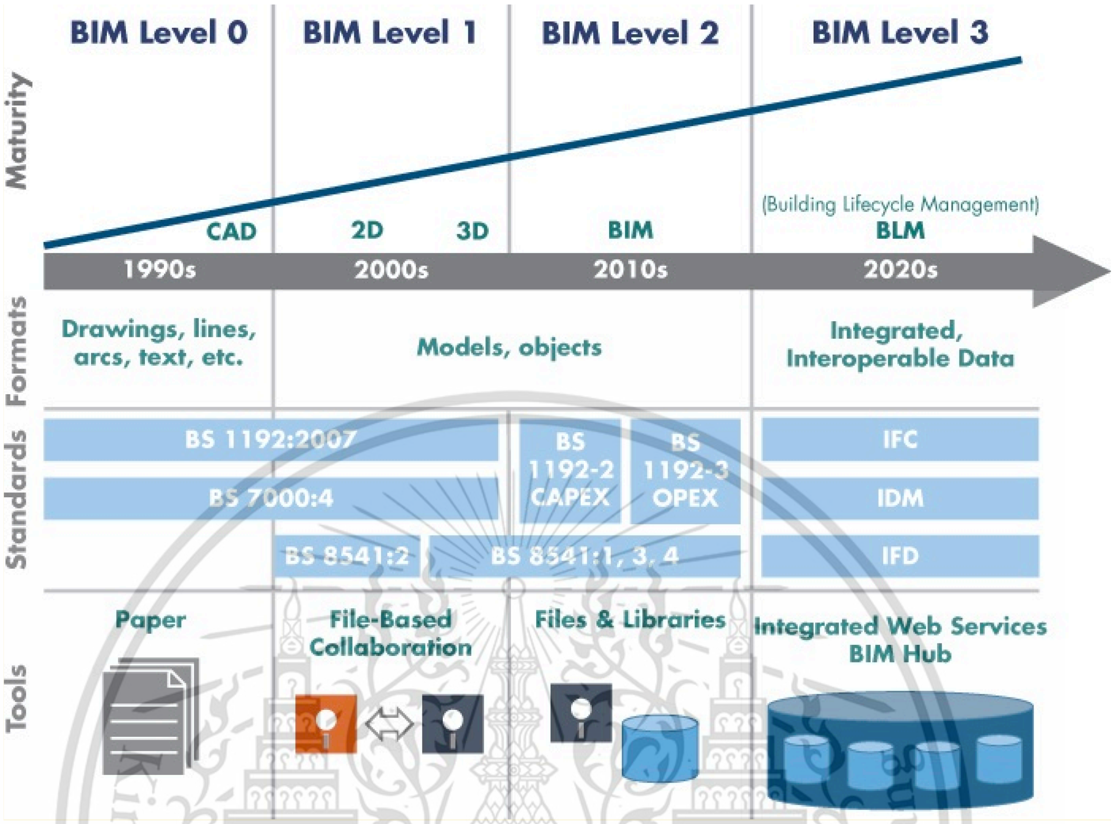


Figure 2.3 BIM maturity model (Source: Sacks et al., 2018).

Level 1 BIM reflects the operational standard for numerous companies, incorporating a hybrid approach of 3D CAD for conceptual designs and 2D for the drafting of statutory approval documents and production information. CAD standards adhere to BS 1192: 2007, with data exchange facilitated through a Common Data Environment (CDE), typically overseen by the contractor. At this level, model sharing among project team members does not occur.

Level 2 BIM is marked by a collaborative approach, wherein each party utilizes independent 3D models without contributing to a unified, shared model. The essence of collaboration at this stage lies in the method of information exchange among various stakeholders. A common file format for design information sharing allows for the integration of data into a federated BIM model for comprehensive analysis. Therefore, compatibility with a common file format, such as IFC (Industry Foundation Classes) or COBie (Construction Operations Building Information Exchange), is mandatory for any CAD software used, aligning with the UK government's minimum requirement for public sector projects by 2016.

Level 3 BIM signifies the pinnacle of collaboration across all disciplines through a single, unified project model stored in a central repository, typically a cloud-based object database. This arrangement enables all participants to access and modify the model, thereby eliminating the risk of information discrepancies. This stage is referred to as "Open BIM."

2.1.4 Level of Development (LOD)

Essential characteristics of a BIM model include digital representation and parametric modeling for dynamic manipulation, storage of component and object data, automatic updates of changes across views and assemblies, and coordinated data management (Hire et al., 2022). The American Institute of Architects (AIA) defines a BIM model as a digital depiction of a project's physical and functional traits. The detail within a BIM model dictates its classification, providing insights into the model's content.

To offer information on the content of the model, the BIM model is categorized in several ways based on the degree of detail in its characteristics. A model's level of development (LOD), which defines and makes clear the dependability and content of the BIM model, promotes communication, and aids in comprehending the model's limitations and usability, must vary depending on its intended use (Biljecki et al., 2016). The LOD, defined based on informational needs, spans from 100 to 500, facilitating straightforward and efficient modeling that yields dependable data. Figure 2.4 displays details on each LOD attribute. Moreover, each level represents specific content requirements, authorized use of the model, and specific purpose of the model (Porwal & Hewage, 2013), as shown in the following.

LOD 100 addresses the conceptual phase, showcasing the project's initial design and enabling basic analyses such as building orientation and preliminary sustainability considerations.

LOD 200 pertains to the schematic design phase, offering approximate geometries and essential generic object information—like size, quantity, and spatial relationships—allowing for performance analyses and cost estimations.

LOD 300 provides detailed geometries and specific object information, mirroring construction documentation. This level supports comprehensive energy performance analyses and the extraction of precise material quantities for sustainability purposes.

LOD 400 introduces detailed geometries suitable for fabrication and assembly processes, initiating coordination among various project disciplines.

LOD 500 denotes the post-construction as-built phase, furnishing models for facility management throughout the building's lifecycle.

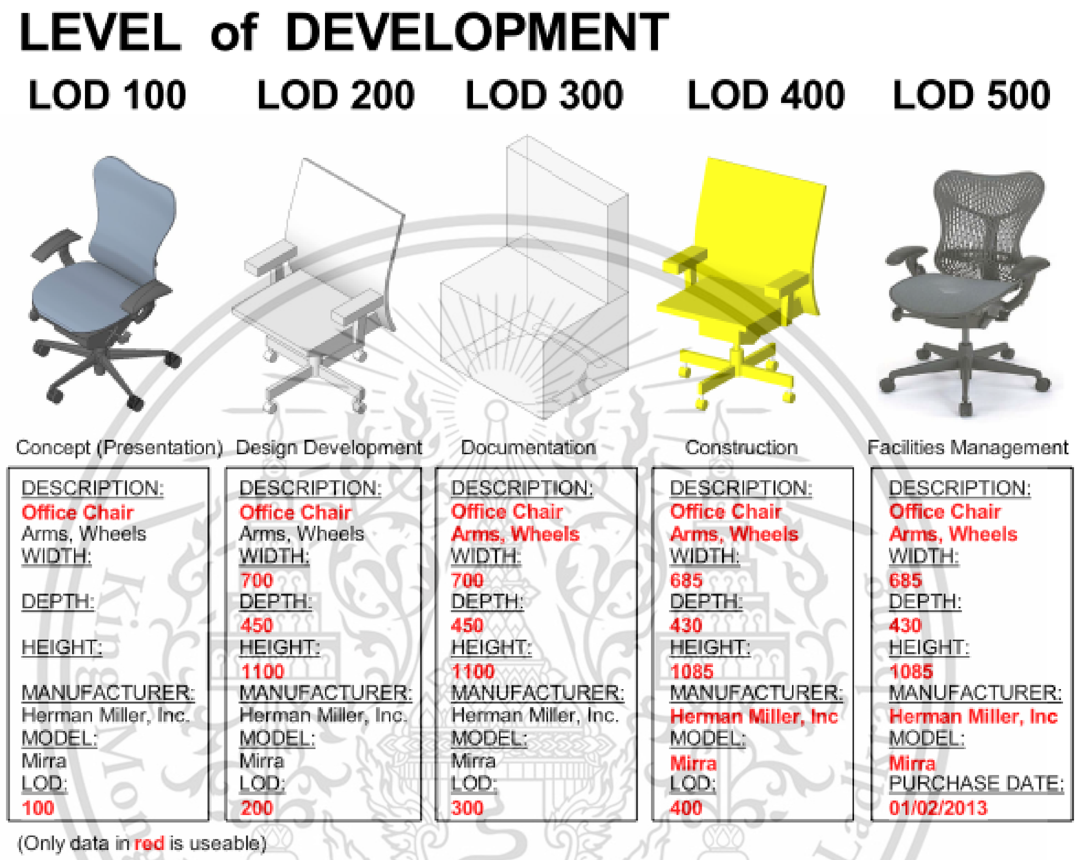


Figure 2.4 The Level of LOD (Source: McPhee, 2013).

2.1.5 Software of BIM

In discussing the technology of BIM and its applications in the AECO industry, it is important to recognize that while BIM offers significant benefits and opportunities, different companies adopt varying implementation strategies based on their specific business needs and areas of activity (such as project development, budgeting, or project management). Therefore, companies must first clearly identify their goals and requirements and then choose the software or combination of software that best suits these goals. Choosing the right BIM tools, although requiring an initial investment of time and energy, can, in the long run, save time and costs and enhance the efficiency and effectiveness of construction processes. Table 2.1 shows some of the BIM software currently in common use in the AECO industry by purpose of use, as shown below.

This highlights the potential of BIM technology to revolutionize the industry by improving project management efficiency, optimizing the design and construction process, and reducing project risks. Among them, Autodesk Revit is currently one of the most popular BIM software programs on the market, used by BIM architects, BIM engineers, and building professionals around the world due to its comprehensive functionality and lower cost of use (Educadd, 2022).

2.1.6 Dimensions of BIM

BIM significantly influences the entire lifecycle of a building, encompassing aspects such as visualization, documentation, management, cost planning, maintenance, operation, detailed analysis, logistics, and demolition (Bryde et al., 2013; Heaton et al., 2019). It extends beyond the 3D model to support various applications across multiple dimensions (Koutamanis, 2020). The advent of n-dimensional (nD) BIM has redefined the concept of "dimension" to denote application domains or uses rather than merely spatial considerations. BIM incorporates multiple dimensions, each enhancing the model's capabilities at different stages of the lifecycle, a topic that has garnered extensive discussion among researchers to foster a unified understanding of the relationship between nD and BIM applications for maximal utilization (Boje et al., 2020).

Table 2.1 Commonly used BIM software.

Use target specialty	BIM Tools
Architecture	Autodesk Revit Architecture ArchiCAD Vector works SketchUp Rhino + Grasshopper AutoCAD Architecture Allplan MicroStation Bentley Architecture
Structure	Autodesk Revit Structure Tekla Structures Bentley Structural SAP2000 ETABS STAAD. Pro

Table 2.1 Continued.

Use target specialty	BIM Tools
	RAM Structural System Robot Structural Analysis
MEP	Autodesk Revit MEP AutoCAD MEP Bentley-Building Electrical Systems Bentley Mechanical Systems Design Builder IES VE TRACE 700
Visualization	Lumion 3Ds Max Blender Cinema 4D Twinmotion Escape KeyShot
Energy Analysis	Autodesk Ecotect Analysis Autodesk Green Building Studio Energy Plus Design Builder IES VE Open Studio ArchiCAD EcoDesigner Insight 360
Projects Management and Engineering Cost Estimate	Autodesk Navisworks Synchro Solibri Vico Software Volare/TCPO Primavera Microsoft Project Tron-orc Orca Plus

Note: (Adapted from: Onur & Nouban, 2019; Landim, 2020)

The nD theory is an extension of the 3D BIM model applications by including different aspects of design information required for different stages of a building life cycle (Charef et al., 2018). The third dimension (3D) represents the visualization capacity of BIM through a spatial representation of the project (Hire et al., 2022).

By augmenting the 3D model with a virtual representation of time, the 4D materialized. This dimension incorporates timing data into the model to enable temporal representation, analysis, and viewing of the BIM process. Scheduling and planning in construction are the primary 4D application domains (Charef et al., 2018; Boje et al., 2020; Koutamanis, 2020; Sertyesilisik et al., 2021). Some authors consider 4D to be the final dimension of Building Information Modeling (BIM), as the ability to calculate additional features using 4D BIM attributes and data is associated with higher dimensions. Furthermore, 3D and 4D data are frequently regarded as essential components of any BIM program (Koutamanis, 2020).

However, the consensus among the majority of authors is that a fifth dimension (5D) exists, which is defined as the incorporation of the cost component into the BIM model (Boje et al., 2020; Koutamanis, 2020). Real-time cost information provided by 5D enables planning and expense management. It facilitates the construction of more sustainable, cost-effective, and efficient structures (Vigneault et al., 2020; Sertyesilisik et al., 2021).

There is a dearth of agreement in the realm of research beyond the fifth dimension (Koutamanis, 2020; Wildenauer, 2020). Other application fields, including but not limited to sustainability, FM, accessibility, safety, energy conservation, acoustics, lean construction, and site monitoring, have been explored with the aim of fully harnessing the potential of BIM. These activities offer novel approaches to accessing and applying nD data, hence introducing increased intricacy and input data, ultimately resulting in the expansion of nD (Charef et al., 2018; Boje et al., 2020).

Sustainability emerges as the most formidable contender for the 6D. Furthermore, this encompasses other dimensions of building performance, including energy, environmental, and acoustic performance (Hire et al., 2022). 86% of practitioners in a web-based study of 28 EU member states concurred that sustainability should be incorporated into BIM 6D (Charef et al., 2018).

With considerable acceptability among practitioners, the 7D is frequently denoted as the FM domain. Its objective is to manage, preserve, and support the facility during its complete life cycle (Sertyesilisik et al., 2021).

As new standard measurements are being established, existing ones are being supplemented. Although the 8D is not frequently discussed in the literature, a few authors have identified its potential relevance in the realm of safety or accident prevention (Kamardeen, 2010).

9D and 10D domains pertaining to the application of Lean construction and industrialization have been the subject of discussion with even fewer references, respectively. The 9D, which falls within the purview of LEAN, endeavors to enhance and streamline the project execution procedure by means of digitalizing processes (Biblus, 2018). The objective of the 10D is to increase sector productivity in the building industry by integrating physical, commercial, environmental, and other data with modern technologies (José, 2019; Piaseckiene, 2022).

An overview of all the defined and recognized dimensions of BIM is illustrated in Figure 2.5 Despite the established dimensions of BIM, ambiguity and misunderstanding persist regarding dimensions beyond 5D, limiting the realization of potential benefits. Addressing this issue requires a consistent approach and the development of appropriate standards to achieve a common understanding of all BIM dimensions.

2.1.7 Application of BIM

Compared to existing technologies, one of the significant distinctions of BIM technology in the design and construction fields is its potential capability to encompass all participants and processes throughout the project lifecycle (Bylund & Magnusson, 2011), rather than being confined to a single discipline or process. This highlights the integrative and interdisciplinary advantages of BIM. At the initial stage of formulating a BIM project execution plan, a key step is to clearly identify the applicable scenarios of BIM based on the goals of the project and team. This means that in the early planning phase of the project, the team needs to face the challenges and opportunities of defining the best application mode of BIM according to the specific characteristics of the project, the goals and capabilities of the participants, and the required risk allocation. The comprehensive utilization of BIM can benefit numerous tasks, and the valuable dataset it provides throughout the project helps owners and decision-makers make more informed decisions during the planning, design, construction, and operation phases.

It is noteworthy that the application needs of BIM are formulated based on the project requirements and goals of the owner (Belcher & Abraham, 2023). Therefore,

Figure 2.5 Dimensions of BIM (Source: Biblus, 2018).

the application scope of BIM is extensive, covering all stages of the project lifecycle, from conceptual design to operation and maintenance (Vignali et al., 2021). BIM is regarded as an infrastructure that can be efficiently applied during the early design feasibility stage of the project and the operation and maintenance process after construction, which reflects its adaptability to the continuity and chain reaction characteristics of various stages of the project lifecycle. Clearly, to ensure that the added value of BIM meets the expectations of employers and contractors, it is crucial to precisely define the domains of this technology's application throughout the entire project lifecycle.

In addition, some scholars have also categorized the main applications of BIM technology into four parts: planning, design, construction, and operation, as shown in

Figure 2.6.

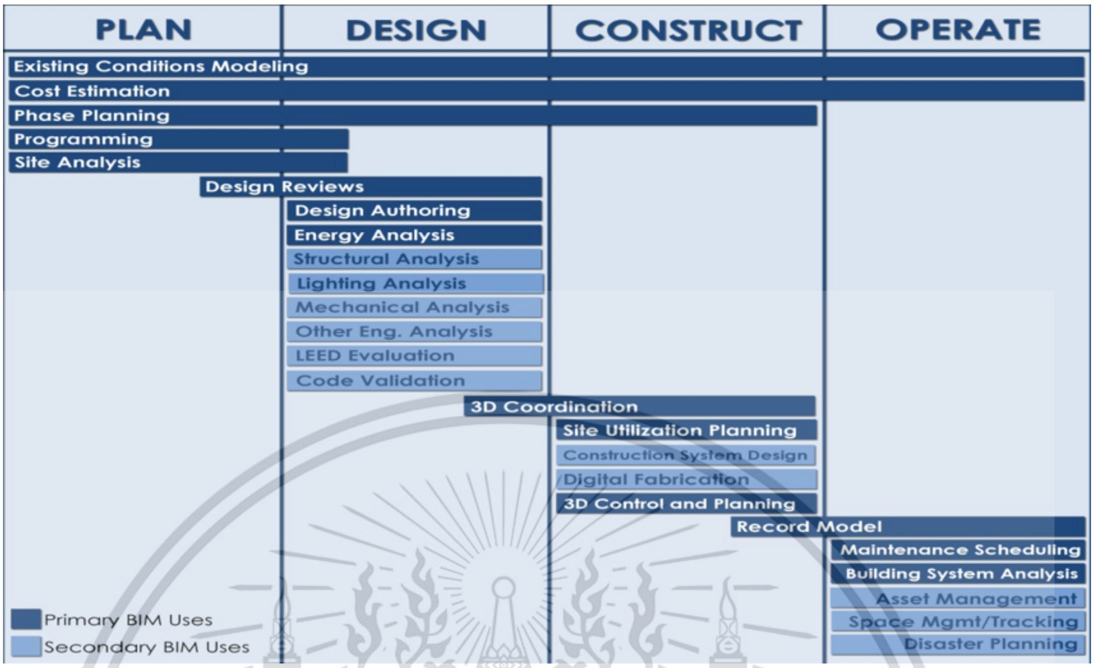


Figure 2.6 Application of BIM technology Across the Building Lifecycle (Source: Messner et al., 2019).

2.1.8 Benefits of BIM

BIM is a revolutionary digital technology that allows professionals in the AECI to design, build, and manage construction projects in the form of three-dimensional models. The implementation of BIM goes beyond the traditional two-dimensional drawing and modeling methods to provide a more dynamic, interactive, and integrated project management framework. Numerous international studies have demonstrated that the implementation of BIM in the AECO sector can yield numerous advantages. These advantages consist of the following: enabling stakeholder and public participation, facilitating interdisciplinary communication and coordination, enhancing productivity and business outcomes, and enhancing customer service (Rogers et al., 2015; Hosseini et al., 2016).

The implementation of BIM can yield several benefits during the design and construction phases, including cost reduction or financial gain (Azhar, 2011), project duration reduction, enhanced information exchange and management, improved design quality and outcomes, enhanced interoperability and information visualization, improved decision making, efficient data and information assembly, and the development of a forward-thinking approach (Doumbouya et al., 2016; Gerges et al., 2016; Matarneh & Hamed, 2017). A number of project stakeholders also gain advantages from the implementation of BIM throughout these phases. To illustrate, the utilization of BIM can provide architects with the ability to generate digitized construction documents, graphically accurate models, and 3D renderings (Eastman, 2011), as shown in Figure 2.7. Similarly, quantity surveyors can benefit from BIM by conducting quantity takeoffs, estimations, and cost planning during the design phases that are more precise (Stanley & Thurnell, 2014). BIM also provides contractors with increased profitability, enhanced customer service, improved teamwork, safety planning and management, construction planning and monitoring, enhanced construction scheduling, and progress tracking during the construction phase (Volk et al., 2014; Hong et al., 2019).

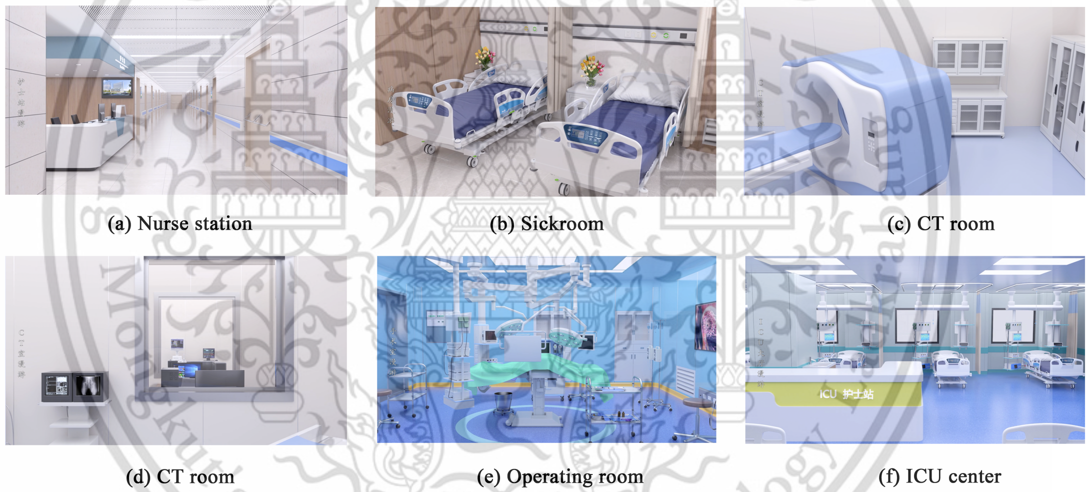


Figure 2.7 BIM model rendering for MBCPs.

BIM can improve sustainability and environmental performance, occupancy, and full lifecycle asset management throughout the operation and maintenance phase of a structure (Doumbouya et al., 2016; Pärn et al., 2017). The adoption of BIM can provide building owners with the ability to attain their intended results, generate tangible business advantages, and execute retrofit strategies to optimize space utilization, reduce material and fuel consumption, and enhance configuration management (Volk et al., 2014). BIM provides the following advantages to facility managers responsible for buildings over their lengthy operational lifecycles: data precision, asset visualization, effective data retrieval and storage, energy and space management, resource allocation, and quality control (Love et al., 2014; Pärn et al., 2017), as shown in Figure 2.8.

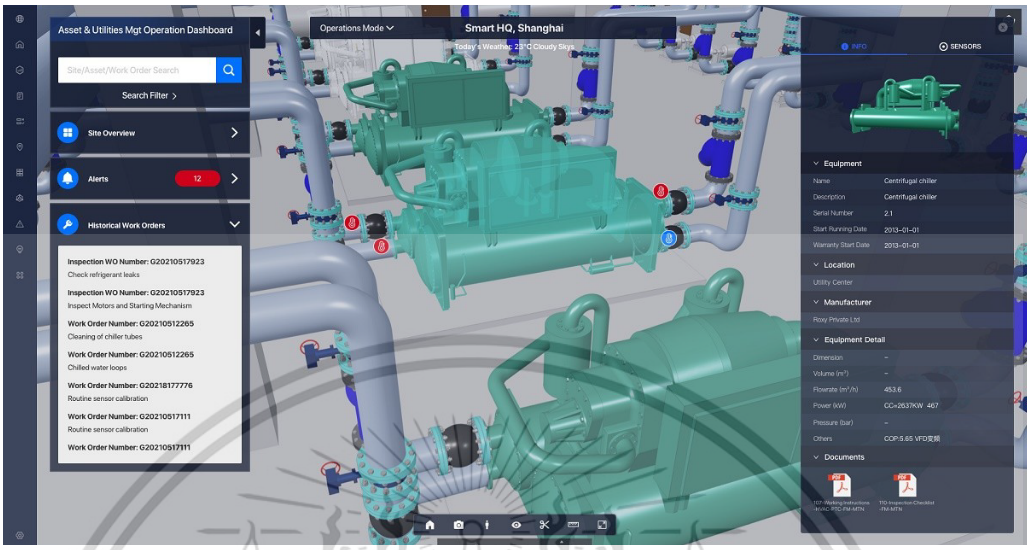


Figure 2.8 BIM Facility Management (FM).

In addition, researchers Quoc et al. (2022) have summarized the benefits of applying BIM technology to project stakeholders in the CI in more detail, as shown in Table 2.2 below.

Table 2.2 Advantages of BIM for stakeholders in construction projects.

Code	Benefits of BIM adoption
BO	Benefits of Owners
BO1	Easier to choose investment options.
BO2	Improve operation and construction management.
BO3	Early design assessment to ensure project requirements are met.
BO4	Maximize project performance.
BO5	Better marketing of the project by making effective use of 3D renderings and walk-through animations.
BO6	Low financial risk because of reliable cost estimates and reduced number of change orders.
BD	Benefits of Designers
BD1	Improve efficiency of design options.
BD2	Improve the quality of design drawings.
BD3	Easy conflict detection.
BD4	Minimize conflicts/changes.
BD5	Easy to adjust design changes.

Table 2.2 Continued.

Code	Benefits of BIM adoption
BD6	Easy quantity take-off and cost estimation.
BD7	Reduce design time and costs.
BD8	Easy energy efficiency evaluation of options.
BD9	Cooperation and commitment of professional bodies.
BD10	Easy product transfer.
BF	**Benefits of Facility Managers**
BF1	Easy planning and resource mobilization.
BF2	Project management and execution improvement.
BF3	Easier to coordinate contractors and stakeholders.
BF4	Easier to track and supervise design, construction, and operation.
BF5	Predicting potential hazards and solving them.
BF6	Convenient for managing project data.
BF7	Better management and operation of facilities.
BF8	Operational simulation for maintainability.
BC	**Benefits of Contractors**
BC1	Easy clash detection.
BC2	Minimize construction errors.
BC3	Convenient for handing over works.
BC4	Convenient for planning and resource provisioning.
BC5	Construction cost saving.
BC6	Construction time saving.

Note: Adapted from Quoc et al. (2022).

2.1.9 BIM Standard

In the field of BIM technology application and research, several international standards have been developed and adopted to facilitate effective communication, collaboration, and delivery of BIM projects. Most developed countries have their own number of national standards and industry standards and the commonly used international standards are detailed in Table 2.3 below. These standards reflect the concerted efforts of the international community to promote the implementation and application of BIM, and by providing harmonized guiding principles and methods of practice, they help industry practitioners to improve the efficiency, quality, and sustainability of construction projects.

2.2 STATISTIC THEORY

This section introduces and explains the statistical theories and methods applied in this study. To ensure the accuracy and scientific nature of data analysis, a series of statistical tools were utilized, including using SPSS V29 descriptive statistical analysis, Kolmogorov-Smirnov (K-S) test for normality, Spearman's rho correlation analysis, non-parametric rank sum tests (e.g., the Mann-Whitney U (M-W U) test and the Kruskal-Wallis H (K-W H) test), and the RII. Through the application of these statistical methods, this study aims to provide a scientifically rigorous analysis framework, offering solutions to problems and objectives in this study.

Table 2.3 Commonly used international BIM standards.

Country	BIM Standard Name	Year	Organizations of Enactment
International Organization	Industry Foundation Classes (IFC)	1997	buildingSMART
The USA	COBie	2007	Construction Operations Building Information Exchange (COBie)
Norway	Statsbygg BIM Manual 1.0 (SBM 1.0)	2008	Statsbygg
The USA	BIM Forum LOD Specifications	2009	Associated General Contractors (AGC)
Australia	The NATSPEC National BIM Guide	2011	NATSPEC
Suomi	Common BIM Requirements 2012 (COBIM 2012)	2012	Senate Properties
Singapore	Singapore BIM Guide Version 2.0	2013	Building and Construction Authority
Japan	Guideline for BIM Application in Public Building Projects	2014	Ministry of Land, Infrastructure and Transport
The USA	National BIM Standard-United States (NBIMS-US) 3.0	2015	National Institute of Building Science (NIBS)
France	Plan for the digital transition in the building industry (PTNB)	2017	Country
The UK	BS EN ISO 19650 Series	2018	British Standards Institution (BSI)
New Zealand	The NZ BIM Handbook 3.0	2019	BIM Acceleration Committee
German	VDI 2552	2020	The Association of German Engineers (VDI)

Note: Adapted from (Wag, 2013; Zhang, 2020).

2.2.1 Descriptive Statistical Analysis

Descriptive statistics are used to summarize data in an organized manner by describing the relationship between variables in a sample or population (Kaur et al., 2018). Descriptive statistics include types of variables (nominal, ordinal, interval, and ratio) as well as measures of frequency, central tendency, dispersion/variation, and position. In addition, scholars have suggested that once a population has been identified and sample data has been collected, the goal of the study is to characterize the sample in a precise and unambiguous manner so that the information can be easily communicated to others (Shayib, 2018). Therefore, this study used descriptive statistical analysis and aims to succinctly describe the basic characteristics (e.g., gender, age, level of education and so on) of respondents through statistical measures such as frequency, percentage, mean, and standard deviation.

In research, frequency refers to the number of times an event occurs, while percentage refers to the proportion or ratio of a particular value in relation to a whole (Yellapu, 2018). The mean gives a central value that represents the data as a whole, while the standard deviation illustrates how spread out or dispersed the data is around this mean (Joseph et al., 2005). Moreover, frequencies and percentages allow the researcher to quickly grasp the basic characteristics of the data set and understand the distribution of different categories or values. The mean provides a measure of the central tendency of the dataset, while the standard deviation reflects the dispersion of data points around the mean. These basic statistical measures lay the foundation for further in-depth analysis, allowing for a preliminary understanding of the dataset.

2.2.2 Kolmogorov-Smirnov (K-S) Test for Normality

The K-S test is a non-parametric test used to assess whether a sample's distribution follows a specified distribution (Lilliefors, 1967). The test is based on the Cumulative Distribution Function (CDF), and hypothesis testing is performed by comparing the maximum difference between two cumulative distribution functions. The main advantage of the K-S test is its non-parametric nature, which does not require any assumptions to be made about the distribution of the data (Kolmogorov, 1933). However, its limitations include sensitivity to sample size and the fact that it may not be as sensitive as some parametric tests when dealing with large samples of data.

Additionally, normal distribution is a prerequisite condition for many statistical methods, thus making the K-S test crucial for confirming whether the data meet the conditions for further analysis. More precisely, the K-S test is primarily used in this study to analyze the normality of data, thereby facilitating the choice between parametric and non-parametric tests.

2.2.3 Spearman's rho Correlation Analysis

Spearman's rho correlation analysis, also known as Spearman's rho correlation coefficient, is a non-parametric measure of statistical dependence between two variables (Astivia & Zumbo, 2017). It assesses the strength to which the correlation between two variables is described using a monotonic function (Puth et al., 2015). Unlike the Pearson correlation coefficient, which measures a linear relationship and requires the assumption that the data are normally distributed, Spearman's rho applies to both continuous and ordered variables and does not require the data to be normally distributed (Liu et al.).

In the field of civil engineering, projects often involve data that are non-linear or not normally distributed, making Spearman's rho an ideal tool for assessing the correlation of such data due to its tolerance for different data distributions. Its main advantage is its non-parametric nature, which allows it to be applied to a wider range of data types and distributions. However, its limitations are its sensitivity to outliers in small data sets and its inability to capture more complex relationships beyond monotonic correlations. Therefore, this study aimed to determine the strength of the correlation between each hindering factor through Spearman's rho correlation analysis.

2.2.4 Non-parametric Rank Sum Tests

The non-parametric test has no special requirements for the data distribution pattern, and any distribution can be used (Kahraman et al., 2004). Moreover, the purpose of this test is not to estimate or compare the parameters but to compare the distribution of each group of data. Therefore, when datasets exhibit non-normal distributions, non-parametric tests should be utilized. Additionally, the Mann-Whitney U test, also known as the Wilcoxon rank-sum test, evaluates differences in a single ordered variable between two groups without a specific distribution requirement (Mann & Whitney, 1947; Wilcoxon, 1992). On the other hand, the Kruskal-Wallis H test extends the Mann-Whitney U test to more than two independent groups. Both methods assess the significance of the differences by determining if the P-value is less than the selected significance level (usually 0.05); if $P < 0.05$, the null hypothesis is rejected. Otherwise, it should accept the null hypothesis (Its original hypothesis: there is no significant difference between the two overall distributions from which the two independent samples come) (McKnight & Najab, 2010).

Therefore, this study employs the non-parametric rank-sum tests, namely the Mann-Whitney U test and the Kruskal-Wallis H test, to investigate whether there is statistical significance in the judgment of the importance of different barriers among respondents who have and have not used BIM technology and among different professions (e.g., manager, designer, and engineer).

2.2.5 The Relative Importance Index (RII)

To assess the importance of various barrier factors, this study used the RII method calculated to indicate the respondents' prioritization of the importance of each barrier factor (Kassem et al., 2020). The RII method, recommended by Shash (1993) for analyzing data collected via Likert scales, has since been adopted by numerous researchers in the construction field to rank factors in a similar manner (Kometa et al., 1995; Kumaraswamy & Chan, 1998; Chan & Pasquire, 2004; Ghosh & Jintanapakanont, 2004). Meanwhile, scholars (Mahdi et al., 2020) and (Ma et al., 2022) have utilized the RII method to identify the top five critical barrier factors.

Additionally, the Relative Importance Index analysis is a suitable method for prioritizing Likert-type scale rating indicators and determines the majority of the significant criteria based on the responses of the participants (Rooshdi et al., 2018). This index provides a numerical value between 0 and 1, with higher values indicating greater importance as perceived by the respondents. Based on the above background, this study plan uses the RII method to identify the top six critical barrier factors to the widespread application of BIM technology in Chengdu's MBCPs.

2.2.6 Hypothesis Test

This study specifically includes the following two hypotheses:

H1: There is a statistically significant difference in the extent to which all interviewees who have used or have not used BIM technology are judged to be important for all barrier factors.

H2: There is a statistically significant difference in the extent to which interviewees of different occupations (e.g., manager, designer, and engineer) are judged to be important for all barrier factors.

2.3 CHENGDU CONSTRUCTION INDUSTRY (CCI)

2.3.1 Overview

This section aims to provide a comprehensive overview of the CCI. It begins with an in-depth exploration of the current research status of the CCI and Chengdu's MBCPs, followed by a discussion on the challenges faced and future development goals.

2.3.2 Definition of the CCI

Based on scholars' definitions of the CI (e.g., Anthony, 2013; Hussain et al., 2022), this study defines the CCI as refers to the sector within the scope of Chengdu, Sichuan Province, China, that involves a series of activities and services related to the design, construction, renovating, maintenance, and management of buildings and infrastructure. This industry encompasses the entire process from project planning, design, construction, to building maintenance and demolition, as well as related engineering consulting, project management, material supply, and related technical services.

2.3.3 Scale of the CCI

As of August 24, 2023, this study is based on searched and cleaned-up data (elimination of enterprises not related to the CI) from the official website of the CCIA, the association which has a total of 255 local member firms (CCIA, 2023), with a detailed list of construction firms shown in Appendix E. The main businesses of these construction firms cover rail transit, municipal engineering, residential construction, and medical construction, among others.

2.3.4 Research Status of the CCI

To guide and promote the transformation and upgrading of the city's CI for high-quality development during the "14th Five-Year Plan (2021-2025)" period, the BURDBC (2021) released the "14th Five-Year Plan for the Development of the Construction Industry in Chengdu" on November 19, 2021.

The report clearly states that the CCI has shown a significant growth trend. During the "13th Five-Year Plan (2016-2020)" period, the CCI completed a total CI output value of 2.55 trillion yuan, with an added value of 496.842-billion-yuan, accounting for more than 6.00% of Chengdu's GDP. During this period, the CI contributed a total tax revenue of 101.132 billion yuan, making a significant contribution to the city's economic development and local fiscal revenue.

Additionally, the construction methods in the CCI have undergone transformation and upgrading. The city actively promoted the development of prefabricated construction, with nearly 100 million square meters of prefabricated buildings started, and the assembly rate increased from 20-30% to 30-50%, being listed as one of the first batch of national prefabricated construction demonstration cities.

At the same time, Chengdu has made efforts to promote the development of green buildings. All new buildings in the city fully implement building energy-saving requirements, with the execution standard comprehensively raised from not less than 50% to not less than 65%. A total of 2.43 million square meters of existing public buildings were retrofitted for energy efficiency, and the "Chengdu Public Building Energy Consumption Detection Information System" was established, achieving energy consumption monitoring of 69 buildings covering 2.86 million square meters.

Furthermore, to strengthen the supervision of engineering quality and safety and ensure the high-quality development of the CI, Chengdu further improved relevant regulations and developed the "Implementation Rules of Chengdu Engineering Quality and Safety Manual (Trial)," demonstrating the commitment to enhancing the level of engineering quality and safety management.

In summary, the "13th Five-Year Plan" period in Chengdu not only promoted the expansion and economic contribution of the CI but also drove the industry's transformation and upgrading through technological and management innovations, achieving a transition to efficient, green, and safe construction. These measures and achievements reflect Chengdu's clear direction and firm commitment to high-quality development in the CI, providing valuable experience and reference for other cities.

2.3.5 Challenges of the CCI

The CCI is facing several challenges and weaknesses during its development process, as summarized below.

1. The quality and efficiency of the CI need to be improved. The transformation from resource-intensive, extensive, low-quality construction models to ecological, refined, high-quality models is

progressing slowly.

2. The CI's value chain needs further enhancement. There is a significant disparity in the development levels of downstream enterprises within the CI's value chain.
3. Innovation and development capabilities need to be strengthened. Compared to developed regions, there is still a considerable gap, with a lack of awareness for investment in scientific and technological innovation. Overall, the innovation capacity is insufficient, and the integration of information technology with the CI is in an exploratory stage.
4. The competitive strength of construction enterprises needs to be enhanced. The overall scale of construction enterprises in the city is relatively small, and they are still in the growth stage.
5. The transformation towards industrial modernization has just begun. There has not yet formed a modern urban construction service provider capable of "integrated operation of investment, financing, construction, and operation."
6. The level of planning and design needs to be improved. The supply capacity of integrated, intelligent, high-end design services needs to be enhanced, which is insufficient to support the development needs of the city's energy level upgrade.
7. The "going global" development is insufficient. Local enterprises lack competitiveness in domestic and international high-end projects, and only two companies have been listed in the "Top 250 International Contractors" by Engineering News-Record (ENR), indicating a low level of outward orientation in the CI.

2.3.6 Development Objective of the CCI

During the "14th Five-Year" plan period, Chengdu is committed to building a well-rounded CI ecosystem aimed at promoting high-quality development across the entire industry chain. By advancing key directions such as internet integration, digitalization, greening, and branding of CI, Chengdu comprehensively promotes the shaping of the "Chengdu Construction" brand. Specifically, the overall objectives for the development of the CCI are presented in the following table.

2.3.7 Chengdu's MBCPs

2.3.7.1 Definition of Chengdu's MBCPs

Building on the definitions of MBCPs by scholars (e.g., Choi et al., 2020; Seko, 2024), this study defines Chengdu's MBCPs as projects involved in the design, construction, and enhancement of medical facilities providing medical services, including but not limited to the planning, design, implementation, and maintenance of hospitals, clinics, laboratories, research centers, and other medical-related facilities. Such projects are inherently multidisciplinary and integrative, combining expertise and skills from architecture, engineering technology, medical, and environmental science, among others. The goal of these construction projects is to optimize the allocation of medical resources, improve the level of medical services, and meet the growing medical needs of the public.

Table 2.4 Main development indicators of the CCI during the "14th Five-Year Plan" period.

Category	Indicator	Current Value (2020)	Target Value (2025)	Attribute
Scale and Efficiency	Total output value of construction industry (Billion Yuan).	5822	7800	Expectational
	Added value of construction industry (Billion Yuan).	1312	1756	Expectational
	The proportion of the construction industry's added value to the city's GDP (%).	7.4	8.0	Expectational
	Labor productivity (Ten thousand Yuan/person).	42	48	Expectational
	Rate of technical equipment in construction industry (Yuan/person).	6695	10210	Expectational
Industrial Structure	Industry outward orientation	32	35	Expectational
	Number of enterprises with top-grade (comprehensive) qualifications.	22	23-25	Expectational
	Selected in ENR's Top 60 Chinese Engineering Design Firms	2	4-6	Expectational
	Number of construction enterprises with annual output value over 100 billion Yuan.	0	1-2	Expectational
Industrial Structure	Number of key enterprises in general contracting.	-	60	Expectational
	Number of key enterprises in full-process consulting.	-	10	Expectational
New Industrialization	Proportion of prefabricated buildings in new urban constructions (%).	-	80.0	Expectational
Technological Progress	Cumulative number of national-level enterprise technology centers.	-	11	Expectational
	Cumulative number of provincial-level enterprise technology centers.	-	70	Expectational
	Number of new invention patents.	-	500	Expectational
	Number of new national-level construction methods.	-	20	Expectational

Table 2.4 Continued.

Category	Indicator	Current Value (2020)	Target Value (2025)	Attribute
Quality and Safety	Number of "Luban Awards", "Zhan Tianyou Awards", "National Quality Awards", and "Tianfu Cup Awards" received.	-	550	Expectational
	Proportion of green buildings in new urban constructions (%)	-	100.0	Expectational
	Application ratio of green building materials in new constructions (%).	-	60	Expectational
	Resource utilization rate of construction waste (%).	-	50	Expectational
Team Building	Proportion of personnel with intermediate skills and above (%).	-	40	Expectational
	Number of new first-class registered constructors.	-	10000	Expectational

Note: Source from BURDBC (2021).

Building on the definitions of MBCPs by scholars (e.g., Choi et al., 2020; Seko, 2024), this study defines Chengdu's MBCPs as projects involved in the design, construction, and enhancement of medical facilities providing medical services, including but not limited to the planning, design, implementation, and maintenance of hospitals, clinics, laboratories, research centers, and other medical-related facilities. Such projects are inherently multidisciplinary and integrative, combining expertise and skills from architecture, engineering technology, medical, and environmental science, among others. The goal of these construction projects is to optimize the allocation of medical resources, improve the level of medical services, and meet the growing medical needs of the public.

2.3.7.2 Overview of Chengdu's MBCPs

The "14th Five-Year" period, socialism with Chinese characteristics into a new era, in order to meet the people's relentless pursuit of a better and healthier life, and the COVID-19 pandemic in 2020 have impacted the Chengdu CI, especially the surge in demand for hospital-specific treatment facilities.

According to the "Operational Guidelines for the Prevention and Control of Novel Coronavirus Infection" released by the JPCMSC on January 19, 2023, although it has now entered the post-pandemic era, it is still necessary to construct and renovate ICUs in accordance with standards (JPCMSC, 2023),. Moreover, these ICU must be readily available at all times and capable of being converted into "convertible ICU," allowing for the swift transformation of regular wards into ICU in times of crisis, as shown in Table 1.1 for details.

Moreover, "2023 government work report" pointed out the need to deepen the creation of a happy Chengdu, the need to deepen the construction of the degree of health, and to strengthen the rescue system and the construction of emergency response capacity. The Chengdu Municipal Government announced a significant plan, which includes the initiation of construction work on 27 major medical projects, encompassing the City Center Hospital and the Municipal Neuroscience Hospital (General Office of the Municipal Government, 2023). Furthermore, the plan aims to complete 10 high-level clinical specialty hospital projects and to construct 15 new medical centers in various districts (counties) by 2025. The purpose of these measures is to enhance emergency support efficiency in wartime conditions and to reserve hospital land for major epidemics and other disasters.

Meanwhile, the report emphasizes the enhancement of information technology infrastructure in healthcare institutions, aiming to improve their level of informatization. It strongly advocates for the development of internet-based hospitals and smart hospitals to support the construction of a smart city. Furthermore, it calls for the establishment of an intelligent public health information service system to provide informational support for major disease prevention and control, as well as for sudden public health events and other health-related fields.

The current planning and initiatives reveal that Chengdu's MBCPs, whether new constructions or renovations possess immense developmental potential. However, these plans and measures also introduce unprecedented new requirements and challenges for the design and construction of medical buildings. Particularly, the introduction of concepts such as "convertible ICU," "green medical buildings," and "smart hospitals" necessitates adherence to a series of complex regulations from the early stages of construction projects for design, undoubtedly increasing the complexity and difficulty of project implementation. Given this context, there is an urgent need for more extensive application of BIM technology throughout the entire lifecycle of BMCPs in order to take full advantage of its potential and strengths in improving project management efficiency and optimizing the design, construction process, and so on.

2.3.7.3 Challenges and Characteristics of Chengdu's MBCPs

Based on the above background, the design and construction of healthcare architecture projects are faced with a multitude of complexities and challenges. These difficulties are not only related to the technical and functional requirements of the architecture itself but also involve considerations of sustainability with the environment, a detailed understanding of user needs, and the complexity of project management. Here are six of the primary difficulties and challenges:

1. High construction technical requirements. Healthcare buildings need to meet extremely strict technical standards, including the maintenance of a sterile environment, transportation, installation, and maintenance of advanced large medical equipment, as well as the tight construction schedule and the diversity of subcontracting specialties (Chan & Chan, 2004). These requirements make healthcare architecture projects more complex than general construction projects, requiring the integration of specialized knowledge and technology.
2. Effective communication is more inconvenient. Since most of the stakeholders involved in MBCPs do not have architectural expertise, the traditional way of communication still utilizes CAD drawings and floor plans, which challenges stakeholder engagement (Eastman, 2011; Somboonwit & Sahachaisaeree, 2012). Poor communication can also lead to errors, such as design errors, cost overruns, and schedule delays. (Okada et al., 2017).
3. Diversity and variability of user needs. The users of healthcare buildings include patients, medical staff, and visitors, each with different space requirements. The design must consider flexibility to adapt to the rapid changes in medical service needs while creating an environment that promotes healing, supports medical work, and provides a comfortable experience (Pemsel et al., 2010; Shi, 2021).
4. Sustainability and environmental impact. With increasing emphasis on sustainable development, healthcare architecture projects need to consider their environmental impact, implement green building design and construction practices to reduce energy consumption and waste generation, while ensuring the long-term sustainable operation of the building (H. Zhang, 2023).

5. Complexity of project management. MBCPs typically involve multiple stakeholders, including government agencies, medical staff, design teams, contractors and so on. Project management requires coordinating the needs and expectations of all parties to ensure the project is completed on time and within budget, which is a challenging process (Shirley, 2020).
6. Complex installation of MEP systems. For technically challenging projects, such as those focused on high-tech, healthcare, and biotechnology industries, MEP systems can sometimes account for 50% of the project's value (Khanzode et al., 2007). Therefore, the coordination and routing of MEP systems on such projects is a significant task. MEP systems need to be wired within limited spaces according to the standards set for the design, construction, and maintenance of the systems (Korman & Tatum, 2001).

2.4 LITERATURE REVIEW

2.4.1 Overview

This present section is committed to conducting a comprehensive review, summarization, and in-depth analysis of the current state of research on BIM technology within the global scope, China scope, and specifically within the construction industry of Chengdu. This includes also summarizing the application status of BIM technology in Chengdu's MBPCs, with a focus on analyzing the barriers encountered and challenges faced when broadly applying BIM technology in the CI. It aims to promote the wide application and deep adoption rate of BIM technology in Chengdu's MBCPs and to propose substantive and targeted recommendations against key challenges and barriers, promoting the widespread application of BIM technology in the CI of Chengdu, China, and globally.

2.4.2 The Development of BIM Technology

2.4.2.1 Research on BIM Technology

As an innovative technology in the construction industry, BIM technology is significantly influenced and constrained by technological advancements, with distinctive development features across different countries. Some nations have already recognized BIM technology as a mainstream tool, while others are making relatively slower progress. Nevertheless, the application of BIM technology demonstrates significant diversity across various fields and specialties. A common trend is the increasingly prominent importance of BIM technology, whose application is gradually extending into more areas. Developed countries such as the United States, the United Kingdom, Japan, South Korea, Singapore, and Finland are leading in BIM technology. With more frequent international exchanges, an increasing number of developing countries have also begun to widely apply BIM technology (Shi, 2020). Although developing countries generally lag behind developed countries in BIM applications, they have a broad scope for BIM technology applications with huge potential benefits, given their large and fast-growing volume of construction works.

Beyond national policy encouragement and support, many experts and scholars have conducted in-depth research on BIM technology, promoting its development and application. In developed countries, scholars have proposed various innovative BIM application models. For instance, American scholar Alizadehsalehi et al. (2020) introduced a model combining BIM with XR (VR, AR, and MR) to enhance visual interaction through humanized and immersive methods; British scholar Sresakoolchai and Kaewunruen (2022) combined BIM with artificial intelligence to develop a railway infrastructure defect detection system with a high defect detection rate; Japanese scholar Hiasa and Kawamoto (2023) proposed integrating BIM technology with 3D laser scanning to improve the accuracy of 3D terrain models, reduce measurement errors, save time and costs; Korean scholar Park and Seo (2021) combined point cloud data from 3D scanning with BIM models to analyze the risk factors of earthquake-damaged buildings, significantly improving the efficiency of seismic damage measurement techniques; Singaporean scholar Syamimi et al. (2020) presented the VRcollab solution, enabling professionals to work efficiently in a VR environment via the internet; Finnish scholars Hussein (2021) integrated BIM with Life Cycle Assessment (LCA) to propose a fast and accurate building carbon assessment solution.

In developing countries, researchers have also shown deep exploration and application of BIM technology. For example, Malaysian scholar Ismail (2021) developed a system based on data flow diagrams and coding using BIM technology, aimed at simplifying the maintenance assessment and defect diagnosis process for industrialized building system (IBS) structural components; Thailand scholar Tokla and Subsomboon (2020) proposed an algorithm for automatically estimating construction costs using BIM 3D smart objects to improve the efficiency and accuracy of cost estimation; Chinese scholar Chen et al. (2021) explored the application of combining BIM, the Internet of Things (IoT), and augmented reality/virtual reality technologies to quickly locate indoor fires and accelerate fire perception; Indian scholar Rane et al. (2023) established a platform integrating BIM with models such as ChatGPT to enhance the cohesion and efficiency of workflow throughout the project lifecycle; Pakistani scholar Maglad et al. (2023) used Autodesk Revit, Autodesk Insight 360 and Green Building Studio developed a method to improve the energy efficiency of new buildings by using BIM technology and energy consumption analysis in the early design stage, aiming to significantly reduce energy consumption and establish optimal energy patterns.

In summary, the development and application of BIM technology have attracted global attention from scholars and experts. It plays an important role in improving the efficiency and accuracy of construction projects and shows great potential in promoting sustainable development and energy efficiency. As technology continues to advance and international cooperation deepens, the application of BIM technology will become more widespread and profound, continually expanding its impact on the CI.

2.4.2.2 Research on BIM Technology in MBCPs

The rapid progress of BIM technology has brought revolutionary changes to the design, construction, and operational management of medical buildings, especially in addressing their inherent complexity. Medical buildings, as a type of construction with complex functions and high demands (National Institute of Building Sciences (NIBS), 2020), require special attention and unique solutions. In recent years, scholars Li et al. (2022) have introduced the concept of "Hospital Information Modeling (HIM)" specifically for medical buildings, aiming to further promote the application and development of BIM technology in the medical building construction sector, the study also summarizes the key points of BIM application in the medical building life cycle, as shown in the Table 2.5. Notably, during the COVID-19 pandemic, BIM technology played a key role in the construction and operation of mobile cabin hospitals such as Wuhan's Leishenshan Hospital (Luo et al., 2020; Zhou et al., 2020). By optimizing design, simulating environments, and producing prefabricated components, BIM technology provided strong support for the rapid construction and safe operation of hospitals.

In terms of enhancing the efficiency of hospital design and construction, Lin et al. (2018) developed a Database-supported VR/BIM-based Communication and Simulation (DVBCS) system, integrating BIM, game engines, and VR technology. This effectively improved communication efficiency between design teams and medical stakeholders and simplified the decision-making process. Moreover, Jung et al. (2019) and others utilized a combination of BIM and cloud computing technologies to propose a system aimed at enhancing effective communication among medical stakeholders, reducing design errors, and supporting the decision-making process of project participants. Choi et al. (2020) introduced a BIM-based benchmarking method that, by reducing manual data collection and entry, improved current benchmarking practices, providing more accurate benchmark data for the MI.

In the area of FM for medical, Kamal et al. (2021) developed a BIM-based medical FM management platform that effectively managed facility maintenance by prioritizing maintenance orders. Demirdöğen et al. (2023) developed a medical FM system integrating Big Data Analysis (BDA), BIM, and NoSQL databases, which efficiently carried out FM data retrieval and analysis, supporting decision-making for medical facility managers. Additionally, As and Bilir (2023) utilized Revit and Green Building Studio (GBS) for energy analysis to improve energy efficiency in the design phase of medical buildings and developed energy-saving hospital models.

Overall, the application of BIM technology in the field of medical construction has demonstrated its tremendous potential in enhancing design and construction efficiency, facilitating the decision-making process, and optimizing facility management and energy efficiency. As technology continues to evolve and more practical applications are accumulated, BIM's role in medical construction is expected to expand further, potentially bringing safer, more efficient, and sustainable building solutions to the MI.

Table 2.5 Points of BIM application in the medical building life cycle

Stages	Points of application
Schematic design	Architectural and structural modeling Site analysis Building performance analysis

Table 2.5 Continued.

Stages	Points of application
	Walkthrough simulation Design comparison Primary healthcare process simulation and optimization* Special facility simulation Special place simulation
Design development	Architectural and structural deepening modeling Structural plans, elevations, and sections check Secondary healthcare process simulation and optimization* List of space by function Building equipment selection analysis Mechanical, electrical, plumbing (MEP) modeling
Construction drawings	Deepening modeling of architecture, structure, MEP, and other building equipment Collision detection and pipeline synthesis Clearance analysis Walkthrough simulation Tertiary healthcare process simulation and optimization* 2D drawings export
Construction preparation	Construction drawing deepening Construction site planning Construction planning simulation and selection BIM-based quantity survey Prefabricated components production
Construction	4D BIM and progress control BIM-based quantity survey Equipment and material management Cost management Quality management Safety management Building the as-built model
Operation and maintenance	Transforming the model to operation and maintenance model Space management Equipment monitoring Energy consumption monitoring Maintenance management Staff training Asset management

Note: Source form Li et al. (2022). * Primary healthcare process simulation and optimization (HPSO) is the simulation of healthcare processes on hospital campuses and building levels based on BIM methods to determine the properties of buildings and the relationships among them. Secondary HPSO conducts HPSO on the functional unit or department level. Tertiary HPSO conducts HPSO on room level to determine the configuration of furniture, interior design, and built environment quality issues, etc.

2.4.3 BIM in Chengdu Construction Industry (CCI)

2.4.3.1 CCI

The construction industry in Chengdu has demonstrated profound technical accumulation and innovative capabilities in the application of BIM technology. These studies span a wide range, covering various domains such as whole life cycle management of construction projects, safety production management, construction process optimization, establishment of energy consumption prediction models, and parametric modeling in the field of underground transportation tunnels. They showcase the enormous potential of BIM technology in enhancing the efficiency, safety, and sustainability of construction projects. Specific applications of BIM technology are shown below.

Ma et al. (2018) proposed to integrate BIM into the whole life cycle of a construction project by introducing a conceptual framework consisting of BIM information flow, BIM model chain, BIM workflow, BIM institutional environment, and BIM-based Project Management Information System (PMIS). Moreover, the conceptual framework was systematically implemented in a construction project in Chengdu, and the final key findings and evidence supported the conceptual framework, offering new perspectives and methods for construction project management. Qin et al. (2020) integrated dynamic simulation of fire incidents, emergency evacuation, and BIM technology to carry out emergency evacuation simulations. This not only provides a technical route for safety production management but also has significant practical value for promoting the informatization management of safety production. Jia et al. (2022) study introduced a bidirectional interaction mechanism between point cloud models and BIM and the construction process in a curtain wall construction project of a stadium in Chengdu. It achieved high consistency between the BIM model and the actual construction status during the construction process, providing technical support to ensure construction quality. Zheng et al. (2022) based on BIM technology and combining Design Builder and Support Vector Machine, established an energy consumption prediction model. The model's accuracy was validated through a case study of a teaching building in Chengdu, offering a scientific basis for energy-saving optimization design in buildings. He and Wang (2022)with the Chengdu Metro Line 9 Phase 1 project as the background, used Civil 3D and Revit + Dynamo to build a parametric tunnel 3D model. This provides innovative solutions and valuable experiences for the application of BIM technology in the field of underground transportation tunnels. Wu et al. (2023) combined BIM, GIS, and VR technologies to effectively tackle the challenges during the design phase of tunnel engineering projects. It offers references for similar projects and demonstrates the application potential of BIM technology in engineering design and verification.

2.4.3.2 Chengdu's MBCPs

In the field of civil engineering, particularly in the design and construction of medical buildings, the application of BIM technology exhibits variations in levels and complexities across different industries and regions. Taking Chengdu as an example, a literature search reveals that the integration of BIM technology in MBCPs is not as widespread as in other construction industries and is still in its early stages of development. Although the application of BIM in this field has not reached the extensive level of other architectural sub-markets, some scholars have shown a strong interest and a positive research attitude towards applying BIM technology in MBCPs. This indicates that, despite facing challenges and limitations, the potential of BIM technology to improve the efficiency and quality of MBCPs is still recognized by both the academic and industrial communities.

Wang (2013) advocated for a BIM-based rule-checking framework to assist architectural design, which was implemented in the Sichuan University West China Hospital project. The core aim of this approach is to enhance decision-making and validation in architectural design by frontloading a substantial portion of work, thereby achieving greater control over project quality and cost. Ren et al. (2021) employed BIM technology in tandem with drone-assisted management techniques in projects at the Chengdu BOE Hospital and West China Tianfu Hospital. Utilizing detailed BIM drawings for construction guidance, this method optimizes the layout of pipelines and outdoor network routing to prevent construction clashes. Moreover, integrating real-time drone data with BIM models enhances site inspection management and progress tracking. The findings indicate the feasibility and superiority of BIM combined with drone-assisted management in construction management. You et al. (2022) applied BIM technology in conjunction with smart construction site techniques in the Sichuan University West China Tianfu Hospital project. This endeavor is focused on elevating construction quality and augmenting industry supervision and service capabilities. The research facilitates quality traceability and the management of labor through real-name systems, contributing to the establishment of a big data platform for integrity, which effectively supports regulatory oversight and services pertaining to on-site quality, scheduling, personnel, and integrity. Kan Wang et al. (2022) applied BIM technology comprehensively in the Tianfu Wanda International Hospital project for project management. The research focused on deep applications of BIM, such as three-dimensional spatial analysis and optimization, detailed modeling of professional nodes, construction planning simulation, and comprehensive pipeline layout optimization. The study's objective was to leverage BIM for comprehensive management of the construction process, thus advancing the informatization of construction projects. Jin et al. (2023) combined BIM technology with the construction of concrete structures in the linear accelerator room of the new Chengdu Renmin Hospital. This integration aimed at addressing construction challenges such as formwork briefing, volume calculation of large concrete projects, and construction joint reservation. By adopting information technology, the study sought to enhance work efficiency, increase technical value, and achieve cost-effectiveness.

Overall, compared to developed countries or other regions, the application of BIM technology in Chengdu's MBCPs is still significantly lagging behind. This gap, while highlighting existing deficiencies, also indicates that Chengdu possesses tremendous potential for development and room for improvement in the application of BIM technology. This suggests that by broadly adopting advanced BIM technologies and management methods, Chengdu's medical building industry can not only reduce the differences with developed regions but also have the opportunity to achieve technological leaps and innovative development in the future.

2.4.4 Barrier Factors to Imply BIM

This study has chosen to conduct literature retrieval from the WoS, Google Scholar, and CNKI databases, three esteemed online databases, each with distinct merits. For example, the WoS database is recognized for its extensive collection of high-quality English literature (Ding & Yang, 2020). Moreover, Google Scholar provides access to a wide range of literature in a variety of subject areas, including many free full-text documents (Jacsó, 2005). The CNKI database is also selected for its unparalleled comprehensiveness in Chinese database offerings (Gan et al., 2022). Collectively, these databases offer a robust and diverse range of resources, making them ideal for this study's research needs.

Currently, there is a scarcity of literature specifically addressing the factors hindering the application of BIM in MBCPs. However, studies on the barriers to using BIM technology in the CI have been initiated earlier and are more comprehensive. Therefore, this study expands the scope of the literature search to not only focus on the MBCPs but also to refer to related studies in the CI. Therefore, this study specifically designed a set of retrieval strategies to conduct a comprehensive search of related literature and studies over the past decade in three online databases: WoS, Google Scholar, and CNKI, as shown in Table 2.6. This search included articles in both English and Chinese, review articles, master's and doctoral thesis, and other editorial sources to ensure that this study could comprehensively cover and analyze current research dynamics and development trends in the field.

Table 2.6 Papers search rules for this study.

Type of Rules	Content
Online Databases	WoS, Google Scholar, and CNKI.
Search Formula	TS = (("BIM" OR "Building Information Model*") AND ("Barrier*" OR "Challenge" OR "Hindrance*" OR "Obstructive"))
Time limit	10 Years
Language	Chinese and English
Document Type	Articles, Review Articles, Master's and Doctorate Thesis, and other editorial sources.

Note: * denotes a wildcard search. TS denotes Topic Search.

In this study, after conducting a thorough analysis and meticulous review of the literature retrieved, a total of twenty papers closely related to the research topic were selected and cited (e.g., Qiu & LI, 2019; Mahdi & Mawlood, 2020; El Hajj et al., 2021; He, 2022), see Table 2.7 for details for barrier factors. This work not only encompasses a comprehensive record of the critical barrier factors and challenges mentioned in the literature but also lays a solid theoretical foundation for subsequent research.

Table 2.7 Potential of barrier factors based on the literature review.

<table>
<tr><th>Researchers</th><th>Barrier Factors</th></tr>
<tr><td>Migilinskas et al. (2013)</td><td>Fears of too low success or too big failure;
High initial investment costs;
The time to learn how to use the software too long;
The lack of support from senior leadership of the company (conservative approach);
Data transfer is often limited due to software incompatibility.
The lack of information about the strict BIM implementation standards and rules for project participants, contract obligations in certain countries, or unified documentation for regions (such as the European Union, Americas, Asia, and others).
Limitations of 3D/4D modeling software tools and information management as well as data exchange and efficient hardware to be used and problems arising from organization and organization.</td></tr>
<tr><td>Xu et al. (2014)</td><td>Monitoring of construction quality and progress;
Lack of interoperability between applications;
Lack of Compatibility of software;
Visualization of the design effect;
Lack of BIM standards;
Lack of Professional training in BIM technology;
Lack of BIM professionals;
Lack of Support from senior management or owners;
Lack of Interest in learning BIM;
Perceived cost of the BIM technology;
Lack of Willingness to use BIM for stakeholders.</td></tr>
<tr><td>Qin et al. (2016)</td><td>Lack of understanding of BIM technology, not clear about the advantages of BIM technology and how to apply it to their own work;
Lack of BIM education and training;
Lack of BIM technicians and experts within the organization or in the project team;
Lack of effective cooperation between the participants in the project team;
Unwillingness to change the inherent mode of thinking and way of working;
Lack of external motivation for stakeholders such as owners/contractors/subcontractors/consultants to use BIM technology;
An organizational model and workflow based on BIM have not yet been established;
Responsibilities and risks for updating and maintaining BIM model data are not clearly shared among the participants;
Lack of data exchange standards, resulting in poor compatibility of BIM software;
Lack of BIM standards;
Additional expenses, i.e., BIM software/hardware investment, personnel training, etc.</td></tr>
<tr><td>Li et al. (2017)</td><td>Lack of understanding;
Lack of owner demand;
Lack of experienced BIM professionals;
High costs of education and training;
High costs of hardware and software;
Lack of applicability and practicability regarding the BIM software;
Not sure if the benefits outweigh the costs when implementing BIM;
Increased workload and decreased efficiency;
Lack of standards, laws, and regulations;
Insufficient information sharing;
Insufficient government lead/direction;
Resistance to change of culture/thinking mode.</td></tr>
<tr><td>Azmi et al. (2018)</td><td>High initial cost in BIM;
Extra cost implication;
The cost is expensive;
Cost implication to hardware is high;
Unsupportive BIM environment;
Limited choices of software;
BIM simulation helps in the construction process;
Malaysia is limited to BIM exposure;
Low BIM implementation level due to lack of awareness;
The software of BIM is hard to find in Malaysia;</td></tr>
</table>

Table 2.7 Continued.

Researchers	Barrier Factors
	Properties missing in file conversion; Unstandardized BIM platform; Multiple BIM definitions; Simulation helps in the project life cycle; Unstandardized file format; Limited BIM trainer; Training should provide to all parties; Do not alert of technology change; Lack of experience in BIM; Time constraints to attend the training; Lack of professional skills; Reluctant to change; Commitment to implement BIM; Difficult to understand the BIM model; No enhancement from authority limited BIM awareness campaign; No confidence in BIM.
Ahmed (2018)	The construction market is not suitable and ready yet; Unavailability of proper training on BIM Training expenses and the learning curve are too expensive; Higher authority and decision-makers don't provide full support; Unavailability of BIM risk insurance; The system of single-discipline design but not integrated design; The benefits are not tangible enough to warrant its use; Contractors don't usually empirically prove the benefits of BIM to clients; Difficult to have everyone on the project to make the effort worthwhile; Too many legal barriers exit; The legal barriers overcome cost; Lack of global use in the local construction industry; Not sufficient demand from clients and/or other organizations on projects Lack of guidelines and standards of the way BIM has to be implemented for the construction industry. Uncertainty of the benefits of BIM implementation; Current technology in construction is enough; Social and habitual resistance to change; Complexity of BIM; Traditional methods of contracting; High cost of software purchasing; High cost of BIM hardware and tools; BIM licensing problems; High Maintenance costs; Low computer skills among a lot of participants in the construction industry; Requirement of advanced electronics equipment; The shortage of sufficient time to evaluate BIM and its training; Absence or incomplete national standard for BIM; Lack of BIM experts; Lack of information sharing in BIM; Firms are not familiar enough with BIM use; It does not help if your counter-parties are not using the BIM; The initial setup of BIM is difficult; Lack of awareness about BIM; People comparing BIM to CAD; Poor internet connectivity; Frequent power failure; Product liability risks.
An and Xu (2019)	Mismatch of existing organizational management models; Lack of supporting software; Lack of relevant BIM application talents;

Table 2.7 Continued.

Researchers	Barrier Factors
Tan et al. (2019)	The existing contract management process is not applicable; Insufficient BIM experience and knowledge of BIM; BIM-related policies are not perfect. Difficulty in Adapting to the BIM Technology and Process; Lack of Domestic-oriented BIM Tools; Increased Workload for Model Development; Resistance to Change; Negative Attitude towards Data Sharing; Misunderstanding of BIM; Negative Attitude towards Working Collaboratively; Lack of a Well-established BIM-based Workflow; Immature Dispute Resolution Mechanisms for BIM Implementation; Lack of Professional Interactivity; Insufficient External Motivation; Lack of Research on BIM Implementation in China; Cost and Time Required for Training; Cost of BIM Experts and Tools; Increased Design Costs; Ambiguous Economic Benefits; Lack of Protection for Intellectual Property Rights; Lack of BIM Standards; Lack of a Standard Form of Contract for BIM Implementation; Lack of Insurance Applicable to BIM Implementation.
Wang (2019)	Domestic B1M Software Function Development; Degree of localization of foreign BIM software; BIM implementation experience that can be referenced and reused; Security of BIM cloud data; External driving force; Management mode after business process reorganization; Application program and planning of BIM technology; BIM software purchase, maintenance, and other costs; Time and cost of staff training on BIM technology; Consulting costs for hiring BIM experts; The degree of recognition and wood understanding of BIM; Quantity and quality of B1M specialists and media personnel; National policies; Legal constraints; B1M standards, application guidelines.
Qiu and LI (2019)	Difficulty in changing traditional ways of working and thinking; Lack of time and motivation for practitioners to learn professional BIM technology; Lack of BIM education and training; Lack of understanding of BIM technology; High additional costs (investment in hardware and software, training, and hiring experts); Lack of BIM technology experts; Lack of effective cooperation between the various parties involved in the project; Lack of external motivation for stakeholders to use BIM; Lack of new organizational models and new workflows; Lack of practical experience, technical research, and academic exchanges on BIM projects; Traditional behavioral and managerial practices in the construction industry limit the entry of new technologies; Risk of losing market share due to technical and quality problems caused by the initial use of BIM technology; Uncertainty of responsibility and risk sharing among participants under the new technology model led to disputes, claims, insurance, and other legal issues; Risk of business transformation due to BIM application; Loss of profit and high risk due to information sharing; Lack of data exchange standards, resulting in poor compatibility of BIM software.

Table 2.7 Continued.

Researchers	Barrier Factors
	Lack of BIM standards; Immature development of core BIM software; Parallelism and interface problems of BIM software; Lack of database related to the BIM platform in China; Lack of legal provisions and measures to protect intellectual property rights of BIM models; Lack of BIM standard model contract; Lack of effective incentives for relevant management departments.
Mahdi and Mawlood (2020)	Believing the current used technology is enough; People refuse to learn / Social and habitual resistance to change; The high cost of training for BIM software; The cost of hiring BIM specialists and additional staff; The cost of BIM software and the cost of its updates; Lack of support / Lack of BIM-related investments; Uncertainty of the benefits of BIM implementation; Traditional methods of contracting (BIM needs special contracting conditions); Absence or incomplete national standard for BIM; Lack of BIM experts; Lack of demand from customers or other companies for projects implemented using BIM technologies.
Jin et al. (2020)	Insufficient promotion of government policies on BIM technology and lack of specific policies and supporting measures that are truly practical and feasible; Hospital builders are unable to select BIM technology services that match the construction project and support the application; Lack of mature BIM team; Difficulty in changing the traditional thinking and accepting new technologies of hospital engineering and construction units; The economic benefits of BIM technology for hospitals are not obvious; Difficulty in managing the accuracy of BIM models; Lack of sufficient time to evaluate the effectiveness of BIM applications in hospital projects; BIM-based workflow has not been established; Incompatibility between BIM application software; High cost of hardware and software, training, and consulting
El Hajj et al. (2021)	Lack of awareness and knowledge; Waste of time; Lack of project finance; Lack of collaboration and information sharing; Lack of client demand; Lack of BIM skills, qualified staff; Lack of government support; Resistance to change; Liabilities Legal impact and copyright; Difficulty in intellectual property allocation; Lack of standards and guidelines Interoperability; Insufficient infrastructure; Lack of management support; Absence of contractual requirement; Lack of incentive/satisfaction with old methods; Lack of immediate benefits/ROI; Complexity of implementation; Commercial issues and investment cost; Lack of compatibility;
Vigneshwar et al. (2022)	The initial cost of purchasing BIM software; Education and Training of people; Management strategies; Clients' knowledge on BIM/requirement; The acceptance of the project members;

Table 2.7 Continued.

Researchers	Barrier Factors
	The proficiency level of tools to accept than conventional methods; Profit percentage / Return on investment; Number of BIM knowledge professionals available; Acceptance of BIM by senior/ middle management; Lack of well-developed standards/ government policies.
Olanrewaju et al. (2022)	Technology and business; Software accessibility; Insufficient contractual management and coordination; Data and intellectual property; Technological availability; Absence of training and knowledge; Interoperability issues; The reluctance of other stakeholders; Cost of data and information sharing; Business and cultural changes; Absence of specified standards; Cost of BIM adoption; Insufficient studies on BIM and the absence of information; Insufficient government rules and strategies; Absence of demand BIM implementation.
Long (2022)	Insufficient secondary research and development of domestic BIM software; Low localization of foreign BIM software; Lack of open exchange platform based on BIM; Immature core BIM software (including poor drawing performance, low degree of completeness of BIM model family library, lack of corresponding data sources, and difficult software operation, etc.); Lack of data exchange standards and poor compatibility of BIM software; Costs of purchasing and maintaining BIM software, hardware and platforms; Personnel costs (including the cost of hiring BIM experts, consulting experts, staff training fees and staff salaries, etc.); Low economic benefits of using BIM; Costs after reorganization of business processes; Lack of BIM technology application program and plan; Lack of integrated management model for BIM application; Lack of an organizational framework for BIM compatible with the enterprise structure; Participants are not adapted to the collaborative working model; Poor interaction between specialties; Business process constraints on BIM application; Lack of mature BIM composite talents; Not willing to share BIM results and data; Difficult to change the traditional thinking mode and working style; Insufficient support for BIM from national policies and senior leaders; Lack of legal constraints (including whether there is a standard BIM implementation contract sample, whether the model data of the BIM information platform is safe and reliable, whether the BIM model results are recognized and protected by law, insurance of BIM, etc.); Immature dispute handling mechanism of BIM; Lack of BIM application standards and guidelines; Insufficient knowledge of BIM; Lack of referable BIM implementation experience, academic exchanges, and systematic training courses; Lack of external impetus (including whether the government has implemented a mandatory BIM implementation policy for construction companies and whether the owner has explicitly requested construction companies to implement BIM in their projects during the bidding stage); The workload is high, and there is little opportunity to develop new knowledge.
Y. Zhang (2022)	BIM software is complicated to operate; BIM software is not perfect, and the secondary development is not enough different; Poor interactivity and compatibility of BIM software;

Table 2.7 Continued.

Researchers	Barrier Factors
	Scarcity of practitioners who master BIM technology; High cost of hardware and software configuration and maintenance; High cost of practitioners' training and experts' consulting; The mismatch between BIM inputs and outputs and the actual benefits are not obvious.; Insufficient understanding of BIM technology by enterprise executives and low importance attached to it; Practitioners lack time and motivation to learn BIM; Lack of industry BIM technology development plan; Lack of industry BIM technology standards and specifications; Lack of industry BIM charging standards and contract model texts; Lack of legal protection of intellectual property rights of BIM technology and immature dispute handling mechanism; Lack of BIM technology sharing and communication platform; Lack of policy support from administrative departments.
Takyi-Annan and Zhang (2023)	Associated Cost (high cost of software, hardware, etc.); Lack of supporting technology physical infrastructure/BIM training centers; Lack of BIM studies In Higher Educational Curricular (HEC) & the lack of BIM research; No/limited awareness & understanding of BIM, BIM benefits, and BIM ROIs; Lack of BIM experience &expertise/skilled personnel; A general resistance to change due to the lack of executive buy-in and client demand; Steep learning curve; Interoperability & compatibility issues; Data-related problems; Collaboration &communication issues + unclear roles and responsibilities; Complex BIM software & tools +BIM process is time-consuming & cumbersome; Lack of Government support, regulations &incentives + lack of BIM standards; Unavailability of Contractual &legal framework; BIM risks & the lack of dispute resolution mechanisms.
Youkhanna Zaia et al. (2023)	Believing the currently used technology is enough; People refuse to learn new technology; The high initial cost of implementing BIM; Lack of adequate training and their costs; Interoperability with other technology; Lack of BIM awareness; Stakeholder's resistance to change; The complexity of the BIM package Lack of BIM experts; Lack of demand from customers or other companies for projects; Traditional methods of contracting; Lack of BIM researchers and university courses.
Fu (2022)	Low degree of localization of software design, not in line with the domestic habits of use; Poor interoperability between software and lack of unified transfer format; Lack of effective BIM technology measures for the management of subway intervals; Lack of integration of the BIM model and surrounding construction environment; Lack of efficient collaborative management platform specifically applicable to metro projects; Independent departmental work, lack of unified collaborative work system; Lack of positive transfer mode of BIM model initiated from design; The gap between the BIM refined management concept and the current management mode is large; The project has not gained additional cost measures by using BIM technology; Higher hardware, software, and training costs for BIM technology inputs; Lack of methods to assess the value benefits of BIM implementation in construction projects; The refined management of BIM technology indirectly reduces the project's additional profit; Imbalance of authority and responsibility of specialized personnel in the BIM application process; Lack of BIM engineers who can take care of both software development and project implementation; Lack of a dedicated BIM application management team within the organization; Lack of basic courses and implementation training on BIM technology in colleges and universities.

Moreover, previous studies have systematically categorized the barriers encountered during the implementation process of Building Information Modeling (BIM). For example, Qiu and LI (2019) have summarized the main barriers faced by BIM implementation into four categories: individual-level barriers, organizational-level barriers, technical barriers, and institutional barriers. Correspondingly, Olanrewaju et al. (2020), from a slightly different perspective, proposed that the main barriers to BIM implementation can be divided into technical and business-related barriers, training and people-related barriers, cost and standard-related barriers, and process and economic-related barriers. Furthermore, El Hajj et al. (2021) classified these barriers from another dimension, believing that they are mainly concentrated in four areas: human resources, technology, organizational structure, and funding. Although these perspectives have different focuses, they collectively reveal the complexity and challenges in the BIM implementation process, providing valuable references for further research and practice. Consequently, in this study, based on their frequency of occurrence and the diversity of factors involved, 15 potential barrier factors affecting the implementation of BIM in Chengdu's MBCPs were initially identified. Then, it has been categorized into four main groups: Cost Factor (CF), People Factor (PF), Technical Factor (TF), and Organizational Factor (OF). The preliminary collation and summary of these factors are presented in Table 2.8.

Table 2.8 The selected BIM barrier factors according to previous researchers.

Barriers / References		Cost Factor (CF)		People Factor (PF)					Technical Factor (TF)				Organizational Factor (OF)			
		CF1	CF2	PF1	PF2	PF3	PF4	PF5	TF1	TF2	TF3	TF4	OF1	OF2	OF3	OF4
The first step: Literature review																
1	Migilinskas et al. (2013)	*	*			*			*			*				*
2	Xu et al. (2014)	*	*	*	*	*	*		*	*	*	*		*	*	*
3	Qin et al. (2016)	*		*	*	*	*		*	*			*	*	*	*
4	Li et al. (2017)	*	*		*	*		*	*	*			*	*	*	*
5	Azmi et al. (2018)	*	*	*	*		*	*	*			*			*	*
6	Ahmed (2018)	*	*	*	*	*	*	*			*		*		*	*
7	An and Xu (2019)			*	*				*	*				*		*
8	Tan et al. (2019)	*	*	*		*		*	*	*	*		*		*	*
9	Wang (2019)	*	*	*	*	*	*	*		*	*		*		*	*
10	Qiu and LI (2019)	*	*	*	*		*		*	*		*	*	*	*	*
11	Mahdi and Mawlood (2020)	*	*	*	*	*		*					*		*	*
12	Jin et al. (2020)	*	*	*	*			*	*	*	*				*	*
13	El Hajj et al. (2021)			*	*	*		*	*	*	*		*		*	*
14	Vigneshwar et al. (2022)	*	*	*	*	*	*	*		*						*
15	Olanrewaju et al. (2022)	*		*	*	*	*	*	*			*				*
16	Long (2022)	*	*	*	*	*	*		*	*	*	*		*	*	*
17	Y. Zhang (2022)	*	*	*	*	*	*		*	*	*		*	*	*	*
18	Takyi-Annan and Zhang (2023)	*	*	*	*	*	*		*	*	*	*		*	*	*
19	Youkhanna Zaia et al. (2023)	*	*	*	*	*	*	*	*		*		*	*	*	

Table 2.8 Continued.

References \ Barriers		Cost Factor (CF)		People Factor (PF)					Technical Factor (TF)				Organizational Factor (OF)			
		CF1	CF2	PF1	PF2	PF3	PF4	PF5	TF1	TF2	TF3	TF4	OF1	OF2	OF3	OF4
20	Fu (2022)	*	*	*	*	*		*	*	*	*	*	*	*	*	*
Frequency of Barrier Factors		18	16	18	18	16	12	12	16	14	11	8	11	10	16	19
Number of Barrier Factors		2		5					4				4			
		15														

Note: **CF1:** The initial investment costs are too high, including software and hardware expenses.

CF2: The training costs and the learning curve are prohibitively expensive.

PF1: Lack of proper understanding of BIM.

PF2: Lack of BIM experts.

PF3: Lack of support from senior management and client demand.

PF4: Insufficiency of appropriate training in BIM.

PF5: Insufficient understanding of BIM benefits.

TF1: Interoperability and compatibility issues among different BIM software.

TF2: Challenges in collaboration and communication coupled with ambiguity in roles and responsibilities.

TF3: The complexity of BIM software and tools, plus time-consuming and cumbersome BIM processes.

TF4: There are difficulties in converting data between different BIM platforms.

OF1: Traditional contracting methods (BIM requires special bidding conditions and a unique BIM service contract).

OF2: Social and habitual resistance to change.

OF3: Lack of specialized study on BIM technology in higher education curricula.

OF4: Lack of government support, regulations, and incentive measures coupled with incomplete standards for BIM.

CHAPTER 3

DATA COLLECTION

3.1 EXPERTS INTERVIEW

3.1.1 Interview Theory

Semi-structured interviews are an extremely flexible method in qualitative research, allowing researchers to delve into participants' insights and experiences while maintaining the directionality of the conversation (Raworth et al., 2012). According to Kvale and Brinkmann (2009), interviews are not merely a means of collecting data; they are also a crucial pathway to understanding participants' perspectives, experiences, and the process of knowledge construction. This study aims to provide an in-depth analysis of the complexity of applying BIM technology and the multidimensional barrier factors it faces in Chengdu's MBCPs based on an extensive and in-depth systematic of the literature, then through the semi-structured expert interview methodology.

To this end, based on an extensive systematic of the literature and preliminary research findings, this study has developed a set of interview outlines containing semi-open-ended questions. The outlines are designed to lead the interview process while allowing ample space for respondents to share their insights and experiences freely. The interview questions focused on the four dimensions of barrier factors to applying BIM technology in MBCPs (e.g., CF, PF, TF, and OF) and contained some main importance questions (e.g., each expert's work experience, different angles of the critical barrier factors to the widespread adoption of BIM technology presently for MBCPs, etc. question). Please refer to Appendix A for the complete interview outline.

Included experts are required to have 5 years of experience in applying BIM technology in MBCPs, BIM certificates of China Graphics Society (CGS), and a specialized degree or higher. The earliest BIM skill level test within China was initiated by the China Graphics Society, which was launched in 2012, and Autodesk's REVIT platform was used as the test software, so it is currently the most recognized BIM certificate in the CI (Y. Liu et al., 2019). In conclusion, this study has carefully selected 7 experts with rich experience in applying BIM technology in Chengdu's MBCPs, including 3 company owners, 3 BIM users, and 1 university teacher (The associate professor from the civil engineering college who is responsible for teaching BIM technology), to ensure in-depth insights from multiple angles and levels. Then the personal details of the experts are detailed in Table 3.1.

The research will use "Tencent Meeting" software to conduct 20 to 30-minute one-on-one online video interviews using Chinese with each expert. "Tencent Meetings" is similar to "Microsoft Teams" and is the most widely used online meeting platform in China (Wang et al., 2024). This approach is not only convenient but also maintains necessary social distancing during special periods, ensuring the privacy and focus of the interviews. Interviews will be recorded using video recording equipment, with prior consent obtained from participants. Interviewers will also take notes to capture non-verbal information and key observations. Upon completion of the interviews, the first step in this study was to accurately transcribe the audio recordings into text, aiming to precisely capture the statements of each expert. Subsequently, a thorough reading of each expert's interview transcript was conducted to deeply understand their core views and arguments. Further, this study synthesized the interview content, distilling critical barrier factors and recommendations pointed out by the experts. Based on summarizing and analyzing all expert opinions, a comparative and contrastive analysis was executed to identify commonalities and differences among the experts' views. This process not only aids in clarifying the consensus foundation within the research field but also provides an important perspective for revealing the diversity of expert insights. To enhance the reliability and validity of the research, the researchers will validate the initial analysis results and, if necessary, re-contact participants for confirmation. Meanwhile, the researchers will reflect on various aspects of the interview process, including interview skills, potential biases, and the accuracy of interpretations.

3.1.2 Interview Question

The outline of the expert interviews for this study is divided into three main parts, namely Personal Information (Part I), Opinions about the potential barrier factors to applying BIM technology in Chengdu's MBCPs (Part II), and Opinions on barrier factors collected from the Literature Review (Part III). The structure of the interview outline for this study is shown in Table 3.2. Please refer to Appendix A for the complete outline of the drop-in interviews.

Table 3.1 Seven MBCPs BIM experts' personal information.

Profession	Name	Age	Job Position	Company	Certificate	Experience
Company Owner	Donghe Lv	31	Manager	Sichuan Lingke Bomu Construction Technology Co., LTD	Level 2 BIM Senior Engineer Certificate in Architecture Major	8 Years
	Shuchao Xu	29	Manager	Sichuan Jinling Shuhui Technology Co., LTD	Level 2 BIM Senior Engineer Certificate in Architecture Major and Level 1 BIM Certificate	8 Years
	Xiaoping Xiang	51	Manager	Shenzhen Boda Construction Group Co., LTD. Sichuan Branch.	Level 2 BIM Senior Engineer Certificate in Architecture Major and Level 1 BIM Certificate	5 Years
BIM User	Kun Li	27	BIM Civil Engineer	Sichuan Highland Engineering Design Consulting Co., LTD	Level 1 BIM Certificate	5 Years
	Yuhui Li	27	BIM Electromechanical Engineer	Sichuan Jingzhi Enterprise management limited liability company	Level 2 BIM Senior Engineer Certificate in M&E Major	5 Years
	Shiheng Guo	26	BIM Electromechanical Engineer	Shanghai Huizhi Construction Consulting Co., LTD. Sichuan branch	Level 1 BIM Certificate	5 Years
University Teacher	Gang Wang	45	BIM teacher at the School of Engineering	School of Civil Engineering, Panzhihua University	Level 1 BIM Certificate	5 Years

Note: Experience means work experience in MBCPs, and certificate means job qualification certificate. The BIM certificates referred to in this study are uniformly the BIM certificates issued by the China Graphics Society (CGS), because the Level 1 BIM certificate is simpler than the Level 2 BIM certificate, so there is no distinction between the specialties, and the Level 2 BIM certificate is divided into three specialties: architectural, structural and M&E Major.

Table 3.2 Questions of Semi-structured expert interview.

No.	Question	Number
Part I: Personal Information.		1
Q1	Would you please give a quick introduction about yourself?	9
Part II: Opinions about the potential barrier factors to applying BIM technology in Chengdu's MBCPs.		5
Q1	What do you perceive as the critical barrier factors to the widespread adoption of BIM technology presently for MBCPs?	1
Q2	What are the cost factors (CF) for barriers associated with the application of BIM technology in MBCPs?	2
Q3	What are the technical factors (TF) for barriers that have a significant impact on the adoption of BIM technology in MBCPs?	5
Q4	What are the people factors (PF) for barriers that are significant in applying BIM technology in MBCPs?	3
Q5	What are the organizational factors (OF) for barriers to the adoption of BIM technology in MBCPs?	8
Part III: Opinions on barrier factors collected from the Literature Review.		5
Q1	As shown in the table below, which barrier factors are not barriers to the application of BIM in Chengdu's MBCPs?	15

3.2 QUESTIONNAIRE DESIGN

3.2.1 Questionnaire Theory

Questionnaire surveys are a commonly used method of data collection in social science research (Young, 2015), capable of efficiently gathering quantitative data from a larger sample size. Therefore, the questionnaire survey method is the key tool for collecting quantitative data in this study, which aims to identify the critical barrier factors and challenges to the wide application of BIM technology in Chengdu's MBCPs. Moreover, according to Dillman et al. (2014), who proposed the Tailored Design Method, designing high-response-rate questionnaires requires consideration of the characteristics and preferences of the target audience. This study adopts this theoretical framework to ensure that the questionnaire design maximizes participation rates and data quality.

In the AECI, the majority of researcher's questionnaires on BIM technology for barrier factors are categorized into three parts (e.g., Youkhanna Zaia et al., 2023; X. Zhang, 2023), so this study's online survey questionnaire comprised three sections: (1)

personal information of the respondents, (2) BIM expertise, and (3) potential barrier factors, see Table 3.3 for details. Moreover, based on the systematic of the literature and semi-structured expert interviews, this study initially identified 12 impediments, as well as three unimportant impediments that were removed based on expert feedback after IOC validation; see Table 3.5 for details. This study categorized these factors into Cost Factors (CF), People Factor (PF), Technical Factor (TF), and Organizational Factor (OF). Each category of factors was translated into specific questionnaire entries to ensure coverage of all study-identified hindering factors.

This study aims to quantify the impact of barrier factors through the use of a 5-point Likert scale (ranging from 1="very unimportant" to 5="very important"), thereby allowing participants to express their views on the importance of each barrier factor accurately. Prior to the formal distribution of the questionnaire, the questionnaire design was adjusted and optimized for clarity and overall validity through a pilot study conducted among 30 experienced BIM users in the AECI of Chengdu.

To ensure the representativeness of the research sample, this study used purposive sampling, with the target group being the management, designers, and engineers of 48 architectural firms in Chengdu that have been involved in healthcare building projects. This strategy takes into account the direct experience of these participants with the application of BIM technology in healthcare construction projects. Additionally, the questionnaire was directly sent to the target audience via email and the "WeChat" software, and the sample size was expanded through the participants' networks using snowball sampling techniques, ensuring that the questionnaire could reach the target group quickly and effectively. Data collection was facilitated by online survey tools such as Questionnaire Star, which not only facilitated the automated processing and analysis of data but also aimed to increase the response rate with an attached letter explaining the research purpose and data security.

Data processing and analysis will be performed using SPSS V29 and Microsoft Excel software, encompassing a variety of analytical methods including descriptive statistical analysis (such as mean, mode, median, standard deviation, etc.), reliability analysis (Cronbach's alpha), correlational analysis (Spearman's rank correlation coefficient), and non-parametric rank sum tests (Mann-Whitney U and Kruskal-Wallis H tests), in order to comprehensively evaluate the research data and reveal the barriers and their impacts in the application of BIM technology.

Furthermore, the study, which was an expert proficient in both English and Chinese, as well as BIM technology, was specially invited to translate it into a well-crafted Chinese version, ensuring the linguistic quality and technical accuracy of the questionnaire. The specific content of the English and Chinese versions of the questionnaire and its corresponding items can be found in Appendix B and Appendix C.

Table 3.3 Questionnaire structure of this research.

Questions	Number
Part I: Personal Information of the Respondents.	8
1.1 Gender.	1
1.2 Age.	1
1.3 Current level of education.	1
1.4 Employment Position.	1
1.5 How long have you worked since graduating?	1
1.6 Organizations Sector.	1
1.7 What is the nature of your organization?	1
1.8 Frequently used BIM software.	1
Part II: BIM Expertise.	6
2.1 Your level of understanding of BIM technology.	1
2.2 Your attitude to the promotion of BIM technology in the MBCPs.	1
2.3 Years of Using BIM Technology?	1
2.3 The number of MBCPs in which you have been involved in using BIM technology.	1
2.4 What kind of BIM models are often used when implementing BIM technology？	1
2.5 In your day-to-day work, do you consider the BIM model to be more important or the visualization of BIM technology?	1
2.6 The BIM Level of Details (LOD) level used when building the BIM model?	1
Part III: Possible barrier factors or challenges facing implementing BIM in Chengdu's MBCPs.	12
3.1 Cost Factor (CF)	2
3.2 People Factor (PF)	4
3.3 Technical Factor (TF)	3
3.4 Organizational Factor (OF)	3

Note: Adapted from (Youkhanna Zaia et al., 2023; X. Zhang, 2023).

3.2.2 Scale

This article employs the Likert five-point scale to quantitatively assess the importance of the listed barriers, ranging from 1= strongly unimportant to 5= strongly important, as shown in Table 3.4 below. This method of quantification aids in objectively measuring the extent to which various barriers impact the implementation of research or engineering projects in practice, providing a standardized basis for further analysis and decision-making (Nemoto & Beglar, 2014).

Table 3.4 The Likert five-point scale.

Numerical Value	Specific Implications
1	Strongly Unimportant
2	Unimportant
3	Neutral
4	Important
5	Strongly Important

Note: Source from Tsai and Lu (2012).

3.2.3 Surveyed Barrier Factors

Based on the results of the Interview results and IOC validation results conducted with seven BIM expert, this study revised the survey questionnaire, which included the removal of three identified barriers, namely: PF5: Insufficient understanding of BIM benefits, TF4: There are difficulties in converting data between different BIM platforms, and OF2: Social and habitual resistance to change. Following this adjustment, the study still considers 12 potential barriers that could affect project implementation. See Table 3.5 for details for barrier factors.

3.2.4 Questionnaire Testing

3.2.4.1 Quality of Research Instrument

1) Validity Analysis

A validity test is employed to assess the questionnaire's rationality and validity. Moreover, assessing content validity is crucial in the early stages of questionnaire development. Therefore, this study aims to use IOC validation for content validity analysis and to ensure that the questionnaire items genuinely cover all relevant concepts or dimensions intended to be measured (Tongprasert et al., 2014). Typically, IOC validation requires evaluation by multiple experts with experience in the relevant field.

Table 3.5 The selected BIM barrier factors are based on the expert interviews.

Group	Code	Barrier Factors	Post-expert interview and IOC validation	After final revision
Cost Factor (CF)	CF1	The initial investment costs are too high, including software and hardware expenses.	Passed	Retain
	CF2	The training costs and the learning curve are prohibitively expensive.	Passed	Retain
People Factor (PF)	PF1	Lack of proper understanding of BIM.	Passed	Retain
	PF2	Lack of BIM experts.	Passed	Retain
	PF3	Lack of support from senior management and client demand.	Passed	Retain
	PF4	Insufficiency of appropriate training in BIM.	Passed	Retain
	PF5	Insufficient understanding of BIM benefits.	Unpassed	Deleted
Technical Factor (TF)	TF1	Interoperability and compatibility issues among different BIM software.	Passed	Retain
	TF2	Challenges in collaboration and communication coupled with ambiguity in roles and responsibilities.	Passed	Retain
	TF3	The complexity of BIM software and tools, plus time-consuming and cumbersome BIM processes.	Passed	Retain
	TF4	There are difficulties in converting data between different BIM platforms.	Unpassed	Deleted
Organizational Factor (OF)	OF1	Traditional contracting methods (BIM requires special bidding conditions and a unique BIM service contract).	Passed	Retain
	OF2	Social and habitual resistance to change.	Unpassed	Deleted
	OF3	Lack of specialized study on BIM technology in higher education curricula.	Passed	Retain
	OF4	Lack of government support, regulations, and incentive measures coupled with incomplete standards for BIM.	Passed	Retain

Hence, this study specifically invited 7 BIM experts (experience ≥ 5 years) in the MBCPs to assess each barrier through a questionnaire, and the IOC validation questionnaire is detailed in the attached Appendix C. This assessment aims to determine the consistency of each barrier factor with this study's corresponding objectives or concepts. Moreover, the seven BIM experts' personal information is shown in Table 3.1. Each question in the questionnaire was evaluated by each expert. For each question, the scores are averaged to calculate the IOC. In addition, The IOC value between 0.6 and 1.00 is acceptable (Wuthisuthimethawee et al., 2021; Tulyakul, 2022), and how to judge IOC validity, as shown in Table 3.6.

Score +1 = if the expert determines that the question accurately assesses the attribute.

Score 0 = if the expert is unsure whether the question accurately assesses the attribute.

Score -1 = if the expert determines the question does not assess any attribute.

The calculated formula for Content Validity is shown in Formula 3.1 (Champabhoti & Sae-Joo, 2019).

$$IOC = \frac{\sum R}{N} \tag{3.1}$$

Where R = Congruent score

N = Number of experts = 7

1 = Congruent

0 = Questionable

-1 = Incongruent

The range of IOC scores is -1 and +1; the closer it is to 1, the better. Then, the item is considered to be highly consistent with the objective, and no modification is required.

Table 3.6 Judgment criteria for content validity.

The item with IOC score	Result
0.6 < IOC < 1.00	Passed
0.5 < IOC < 0.6	Need to modify
IOC < 0.5	Unpassed

Note: Source from (Wuthisuthimethawee et al., 2021; Tulyakul, 2022).

2) **Reliability Analysis**

One of the fundamental requirements of any research paper is to maintain accurate measurements and acceptable results. To achieve this, this study conducted a pilot survey to examine the validity and reliability of the questionnaire. The researchers performed internal consistency measurements and used Cronbach's alpha, as it is one of the most important and commonly used methods for testing reliability (Yockey, 2023). The normal range of Alpha values is between 0 and +1; the higher the value, the higher the degree of internal consistency (BrckaLorenz et al., 2013). For most purposes, a reliability factor above 0.7 is considered satisfactory (Reinius et al., 2017). The calculated formula for Cronbach's alpha is shown in Formula 3.2 (Bland & Douglas, 1997).

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum S_i^2}{S_x^2}\right) \qquad (3.2)$$

Where α = the reliability coefficient,

K = the number of test items,

S_i^2 = the variance of each item,

S_x^2 = the variance of the total scores.

And how to judge Cronbach's Alpha criteria, as shown in Table 3.7.

Table 3.7 Judgment criteria for Cronbach's Alpha.

Cronbach's Alpha	Degree of reliability
$0.9 \le \alpha$	Excellent
$0.8 \le \alpha < 0.9$	Good
$0.7 \le \alpha < 0.8$	Acceptable
$0.6 \le \alpha < 0.7$	Questionable (Moderate)
$0.5 \le \alpha < 0.6$	Poor
$0.5 < \alpha$	Unacceptable

Note: Source from Gliem and Gliem (2003).

3.2.4.2 Normality Distribution

Maintaining the accuracy of results is one of the primary objectives of any research. Therefore, prior to commencing data analysis, the Kolmogorov-Smirnov (K-S) test was conducted using IBM SPSS V29 statistical software to assess the normality of the data, thereby facilitating the selection between parametric and non-parametric tests (Lilliefors, 1967). Therefore, the criteria for judgment are presented in Table 3.8. In other words, if the P-value is below the default significance level (0.05 or 5%), the original hypothesis is rejected, and further non-parametric statistical tests will be conducted (Maity, 2022). Meanwhile, the calculated formula for its one-sample test statistic is shown in Formula 3.3 (Berger & Zhou, 2014).

$$D = max\ |F_x - F_0(\chi)| \tag{3.3}$$

Where D is the K-S test statistic,

F_x is the Empirical Distribution Function (ECDF) of the sample,

$F_0(\chi)$ is the hypothesized theoretical distribution function,

max denotes the operation of taking the maximum value,

| | denotes the operation of taking the absolute value.

Table 3.8 The K-S test judgment criteria.

Confidence Level	Results	Data Distribution Status
95%	Sig ≥ 0.05 (Accept the null hypothesis)	Normal distribution
	Sig < 0.05 (Reject the null hypothesis.)	Non-normal distribution
99%	Sig ≥ 0.01 (Accept the null hypothesis)	Normal distribution
	Sig < 0.01 (Reject the null hypothesis.)	Non-normal distribution

Note: K-S test's null hypothesis is normally distributed. Vice versa. Source from Massey Jr (1951).

3.2.4.3 Descriptive Statistics Analysis

Descriptive statistics involve calculating the characteristics of variables used in the data, such as Mean (M), Mode, Median, Standard Deviation (SD), Percentiles, Skewness, Kurtosis, and Maximum and Minimum Values. The purpose of performing descriptive analysis is to understand the characteristic behaviors of the data before conducting in-depth statistical analysis. This research will collect valid questionnaires from formal surveys and perform statistical distribution of percentages and sample frequencies on the content of this online survey questionnaire's first and second parts, such as information on respondents' gender, age, educational level, position, and years of work experience. Additionally, for the content of the third part of this survey questionnaire (barrier factors), the Maximum and Minimum Values, M and SD, will be calculated to understand the basic characteristics of the sample data. Moreover, the formula for the mean is shown in Formula 3.4, and the formula for the standard deviation is shown in Formula 3.5 (Lee et al., 2015).

$$\overline{X} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{3.4}$$

Where $\overline{X}$ is the sample mean, which represents the average of all sample values.

n is the sample size, the total number of observations in the data set.

$\sum_{i=1}^{n} x_i$ is summation notation, which indicates that for all from $i = 1$ to n values are summed.

x_i is the i observation.

$$s = \frac{\sum_{i=1}^{n} (x_i - \overline{X})^2}{n} \tag{3.5}$$

Where s is the Sample standard deviation, a measure of how far the values in a data set are dispersed from the sample mean.

n is the sample size, the total number of observations in the data set.

x_i is the i observation.

$\overline{X}$ is the sample mean, which represents the average of all sample values.

$\sum_{i=1}^{n} (x_i - \overline{X})$ is summation symbols, denoting for all $x_i - \overline{X}$ from $i = 1$ to N values are summed.

$(x_i - \overline{X})^2$ is the square of the difference between the ith observation and the sample mean is calculated as the deviation of each observation from the mean.

3.2.4.4 Correlation Analysis

When the data is not bivariate normal, Spearman's rho correlation coefficient is commonly used as an indicator of correlation (Myers & Sirois, 2004). Therefore, this study will employ Spearman's rho correlation analysis to examine the associations between 12 barrier factors meticulously. This analytical method aims to confirm and quantify the interrelationships among these variables (Schober et al., 2018). Its value ranges from -1 to 1. When it is close to 1, it means that the two have a strong positive correlation; when it is close to -1, it means that there is a strong negative correlation; and when the value is close to 0, it means that the correlation is very low. Moreover, the calculated formula for Spearman's rho correlation coefficient is shown in Formula 3.6 (Zar, 2005). The easy criteria for the correlation analysis are outlined in Table 3.9.

$$r_s = 1 - \frac{6 \sum d_i^2}{n^3 - n} \quad (3.6)$$

Where d_i^2 is the square of the difference in the ranks of the two coordinates represented.

n is the total number of observation samples.

Table 3.9 Levels of the correlation coefficient.

Correlation Coefficient (r_s)	Levels of relationships
$0.8 < \lvert r_s \rvert \leq 1$	Very Strong correlation
$0.6 < \lvert r_s \rvert \leq 0.8$	Strong correlation
$0.4 < \lvert r_s \rvert \leq 0.6$	Moderate correlation
$0.2 < \lvert r_s \rvert \leq 0.4$	Weak correlation
$\lvert r_s \rvert \leq 0.2$	Very weak correlation

Note: Source from Prion and Haerling (2014).

3.2.4.5 Non-parametric Rank Sum Tests

This study will utilize non-parametric rank sum tests, including Mann-Whitney U (M-W U) and Kruskal-Wallis H (K-W H) tests, to analyze 12 barrier factors for the datasets. Moreover, after identifying significant differences, post-hoc analysis pairwise comparisons will be conducted to elucidate the specific group differences further. In addition, Bonferroni-Dunn test will correct P-values of all barrier factors to avoid Type I errors when post-test (Pohlert, 2014). Non-parametric tests are employed to interpret data that do not follow a normal distribution (Field, 2013). As non-parametric methods, both M-W U and K-W H tests compare data through mean ranks correlated positively with average values, to examine differences between and within independent groups using random sample sizes, respectively (Salkind, 2010).

1) M-W U Tests

Due to the non-normal nature of the collected data, for this reason, this study is based on the work of researchers Oti et al. (2021), the M-W U test will be employed to determine whether there is a statistically significant difference in the respondents' perceptions of the importance of these barrier factors by whether they have used BIM technology in the past or not, and the calculated formula for M-W U test is shown in Formula 3.7.

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1 \quad (3.7\text{-}1)$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - R_2 \quad (3.7\text{-}2)$$

Where U_1 is the U-value of the first sample group,

U_2 is the U-value of the second sample group,

n_1 is the sample size of the first sample group,

n_2 is the sample size of the second sample group,

R_1 is the rank sum of the first sample group,

R_2 is the rank sum of the second sample group.

2) K-W H Tests

Moreover, this study based on the work of researchers Alexander and Quade (1968), the K-W H test will be employed to examine whether there are statistically significant differences in the perceptions of the importance of these barrier factors among different professional identities (e.g., managers, designers, and engineers), with the calculated formula for the K-W H test shown in Formula 3.8. M-W U tests and K-W H tests are the determination of significance is based on whether the p-value is less than the predetermined level of significance (usually 0.05) (Neely et al., 2003), the judgment criteria as shown in Table 3.10.

$$H = \frac{12}{n\,(n+1)} \sum \frac{R_i^2}{n_i} - 3(n+1) \quad (3.8)$$

Where n is the sum of sample sizes for all samples,

R is the sum of the ranks for each sample,

n_i is the number in each sample.

3) The post-hoc Dunn-Bonferroni pairwise comparison

The post-hoc Dunn-Bonferroni pairwise comparison was used for two-by-two analyses after the M-W U and K-W H tests had determined that a factor was significantly

Table 3.10 Judgment criteria for M-W U and M-W H tests.

Number	Meaning
P-value ≥ 0.05	Retain the null hypothesis.
P -value < 0.05	Reject the null hypothesis.

Note: P-value means probability value. The null hypothesis means there was no statistically significant difference. Source from Neely et al. (2003).

different. The Bonferroni-Dunn test is a statistical procedure used to control for the family-wise error rate (FWER) when conducting multiple pairwise comparisons (Singh, 2013; Dinno & Dinno, 2017). This test is particularly useful in the context of post-hoc analysis following a significant omnibus test result, such as ANOVA or Kruskal-Wallis test. The Bonferroni-Dunn method adjusts the significance level to account for the increased risk of Type I errors that occur when multiple comparisons are made, with the calculated formula for the Dunn-Bonferroni test shown in Formula 3.9. Moreover, a pairwise comparison is considered statistically significant if the adjusted P-value (α') is less than the default significance level (0.05 or 5%) (Pohlert, 2014).

$$\alpha' = \frac{\alpha}{k(k-1)/2} \quad (3.9)$$

Where α is the original significance level (commonly set at 0.05).

k is the number of groups being compared.

$k(k-1)/2$ represents the total number of pairwise comparisons.

3.2.4.6 The Relative Importance Index (RII) Analysis

This study will use the RII analysis to rank each barrier factor in the questionnaire. Due to assess the relative importance of the impediments affecting the widespread use of BIM technology in Chengdu's MBCPs. The RII is one of the most reliable methods for rating variables using a structured questionnaire on a Likert scale (Abinaya Ishwarya & Rajkumar, 2021). The calculated formula for the RII test is shown in Formula 3.10 (Saleh, 2015).

$$RII = \frac{\sum W}{A*N} \; (0 \leq RII \leq 1) \quad (3.10)$$

Where W is the rating of each item by respondents, ranging from 1 to 5,

A represents the maximum weight, which is 5 in this research, N is the number of respondents.

The RII ranges from 0 to 1 (excluding 0). According to, the RII values are converted into six levels of importance; in other words, the higher the RII value, the greater the impact of the attribute, as shown in Table 3.11 (Hossen et al., 2015; Boakye & Adanu, 2022). Nonetheless, RII does not reflect the interrelationship among various attributes.

Table 3.11 Five levels of importance of the RII test.

Levels	Value of number
Very High (VH)	$0.9 \leq RII \leq 1.0$
High (H)	$0.8 \leq RII < 0.9$
High-Medium (H-M)	$0.6 \leq RII < 0.8$
Medium (M)	$0.4 \leq RII < 0.6$
Medium-Low (M-L)	$0.2 \leq RII < 0.4$
Low (L)	$0.0 < RII < 0.2$

Note: Source from (Hossen et al., 2015; Boakye & Adanu, 2022).

3.2.5 Pilot Study

The pilot study's aims to evaluate the clarity of scale items, the respondents' ability to answer, the accuracy of questions, and whether the structure and sequence of the questionnaire are reasonable and free of apparent issues. This process includes a testing phase for the questionnaire. Consequently, a small-scale pilot study was conducted, and this method is considered to significantly improve the quality of the questionnaire. Subsequently, based on the results of the pilot study, adjustments are made to the measurement items to form the official survey questionnaire. Before releasing the official survey, the research team will meticulously review every detail of the questionnaire again to ensure its accuracy in language expression, logical structure, and format.

For this purpose, the pilot study randomly selected 30 BIM users from various construction firms in Chengdu with extensive experience in the AECI. The survey was generated through the Chinese online survey platform "Wen Juanxing" and distributed to participants via email and "WeChat" in the form of online links and QR codes, with responses collected 100% within a week. Moreover, to encourage honest and frank feedback, anonymity was ensured for participants.

To assess the survey's reliability, this study calculated the Cronbach's Alpha values of the questionnaire items using SPSS V29 software, setting 0.7 as the acceptable threshold for reliability. For validity, content validity was ensured through a pre-review of the survey questions by industry experts. This pilot study's Cronbach's Alpha value was 0.893 > 0.7, also the Alpha of each dimension is > 0.7, indicating good internal consistency, as shown in Table 3.12. This result supports the reliability of the survey and lays the groundwork for further research. However, despite the encouraging overall reliability score, feedback from respondents indicated that the survey missed some commonly used BIM software (such as Rhino, Tekla and CNIEMA 4D), and some questions were phrased ambiguously, which could affect the survey's validity. Based on the feedback received, the research team quickly revised the questionnaire to improve question clarity and eliminate ambiguity, aiming to enhance the validity of the survey content and ensure an accurate reflection of BIM users' experiences and opinions. The pilot study highlighted the importance of formulating clear and explicit survey questions for gathering meaningful data and emphasized the value of conducting pilot testing before major research to identify and address potential issues.

Table 3.12 Reliability analysis results of the pilot study.

Factor Group	Barrier Factor	Cronbach's Alpha		CITC	CAIID
		Group	Overall		
Cost Factor (CF)	CF1	.847	.893	.581	.886
	CF2			.501	.891
People Factor (PF)	PF1	.962		.806	.873
	PF2			.848	.871
	PF3			.711	.880
	PF4			.750	.876
Technical Factor (TF)	TF1	.904		.578	.886
	TF2			.536	.888
	TF3			.476	.892
Organizational Factor (OF)	OF1	.788		.530	.888
	OF2			.455	.892
	OF3			.525	.888

Note: CITC means Corrected item-total correlation. CAIID means Cronbach's alpha if item deleted.

3.2.6 Used Questioned

This study was based on the feedback from experts, and several critical adjustments were made: three original potential barrier factors were removed, namely PF5 (Insufficient understanding of BIM benefits), TF4 (There are difficulties in converting data between different BIM platforms), and OF2 (Social and habitual resistance to change). The specific results of the IOC validation are presented in Table 4.7. After this series of careful modifications, the number of barrier factors ultimately identified in the questionnaire was reduced to twelve, as shown in Table 3.13. This step not only enhanced the rigor of the research method but also ensured the high professionalism and practicality of the questionnaire content, providing a solid foundation for subsequent research.

Table 3.13 Revised barrier factors based on experts' comments.

Factor Group	Code	Barrier Factors' Name
Cost Factor (CF)	CF1	The initial investment costs are too high, including software and hardware expenses.
	CF2	The training costs and learning curve are excessively expensive.
People Factor (PF)	PF1	Lack of proper understanding of BIM.
	PF2	Lack of BIM experts.
	PF3	Lack of support from senior management and client demand.
	PF4	Insufficiency of appropriate training in BIM.
Technical Factor (TF)	TF1	Interoperability and compatibility issues between different BIM software.
	TF2	Challenges in collaboration and communication coupled with ambiguity in roles and responsibilities.
	TF3	The complexity of BIM software and tools, plus time-consuming and cumbersome BIM processes.
Organizational Factor (OF)	OF1	Traditional contracting methods (BIM requires special bidding conditions and a unique BIM service contract).
	OF2	Lack of specialized study on BIM technology in higher education curricula.
	OF3	Lack of government support, regulations, and incentive measures coupled with incomplete standards for BIM.

3.3 DATA SAMPLING

3.3.1 The Sampling of the Questionnaire

Purposive sampling was utilized as the sampling method. This non-probability sampling technique is optimal when a substantial number of individuals are knowledgeable in the field of study (Tongco, 2007). Purposive sampling is also compatible with both qualitative and quantitative research. Its advantages include accessible and rapid data, while its limitations include the potential non-representativeness of the entire population and possible bias from respondents (Barratt et al., 2015).

3.3.2 Research Population

This study aims to investigate the critical barrier factors and challenges affecting the widespread application of BIM technology in Chengdu's MBCPs. Therefore, this study analyzed the member list of the CCIA, and it was determined that there were 280 member construction companies in Chengdu (CCIA, 2023). Please see Appendix E for a detailed list of specific construction companies. However, after excluding 25 members that belonged to branches of the CCIA, 255 qualified construction companies were ultimately identified. Notably, these construction companies cover all subdivisions of the CI, including rail transit, municipal engineering, residential construction, and medical construction. Therefore, these data can serve as a foundational reference for assessing the BIM technological capabilities of construction companies. In other words, these 255 construction companies are this study's population.

3.3.3 Sample and Sample Size

In September 2023, this study conducted a detailed keyword search on the "Sichuan Public Resources Trading Information Network (SPRTIN)," with keywords including "Chengdu," "hospital," "construction," and "winning bids." Through this search, 48 construction companies were identified as having successfully won the bids for major MBCPs in the Chengdu area, as detailed in the data provided in Table 3.14. The "Sichuan Public Resources Trading Information Network" is an official platform operated by the government of Sichuan Province in China, specifically for the public tendering of construction projects, providing key data support for this study. These data reveal that the companies winning the bids are primarily state-owned construction enterprises, most of which have specialized BIM teams or departments, such as BIM centers. Given that these data all come from government public information, they are highly reliable and trustworthy. Based on this, the study adopted a purposive sampling method, selecting the management, designers, and engineers from these 48 companies as survey subjects and planning that 144 valid questionnaires would be returned, so 164 online questionnaires would be distributed. Moreover, the list of 48 construction firms winning bids for MBCPs in Chengdu is shown in Table 3.14.

Table 3.14 List of 48 construction firms winning bids for MBCPs in Chengdu.

No.	Company's name
1	Beijing Zhong Jianhua Teng decoration engineering Co., LTD
2	Bingsen Hongye Group Co., LTD
3	Boe Health Investment Management Co. LTD
4	CCCC Second Highway Engineering Bureau Co., LTD
5	Chengdu best construction and installation engineering Co., LTD
6	Chengdu construction decoration Co., LTD
7	Chengdu Construction Engineering eighth construction engineering Co., LTD
8	Chengdu Construction Engineering Group Co., LTD
9	Chengdu Construction Engineering third construction engineering Co., LTD
10	Chengdu construction first construction engineering Co., LTD
11	Chengdu construction industrial equipment installation Co., LTD
12	Chengdu Construction seventh construction engineering Co., LTD
13	Chengdu Hongda clean Technology Engineering Co., LTD
14	Chengdu Huayang Construction Co., LTD
15	Chengdu Pujiang County three construction engineering Co., LTD
16	China Architecture Southwest Design and Research Institute Co., LTD
17	China Construction Eighth Engineering Bureau Limited
18	China Construction fifth Bureau Third construction Co., LTD
19	China Construction Oriental decoration Co., LTD
20	China Construction seven Bureau building decoration engineering Co., LTD
21	China Construction Shenzhen decoration Co., LTD
22	China Construction third Bureau first construction engineering limited liability company
23	China Construction Third Bureau Group Co., LTD
24	China Five Metallurgical Group Co., LTD
25	China Huaxi Enterprise Co., LTD
26	China Nuclear Industry Zhongyuan Construction Co., LTD
27	China Railway 20th Bureau Group Sixth Engineering Co., LTD
28	China Railway Beijing Engineering Bureau Group Co. LTD

Table 3.14 Continued.

No.	Company's name
29	China Xinxing Construction Engineering Co., LTD
30	Dingkui Construction Group Co., LTD
31	Guizhou Aerospace Construction Engineering Co., LTD
32	Laoken Medical Technology Co., LTD
33	Lida Decoration Group Co., LTD
34	Shandong Xingrun construction Co., LTD
35	Shenzhen Meizhao Environment Co., LTD
36	Sichuan Chaoyu Construction Group Co., LTD
37	Sichuan Fusheng Project Management Co., LTD
38	Sichuan Golden Cube Construction Engineering Co., LTD
39	Sichuan Guojin Construction Development Co., LTD
40	Sichuan Guoyu architectural decoration Engineering Co., LTD
41	Sichuan Hanxiang Construction Engineering Co., LTD
42	Sichuan Shangtian Construction Engineering Co., LTD
43	Sichuan Shuyu Construction Engineering Co., LTD
44	Sichuan Yinming Construction Engineering Co., LTD
45	Sichuan Zhenhua Construction Group Co. LTD
46	Sunrise Medical Technology Co., LTD
47	Zhongcheng Investment Construction Engineering Group Co., LTD
48	Zhongjian Hongteng Construction Group Co., LTD

Note: All information adapted from SPRTIN (2023).

3.4 QUESTIONNAIRE DISTRIBUTION

This study conducted an anonymous survey using the Wen Juanxing online survey platform. The choice of this platform was due to its professionalism and user-friendliness, akin to Google Forms. It supports not only powerful survey design, data collection, reporting customization, and result analysis features but also mobile device completion and dissemination via WeChat groups, showcasing the convenience of a one-stop survey tool (Mou et al., 2019). Before distributing the questionnaire, the study first used Wen Juanxing to create an online survey questionnaire based on the expert-translated Chinese version, along with making a QR code and online webpage link for the survey, which were then distributed via WeChat and email. Finally, in order to improve the enthusiasm of the respondents, this study gave a small gift to each company to express their gratitude. Below is a detailed explanation of the questionnaire distribution.

To effectively distribute the online survey questionnaire, the study adopted two specific strategies:

1) Employing the Email Invitations method. The "Baidu" search engine (www.baidu.com) searched for the official websites of the 48 construction companies listed in Table 3.14 to obtain their email addresses. Managers, designers, and engineers who had participated in medical construction projects were randomly selected from each company to receive the online survey questionnaire (QR code and online webpage link), with the plan to collect at (say) least three valid questionnaires from each construction company.
2) Employing a snowball sampling method. The construction companies that cannot be contacted by the authors are listed in Table 3.4. will be contacted by experts, managers, designers, and BIM engineers in Chengdu's MBCPs. Managers, designers, and engineers who have participated in medical construction projects will be randomly selected from these companies to participate in the survey. Once again, the online survey questionnaire (QR code and online webpage link) will be sent to each of them via WeChat.

CHAPTER 4
DATA RESULTS

4.1 INTERVIEW RESULTS

4.1.1 Interview Answer

The collective insights from seven excellent BIM experts, each with extensive experience in integrating BIM technology in Chengdu's MBCPs in Chengdu, illuminate the complex array of barrier factors hindering the broader adoption of BIM. Despite variations in perspectives attributable to differences in professional backgrounds or affiliations, these expert viewpoints enrich the comprehensiveness of this study. Moreover, please see Annex F for details of the results of the full interviews with the seven experts. Meanwhile, all the experts have always believed that in Chengdu's MBCPs where BIM technology is widely used, various factors have an impact on the promotion and application of BIM technology, see Table 4.1 for details.

Table 4.1 Summary of the interview result.

Experts		Expected Factors				Most Important Factors
		CF	PF	TF	OF	
Company owner	Donghe Lv	Agreed	Agreed	Agreed	Agreed	PF, TF
	Shuchao Xu	Agreed	Agreed	Agreed	Agreed	PF, OF
	Xiaoping Xiang	Agreed	Agreed	Agreed	Agreed	PF, TF, OF
BIM User	Kun Li	Agreed	Agreed	Agreed	Agreed	CF, PF, TF
	Yuhui Li	Agreed	Agreed	Agreed	Agreed	TF
	Shiheng Guo	Agreed	Agreed	Agreed	Agreed	CF
University teacher	Gang Wang	Agreed	Agreed	Agreed	Agreed	PF

Notably, Expert Donghe Lv highlights a critical issue: the insufficient awareness among project owners about BIM technology. Lead to many project owners lack a definitive objective for BIM implementation at the project's inception. Eventually, it will affect the subsequent use of BM technology. Moreover, both expert Donghe Lv and Xiaoping Xiang, who also point out the challenges in cross-software collaboration and information exchange, as well as interoperability issues between various BIM software. These technical barriers complicate seamless integration and utilization of BIM across different project stages. Experts Shuchao Xu and Xiaoping Xiang bring attention to the gap between policy support and its execution. Despite policies favoring BIM adoption, actual implementation falls short, often due to a limited understanding of BIM's benefits and suboptimal promotion stemming from insufficient policy backing. Expert Kun Li and Shiheng Guo emphasize the substantial initial investment required for deep BIM integration, covering training, software, plugins, and specialized workstations. These costs are unbearable for small and medium-sized construction enterprises, so BIM technology is more used by some large state-owned construction enterprises. Expert Gang Wang identifies resistance among project management personnel, who frequently perceive their existing methodologies as adequate, relegating BIM teams to roles that merely satisfy basic requirements or seek commendations rather than fully leverage BIM's capabilities. Yuhui Li underscores the significant hurdles in collaborative efforts and communication, particularly highlighted by the complexities involved in the installation of mechanical and electrical systems in medical buildings. Such communication gaps can lead to construction discrepancies, necessitating rework and diminishing the efficacy of BIM planning. Moreover, this study summarizes the main impediments barrier factors by each expert in Table 4.2.

Table 4.2 Main barrier factors of seven BIM experts.

Occupation	BIM Experts	Main Barrier Factors
Company Owner	Donghe Lv	The owner's goal of applying BIM technology in the early stage is not clear.
		Difficulties in collaboration between different 3D modeling software and problems in model information transfer.
	Shuchao Xu	Although our country has certain policy support, most of the construction and policy implementation are not in place.
		There is a lack of fully specialized BIM experts who understand BIM technology and also have a strong ability to manage the construction site.
		The management of many construction companies for the BIM technology is not enough to recognize.

Table 4.2 Continued.

Occupation	BIM Experts	Main Barrier Factors
	Xiaoping Xiang	There is insufficient understanding of the benefits of BIM technology.
		There are barriers to interaction between different BIM software and problems with interoperability and compatibility between software.
		There is also insufficient support from relevant policies, which leads to the poor popularization of BIM technology.
		Most of the executives of construction companies do not pay enough attention to BIM technology, which leads to a lack of capital investment in BIM technology.
BIM user	Kun Li	Deep application of BIM technology, the project's upfront cost is relatively high.
		Lack of BIM technology for a large number of composite talents.
		MBCPs have multiple specialized subcontractors, which makes it more difficult for BIM engineers to communicate with each other at work.
	Yuhui Li	Collaboration and communication challenges, along with ambiguous roles and responsibilities, make the original most complex M&E professional-related work in MBCPs more challenging to continue carrying out, weakening BIM's advantages from an early age.
	Shiheng Guo	The application of BIM technology needs to be invested in the early stage of the high cost, for example, the staff of the BIM technology training, as well as some of the genuine BIM software, BIM plug-ins, and BIM workstations as procurement.
University Teacher	Gang Wang	The primary challenge in adopting BIM technology as stemming from the project management team's perspectives. Many project managers believe that their current professional capabilities and management teams are sufficient for completing MBCPs without the additional expense of hiring BIM teams. Furthermore, even when BIM teams are employed, the aim often isn't to leverage BIM technology to its fullest potential but rather to meet owner requirements or pursue awards.

4.2 QUESTIONNAIRE RESULTS

4.2.1 Received Response

During November 2023, the study a questionnaire survey was conducted, and 164 questionnaires were distributed and retrieved. After an initial screening of the collected data, 20 questionnaires were deemed invalid and excluded. Additionally, given the significance of work experience in the construction industry for the outcomes of this study, 13 questionnaires from respondents with two years or less of work experience in the CI were further eliminated. Through this filtering process, the final count of valid questionnaires was established at 131, resulting in an effective recovery rate of 79.88%, as shown in Table 4.3. This high rate of effective responses provides a reliable data foundation for the research, aiding in ensuring the accuracy and credibility of the analytical results.

Table 4.3 Steps to remove invalid questionnaires.

Steps to Remove Invalid Questionnaires		Frequency	Percentage (%)
Issuance	Number issued	164	100
Recycling	Screening questions recalled and passed	164	100
Remove	Invalid questionnaire	20	12.20
	≤ 2 years of experience in the CI	13	7.92
Results	Remaining valid questionnaires	131	79.88

4.2.2 Raw Data

Please see Appendix G for details of the raw data results of the online questionnaire survey for the study.

4.2.3 Result of Descriptive Statistics Analysis

4.2.3.1 Personal Information of the Respondents

Table 4.4 lists the characteristics of the respondents in this study, giving the frequency and percentage of each category.

Table 4.4 Personal information of the respondents.

Questionnaire Result		
Variables	Frequency	Percentages (%)
Gender		
Male	104	79.39
Female	27	20.61
Age(years)		
≤ 25	2	1.53
26 - 35	65	49.62
36 - 45	44	33.59
≥ 46	20	15.26

Table 4.4 Continued.

Questionnaire Result		
Variables	Frequency	Percentages (%)
Education Level		
Diploma	12	9.16
Undergraduate Degree	77	58.78
Master	32	24.43
PhD	10	7.63
Employment Position		
Managers	48	36.64
Designers	42	32.06
Engineers	41	31.30
How long do you have years of experience in the construction industry?		
3-5	50	38.168
6-9	41	31.298
≥ 10	40	30.534
Sector of the Organization		
Public	91	69.47
Private	40	30.53
Nature of Organizational Operations		
Construction Companies	35	26.72
Design Companies	30	22.90
BIM Consulting Companies	17	12.98
Design and Construct Companies	17	12.98
Engineering Procurement Construction (EPC)	32	24.42
Total	131	100

4.2.3.2 Common Software for Working

Table 4.5 lists the software commonly used by the respondents of this study in their work and gives the rates and percentages for each category. Moreover, this study categorizes commonly used software into a total of five broad categories (e.g., CAD Drawing, BIM Modeling Software, BIM Visualization Assistance Software, BIM Rendering Software, and Project Management Software).

Table 4.5 Common software for working in the CI.

Group	Software Name	Frequency	Percentage (%)	Rank
CAD Drawing	Autodesk AutoCAD	131	100	1
	Graphisoft ArchiCAD	9	6.87	12

Table 4.5 Continued.

Group	Software Name	Frequency	Percentage (%)	Rank
BIM Modeling Software	Autodesk Revit	70	53.44	4
	Bentley MicroStation	5	3.82	14
	Rhino	40	30.53	9
	Tekla	20	15.27	11
BIM Visualization Assistance Software	Autodesk Navisworks	53	40.46	5
	Fuzor	44	33.59	7
BIM Rendering Software	Google SketchUp	49	37.40	6
	Autodesk 3Ds Max	44	33.59	8
	Cinema 4D	5	3.82	15
Project Management Software	Primavera	9	6.87	13
	Microsoft Excel	102	77.86	2
	Microsoft Project	102	77.86	3
	Microsoft PowerProject	31	23.66	10

4.2.3.3 The Expertise of Use BIM Technology

In addition, in order to fulfill the research objectives, the respondents were also asked some questions about their experiences in using BIM technology as a way to understand the actual situation of applying BIM technology in in Chengdu's MBCPs. For example, "Is your level of understanding of BIM Technology?" and other questions as detailed in Table 4.6. Moreover, Table 4.6 shows the frequency and percentage of each response.

Table 4.6 BIM expertise.

BIM Expertise	Frequency	Percentage %
Is your level of understanding of BIM Technology?		
Don't know about BIM technology.	3	2.29
Know about BIM technology but never use it.	58	44.28
Don't use BIM technology often.	45	34.35
Use BIM technology regularly.	25	19.08
What is your perspective on the promotion of BIM technology in the medical building industry?		
No need	8	6.11
No need for special promotion	53	40.46
More important	30	22.90
Very important	40	30.53

Table 4.6 Continued.

BIM Expertise	Frequency	Percentage %
How many years of experience do you have working with BIM Technology?		
Never utilized BIM Technology	61	46.56
≤ 2 years	36	27.48
3-5 years	32	24.43
6-9 years	2	1.53
How many projects involving the use of BIM Technology have you participated in?		
0 project	61	46.56
1 project	22	16.79
2-5 projects	37	28.24
6-9 projects	10	7.63
≥ 10 projects	1	0.76
What types of BIM models are commonly adopted during the implementation of BIM technology?		
2D Modeling (In the context of work, this often involves using 2D drafting software such as CAD (Computer-Aided Design) to create drawings.)	61	46.56
3D Modeling (Usually use 3D building models in work.)	50	38.17
4D Modeling (Based on the 3D model, incorporate with the construction schedule.)	9	6.87
5D Modeling (Based on the 4D model, incorporate cost elements.)	11	8.40
Which is considered more important: the BIM models or the aspect of visualization?		
Never utilized BIM Technology	61	46.56
Equally important	35	26.72
BIM Modeling	20	15.27
Visualization of BIM technology	15	11.45
What level of detail (LOD) is typically employed in the creation of BIM models?		
Never utilized BIM Technology	61	46.56
LOD 200	1	0.76
LOD 300	49	37.41
LOD 400	17	12.98
LOD 500	3	2.29

4.3 ANALYSIS RESULT

4.3.1 Result of Quality of Research Instrument

4.3.1.1 Result of Validity Analysis

This study used IOC validation to test the content validity of the questionnaire, at the same time IOC value less to 0.5 is unacceptable, as shown in Table 3.6. The IOC results for PF5 (Insufficient understanding of BIM benefits), TF4 (There are difficulties in converting data between different BIM platforms), and OF2 (Social and habitual resistance to change) were all less than 0.5; therefore, these three barrier factors were removed from this study, leaving a total of 12 barrier factors remaining. Please refer to the detailed calculation results of the IOC validation are shown in Table 4.7.

4.3.1.2 Result of Reliability Analysis

This study "Reliability Analysis" using SPSS V29 software was used to calculate the value of Cronbach's alpha. In general, Cronbach's alpha values above 0.7 are considered acceptable, as shown in Table 3.7. According to Table 4.8, it can be seen that Cronbach's alpha values for each factor cluster remained between 0.747 and 0.800, indicating good internal consistency. The Cronbach's alpha value of 0.844 for the overall scale shows higher internal consistency which indicates that the overall scale is very reliable.

4.3.2 Result of Normality Distribution

Table 4.9 demonstrates the results of the normality tests for the various factors of this study. For all factors, the K-S test statistic ranges from .279 to .423, with the degrees of freedom (df) remaining constant at 131 for each factor, and the P-values are all less than .001. In other words, all factors P-values is below the default significance level (0.05 or 5%), which suggests that this study should reject the null hypothesis. Therefore, the subsequent method of data analysis in this study should be non-parametric analysis method.

4.3.3 Result of Correlation Analysis

Spearman's rho correlation analysis was performed using "Bivariate Correlations" SPSS V29 software in this study. In this study, the correlation coefficient value of barrier factors ranged from 0.142 to 0.667, suggesting that all items are consistent and valid, indicative of a positive correlation. That is, the results of this correlation analysis are shown in Table 4.10 for details.

Table 4.7 Result of the IOC validation.

Factor Group	Code	Barrier Factors	Experts' Rating							∑R	IOC	Analysis Result
			1	2	3	4	5	6	7			
Cost Factor (CF)	CF1	The initial investment costs are too high, including software and hardware expenses.	+1	+1	+1	+1	+1	+1	+1	7	1.000	Passed
	CF2	The training costs and learning curve are excessively expensive.	0	+1	+1	+1	+1	+1	+1	6	0.857	Passed
People Factor (PF)	PF1	Lack of proper understanding of BIM.	+1	+1	+1	+1	+1	+1	+1	7	1.000	Passed
	PF2	Lack of BIM experts.	+1	+1	+1	+1	+1	+1	+1	7	1.000	Passed
	PF3	Lack of support from senior management and client demand.	+1	+1	+1	0	0	+1	+1	5	0.714	Passed
	PF4	Insufficiency of appropriate training in BIM.	+1	+1	+1	+1	+1	+1	+1	7	1.000	Passed
	PF5	Insufficient understanding of BIM benefits.	0	+1	0	0	+1	0	0	2	0.285	Unpassed
Technical Factor (TF)	TF1	Interoperability and compatibility issues between different BIM software.	+1	+1	0	+1	+1	0	+1	5	0.714	Passed
	TF2	Challenges in collaboration and communication coupled with ambiguity in roles and responsibilities.	+1	+1	+1	+1	+1	+1	+1	7	1.000	Passed
	TF3	The complexity of BIM software and tools, plus time-consuming and cumbersome BIM processes.	+1	+1	+1	+1	0	+1	+1	6	0.857	Passed
	TF4	There are difficulties in converting data between different BIM platforms.	0	+1	+1	+1	0	0	0	3	0.429	Unpassed
Organizational Factor (OF)	OF1	Traditional contracting methods (BIM requires special bidding conditions and a unique BIM service contract).	+1	+1	+1	+1	+1	+1	+1	7	1.000	Passed
	OF2	Social and habitual resistance to change.	+1	0	0	0	+1	+1	0	3	0.429	Unpassed
	OF3	Lack of specialized study on BIM technology in higher education curricula	+1	0	+1	+1	+1	+1	+1	6	0.857	Passed
	OF4	Lack of government support, regulations, and incentive measures coupled with incomplete standards for BIM.	+1	0	+1	+1	+1	+1	+1	6	0.857	Passed

Table 4.8 Result of reliability analysis.

Factor Group	Barrier Factors	Cronbach's Alpha	Number of Items
Cost Factor (CF)	CF1 CF2	0.747	2
People Factor (PF)	PF1 PF2 PF3 PF4	0.800	4
Technical Factor (TF)	TF1 TF2 TF3	0.798	3
Organizational Factor (OF)	OF1 OF2 OF3	0.784	3
Total		0.844	12

Table 4.9 Result of Normality distribution test.

Barrier Factors	Kolmogorov-Smirnov[a]			Conclusion to H_0
	Statistic	df	Sig.	
CF1	.279	131	< .001	Reject
CF2	.319	131	< .001	Reject
PF1	.369	131	< .001	Reject
PF2	.341	131	< .001	Reject
PF3	.388	131	< .001	Reject
PF4	.323	131	< .001	Reject
TF1	.423	131	< .001	Reject
TF2	.413	131	< .001	Reject
TF3	.398	131	< .001	Reject
OF1	.371	131	< .001	Reject
OF2	.346	131	< .001	Reject
OF3	.365	131	< .001	Reject

Note: a. Lilliefors Significance Correction. df means degrees of freedom. Sig. means significance value (or P-value).

Table 4.10 Result of correlation analysis.

BF	CF1	CF2	PF1	PF2	PF3	PF4	TF1	TF2	TF3	OF1	OF2	OF3
CF1	1											
CF2	.595**	1										
PF1	.297**	.339**	1									
PF2	.279**	.302**	.360**	1								
PF3	.396**	.294**	.612**	.433**	1							
PF4	.230**	.273**	.372**	.395**	.419**	1						
TF1	.220*	.231**	.234**	.275**	0.142	.182*	1					
TF2	.205*	.303**	.256**	.304**	.206*	.314**	.657**	1				
TF3	.208*	.291**	.326**	.392**	.299**	.345**	.530**	.623**	1			
OF1	.438**	.394**	.324**	.322**	.300**	.257**	.274**	.310**	.290**	1		
OF2	.280**	.337**	.214*	.373**	.213*	.361**	.193*	.258**	.185*	.491**	1	
OF3	.373**	.359**	.376**	.229**	.296**	.189*	.265**	.222*	.239**	.667**	.494**	1

Note: BF means Barrier Factors. **. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

4.3.4 Result of Non-parametric Rank Sum Tests

4.3.4.1 Result of Mann-Whitney U (M-W U) Tests

This study utilized "Non-parametric Tests: Two or More Independent Samples" of SPSS V29 software to conduct a non-parametric M-W U test, aiming to ascertain whether there is a statistically significant difference in the perception of the importance of these barrier factors based on whether respondents have previously used BIM technology. The following Table 4.11 shows the result of M-W tests.

Table 4.11 Result of M-W U tests.

Barrier Factors	Used or Not Used BIM Median (P25, P75)		Rank Sum Tests			Conclusion to H_0
	Not Used (N=61)	Used (N=70)	M-W U	Z	P	
CF1	4 (4, 5)	4 (4, 5)	2295.000	.830	.407	Accept
CF2	4 (4, 5)	4 (4, 5)	1982.000	-.800	.424	Accept
PF1	5 (4, 5)	5 (4, 5)	2094.500	-.220	.826	Accept
PF2	5 (4, 5)	5 (4, 5)	2071.500	-.332	.740	Accept
PF3	5 (4, 5)	5 (4, 5)	2052.000	-.457	.648	Accept

Table 4.11 Continued.

Barrier Factors	Used or Not Used BIM Median (P25, P75)		Rank Sum Tests			Conclusion to H_0
	Not Used (N=61)	Used (N=70)	M-W U	Z	P	
PF4	5 (4, 5)	4 (4, 5)	1943.000	-1.009	.313	Accept
TF1	5 (4, 5)	5 (4, 5)	2112.000	-.131	.896	Accept
TF2	5 (4, 5)	5 (4, 5)	2055.000	-.460	.646	Accept
TF3	5 (4, 5)	5 (4, 5)	2013.000	-669	.503	Accept
OF1	5 (4, 5)	5 (4, 5)	2238.000	.554	.580	Accept
OF2	4 (4, 5)	4 (4, 5)	2045.500	-.477	.633	Accept
OF3	5 (4, 5)	5 (4, 5)	2326.500	1.016	.310	Accept

Note: The significance level is 0.05 for this study. * P < 0.05, ** P < 0.01, *** P < 0.001. M-W U means Mann-Whitney U value, and Z means Standardized Test Statistic.

4.3.4.2 Result of Kruskal-Wallis H (K-W H) Tests

This study utilized the "Non-parametric Tests: Two or More Independent Samples" of SPSS V29 software to conduct a non-parametric Kruskal-Wallis H test. The purpose was to determine whether there are statistically significant differences in the perception of the importance of these barriers among respondents with different professional identities (e.g., Manager, Designer, and Engineer). The following Table 4.12 shows the result of K-W H tests, and then Table 4.13 shows the result of post-hoc pairwise comparisons.

Table 4.12 Result of K-W H tests.

Barrier Factors	Median (P25, P75)			Rank Sum Tests		Conclusion to H_0
	Manager (N=48)	Designer (N=42)	Engineer (N=41)	K-W H	P	
CF1	5 (4, 5)	4 (4, 5)	4 (4, 5)	2.676	.262	Accept
CF2	4 (4, 5)	4 (4, 5)	4 (4, 5)	2.616	.270	Accept
PF1	5 (4, 5)	5 (4, 5)	5 (4, 5)	2.739	.254	Accept
PF2	5 (4, 5)	4 (4, 5)	5 (4, 5)	3.935	.140	Accept
PF3	5 (4, 5)	5 (4, 5)	5 (4, 5)	.523	.770	Accept
PF4	5 (4, 5)	4 (4, 5) a	4 (4, 5)	7.523	.023 *	Reject
TF1	5 (5, 5)	5 (4, 5)	5 (4, 5) a	7.509	.019 *	Reject
TF2	5 (5, 5)	5 (4, 5)	5 (4, 5) a	6.539	.032 *	Reject
TF3	5 (5, 5)	5 (4, 5)	5 (4, 5)	5.949	.051	Accept

Table 4.12 Continued.

Barrier Factors	Median (P25, P75)			Rank Sum Tests		Conclusion to H_0
	Manager (N=48)	Designer (N=42)	Engineer (N=41)	K-W H	P	
OF1	5 (4, 5)	5 (4, 5)	5 (4, 5)	3.099	.212	Accept
OF2	4 (4, 5)	4 (4, 4.25)	4 (4, 5)	3.627	.163	Accept
OF3	5 (4, 5)	5 (4, 5)	5 (4, 5)	2.287	.319	Accept

Note: The significance level is 0.05 for this study. * P < 0.05, ** P < 0.01, *** P < 0.001. K-W H means Kruskal-Wallis H value, and K-W Z means Standardized Test Statistic. a indicates a statistically significant difference in comparison with Manager, b indicates a statistically significant difference in comparison with Designer, and c indicates a statistically significant difference in comparison with Engineer. Moreover, Significance values have been adjusted using the Bonferroni correction for multiple tests.

Table 4.13 Result of pairwise comparisons of manager, designer, and engineer.

Barrier Factors	Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Adj. Sig.[a]	Conclusion to H_0
PF4	Engineer-Designer	-5.909	7.320	-.807	1.000	Accept
	Engineer-Manager	12.859	7.091	1.813	.209	Accept
	Designer-Manager	18.768	7.045	2.664	.023 *	Reject
TF1	Engineer-Designer	10.630	6.753	1.574	.346	Accept
	Engineer-Manager	17.890	6.541	2.735	.019 *	Reject
	Designer-Manager	7.260	6.499	1.117	.792	Accept
TF2	Engineer-Designer	8.759	6.688	1.310	.571	Accept
	Engineer-Manager	16.566	6.479	2.557	.032 *	Reject
	Designer-Manager	7.807	6.437	1.213	.676	Accept

Note: * P < 0.05. Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same. Asymptotic significances (2-sided tests) are displayed. The significance level is .050.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

4.3.5 Result of Relative Importance Index (RII) Analysis

This study calculates the RII value for each hindering factor using Excel and Formula 3.10, and also ranks them according to their RII values. Additionally, calculations were categorized by different professions (e.g., manager, designer, and engineer). See Table 4.14 for details.

Table 4.14 The Ranking of barrier factors to BIM implementation.

Barrier Factors		Group RII	Total (N=131)							Manager (N=48)						Designer (N=42)						Engineer (N=41)					
			Mini	Max	M	SD	RII	R	Importance Level	Mini	Max	M	SD	RII	R	Mini	Max	M	SD	RII	R	Mini	Max	M	SD	RII	R
Cost Factor (CF)	CF1	0.869	1	5	4.374	.660	.875	10	High	3	5	4.500	.583	.900	10	1	5	4.286	.774	.857	10	3	5	4.317	.610	.863	11
	CF2		3	5	4.313	.596	.863	11	High	3	5	4.417	.613	.883	11	3	5	4.262	.587	.852	11	3	5	4.243	.582	.849	12
People Factor (PF)	PF1	0.902	1	5	4.511	.778	.902	6	Very High	1	5	4.512	.850	.908	8	1	5	4.548	.832	.910	4	3	5	4.439	.634	.888	6
	PF2		3	5	4.481	.599	.896	7	High	3	5	4.604	.574	.921	6	3	5	4.381	.582	.876	6	3	5	4.439	.634	.888	7
	PF3		1	5	4.573	.668	.915	4	Very High	3	5	4.563	.649	.913	7	1	5	4.595	.767	.919	3	3	5	4.561	.594	.912	1
	PF4		1	5	4.473	.636	.895	8	High	3	5	4.646	.565	.929	4	3	5	4.357	.533	.871	8	1	5	4.390	.771	.878	8
Technical Factor (TF)	TF1	0.923	3	5	4.641	.569	.928	2	Very High	3	5	4.771	.515	.954	2	3	5	4.667	.526	.933	1	3	5	4.463	.636	.893	4
	TF2		1	5	4.649	.607	.930	1	Very High	3	5	4.792	.458	.958	1	3	5	4.667	.526	.933	2	1	5	4.463	.778	.893	5
	TF3		3	5	4.603	.550	.921	3	Very High	3	5	4.750	.484	.950	3	3	5	4.523	.552	.905	5	3	5	4.512	.597	.902	3
Organizational Factor (OF)	OF1	0.882	1	5	4.519	.705	.904	5	Very High	3	5	4.625	.606	.925	5	3	5	4.381	.731	.876	7	1	5	4.537	.778	.907	2
	OF2		3	5	4.282	.572	.856	12	High	3	5	4.354	.526	.871	12	3	5	4.143	.566	.829	12	3	5	4.342	.617	.868	10
	OF3		2	5	4.427	.832	.885	9	High	2	5	4.542	.798	.908	9	2	5	4.257	.821	.871	9	2	5	4.366	.888	.873	9

Note: M means Mean, SD means Standard deviation, and R means Rank.

CHAPTER 5
ANALYSIS AND DISCUSSION

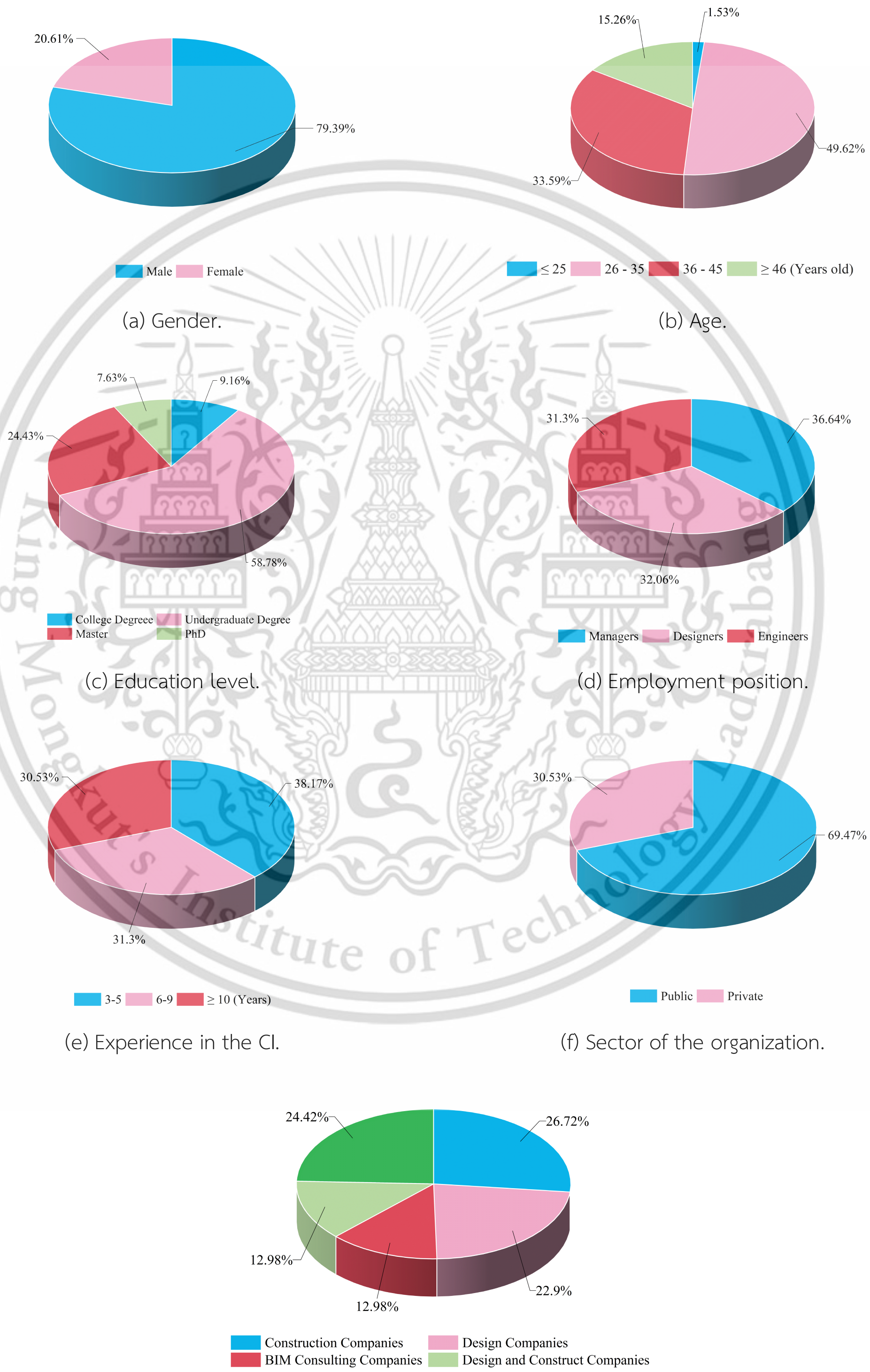
5.1 DATA CHARACTERIZATION

5.1.1 Descriptive Statistics Analysis

5.1.1.1 Personal Information of the Respondents.

Figure 5.1 illustrates some personal information about the participants in this study. According to the survey results, the majority of respondents were male, accounting for 79.39%, a phenomenon not uncommon in the CI. The age distribution was primarily between 26-35 years old, representing 49.62% of respondents, followed by those aged 36-45 years old, accounting for 33.59%, suggesting that professionals involved in construction-related work are typically in the mid-stage of their careers. The respondents had a relatively high level of education, with the majority holding at least an undergraduate degree (58.78%) and a significant portion holding a master's degree (23.43%), indicating a rich knowledge base that could facilitate the adoption and proficient use of BIM technology. Employment positions among respondents varied, with managers (36.64%), designers (32.06%), and engineers (31.30%) representing similar proportions in this study. The diversity of professional roles indicates that the survey captured a broad range of perspectives within the construction industry. Additionally, the distribution of respondents' experience levels was relatively even across three time periods, each occupying about a third, suggesting a balance between emerging professionals and seasoned experts in the field. Most respondents worked in the public sector (69.47%), while the private sector accounted for 30.53%. Respondents belonged to various types of companies, with construction companies (26.72%) leading, followed by Engineering, Procurement, and Construction (EPC) firms (24.42%), and design companies (22.90%). The distribution across different sectors provides comprehensive insights into the awareness and implementation of BIM in Chengdu across the MBCPs.

In summary, the survey's respondents form a knowledgeable and experienced group with broad representation across different roles and sectors in the construction industry. Insights drawn from the demographic data can inform BIM training, adoption, and policy-making strategies, especially in the public sector where most respondents are employed. Understanding these demographic variables is crucial for addressing the specific needs and challenges faced by different groups and for fully leveraging the potential of BIM in MBCPs and the CI.



(a) Gender. (b) Age.

(c) Education level. (d) Employment position.

(e) Experience in the CI. (f) Sector of the organization.

(g) Nature of organizational operations.

Figure 5.1 Personal Information of the Respondents.

5.1.1.2 Common Software for Working in MBCPs

Table 4.5 and Figure 5.2 display the software choices among survey participants in their daily work, with the option for participants to select multiple answers. Those questions aimed to identify frequently used software, especially those related to Building Information Modeling (BIM). The survey results indicate that Autodesk AutoCAD, Microsoft Excel, Microsoft Project, and Autodesk Revit are the most commonly used software in daily operations, scoring 131 (100%), 102 (77.86%), 102 (77.86%), and 70 (53.44%) respectively. These figures underscore the indispensable role of AutoCAD in daily workflows (Ming-Tong & Shun-Yu, 2000), the importance of Excel and Project in engineering bill computations, construction schedule chart creation, and work reporting (Ismail et al., 2013; Hatmoko et al., 2019), as well as the significant industry position of Revit as the most widely applied BIM software in MBCPs at the same time, Revit is widely recognized around the world owing to its friendly interface and powerful functions (Zheng et al., 2020). Additionally, the usage of BIM auxiliary software such as Autodesk Navisworks, Fuzor, Google SketchUp, and Autodesk 3Ds Max is similar, reflecting their highly regarded functions in BIM model visualization and rendering (Huang & Odeley, 2018; Su et al., 2022). Despite this, the penetration rate of BIM software in MBCPs suggests room for improvement, indirectly indicating that the majority of construction enterprises still prefer traditional management styles and methods. Nevertheless, it is observable that Autodesk's suite of software dominates the construction industry thanks to the advanced features, continuous innovation, and comprehensive technical support provided by Autodesk (Wurster et al., 2014).

5.1.1.3 Current Status of BIM Technology Application in Chengdu's MBCPs

Figure 5.3 illustrates the survey participants' experience in applying BIM technology. Figure (a) shows that most respondents know about BIM technology but never use it (44.28%) and do not use BIM technology often (34.35%); only 19.08% of respondents use BIM technology regularly, indicating that although BIM is widely known, its routine application in MBCPs is not common. Figure (b) shows that 22.90% of

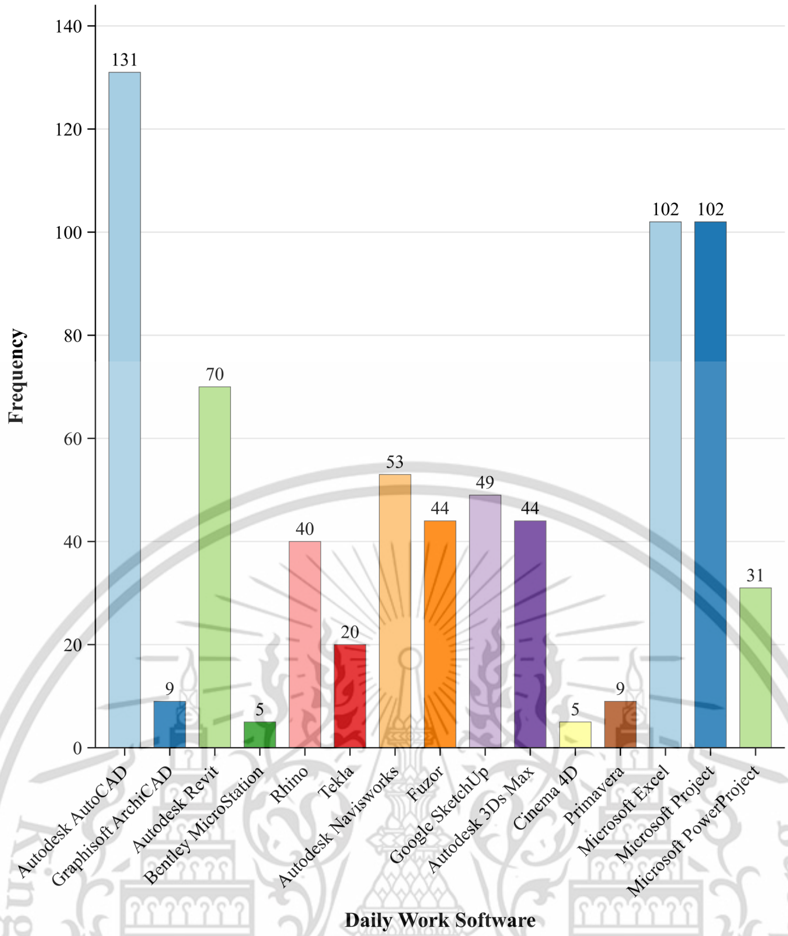
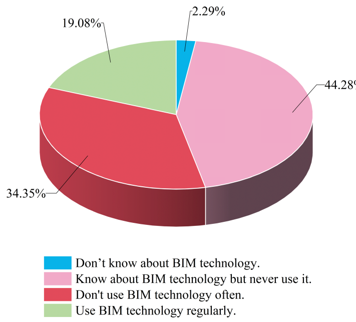
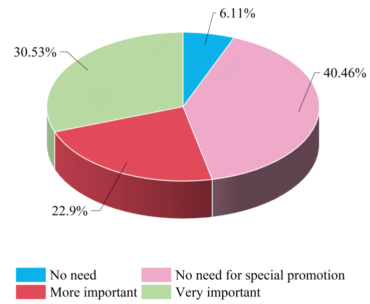


Figure 5.2 Common software for working in MBCPs.

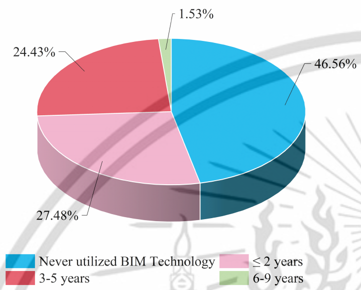
respondents consider it more important to promote BIM technology in the MBCPs; 30.53% of respondents consider it very important; the most of respondents (40.46%) believe there is no need for special promotion, suggesting that although new technologies like BIM are readily accepted by the industry, they may not be practically applied in MBCPs due to certain insurmountable reasons. Figure (c) reveals that nearly half of the respondents (46.56%) have never used BIM; those with 1-2 years of experience (27.48%) constitute the second largest group; and Figure (d) shows that only a small portion of respondents (0.76%) have been involved in more than 10 projects, indicating that there may be an increasing number of professionals in the early stages of BIM adoption, and the core size of users with extensive BIM involvement and experience is small. Figures (e), (f), and (g) respectively show that 2D models (46.45%) dominate in daily work; 26.72% of respondents believe that the BIM model itself and visualization are equally important; LOD 300 is the most commonly used detail level, with 37.41% of respondents using it, indicating that while the move toward



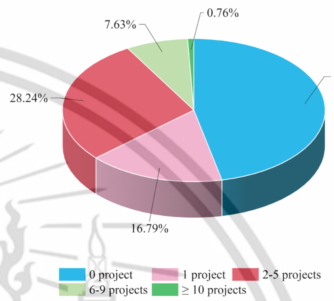
(a) Is your level of understanding of BIM Technology?



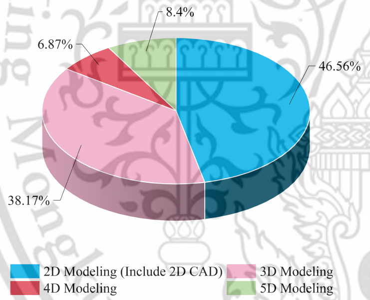
(b) What is your perspective on the promotion of BIM technology in the medical building industry?



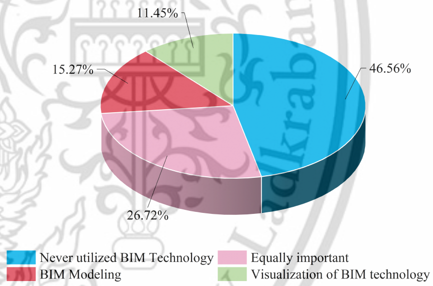
(c) How many years of experience do you have working with BIM Technology?



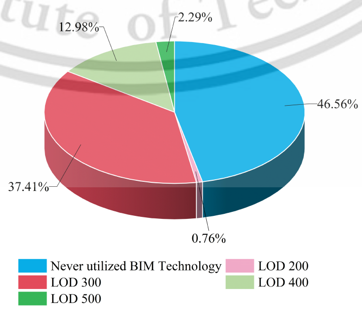
(d) How many projects involving the use of BIM Technology have you participated in?



(e) What types of BIM models are commonly adopted during the implementation of BIM technology?



(f) Which is considered more important: the BIM models or the aspect of visualization?



(g) What level of detail (LOD) is typically employed in the creation of BIM models?

Figure 5.3 BIM Expertise.

more sophisticated BIM models is evident, the focus remains on simpler of 2D modeling and LOD 300, at the same time, the Chengdu's MBCPs values both the technical construction details (modeling) and the communicative elements (visualization) almost equally, highlighting the dual nature of BIM as both a precise design tool and a communication medium.

In summary, BIM technology within Chengdu's MBCPs is still at an emerging stage, with significant room for development. The data suggests that while there is a foundational adoption of 3D modeling, the use of more advanced BIM functionalities such as 4D and 5D modeling and higher LOD is less prevalent. Therefore, it would be beneficial for stakeholders in Chengdu's MBCPs to seek insights from developed countries where BIM technology is more mature. By understanding how advanced BIM applications are utilized in MBCPs in these regions, Chengdu can potentially accelerate its own adoption curve and realize the full spectrum of BIM benefits more rapidly. This might involve examining case studies of successful BIM implementations, participating in international forums, and engaging in knowledge exchange initiatives. By drawing on the experiences of developed countries, Chengdu could better strategize the upskilling of its workforce, align with international BIM standards, and refine its technological infrastructure accordingly. This strategy could lead to enhanced efficiency, accuracy, and collaboration within Chengdu's MBCPs, fostering a more innovative and competitive edge in the industry.

5.1.2 Correlation Analysis of Barrier Factors

Figure 5.4 is a heatmap of Spearman's rho correlation analysis results, which shows the correlation between different factors affecting the implementation of BIM. Moreover, the color gradient from red to blue indicates the strength and direction of the correlation, with red indicating a stronger positive correlation and blue indicating a weaker correlation.

This figure demonstrates a moderate positive correlation between CF1 and CF2 (r_s = .595), suggesting that decision-makers should consider not only the direct financial impacts of adopting BIM but also the broader economic implications, including the necessity and costs of comprehensive training programs.

There is a strong positive correlation between PF3 and PF1 (r_s = .612), indicating that the lack of full support for BIM programs from management and clients is likely due to insufficient understanding of BIM and its benefits and applications. A lack of understanding at the higher levels can spread, hindering the wider organization's

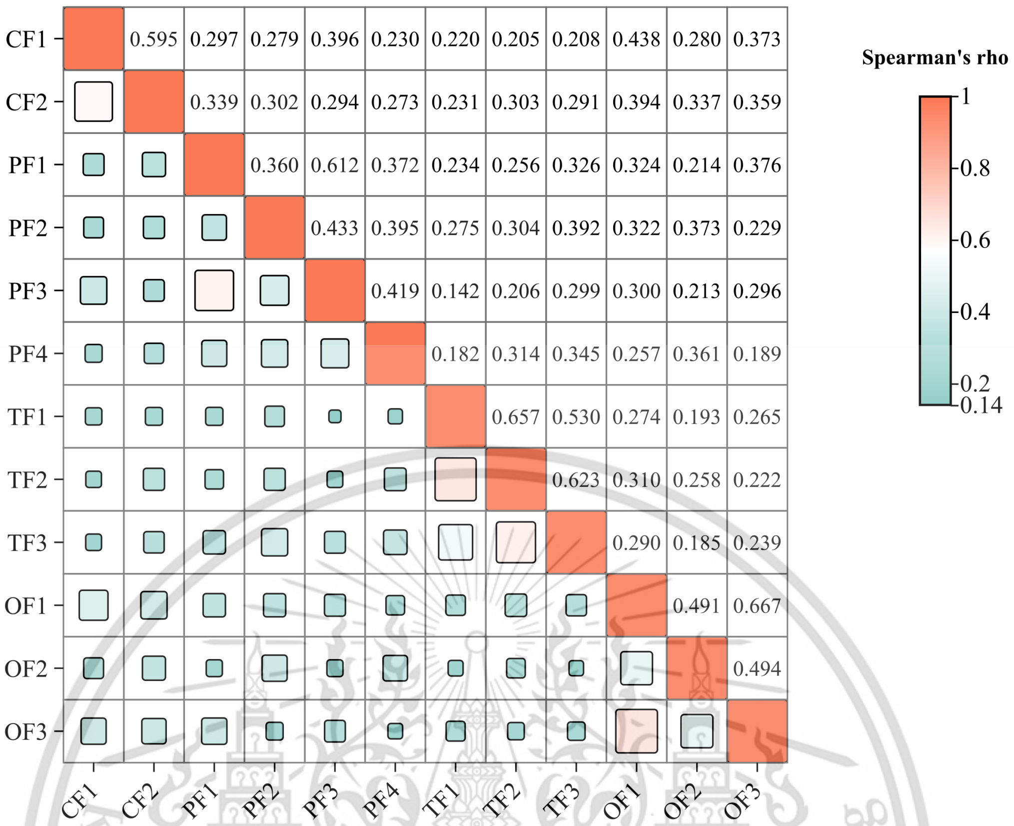


Figure 5.4 Spearman's rho correlation analysis.

acceptance of BIM.

A strong positive correlation between TF2 and TF1 (r_s= .657) suggests that the interoperability of BIM software directly affects the effectiveness of team collaboration. This means that compatibility issues between BIM systems can cause or exacerbate challenges in collaboration and communication among project stakeholders.

Furthermore, there is a strong positive correlation between TF3 and TF2 (r_s= .623), indicating that as BIM tools and processes become more complex, they tend to cause greater collaboration difficulties. This relationship underscores the need for simplifying BIM processes and user-friendly tools to facilitate better communication and teamwork.

A strong positive correlation between OF3 and OF1 (r_s= .667) indicates that traditional contracting practices and lack of government support are significantly interrelated barriers to BIM implementation. Transformation of traditional contracting practices is challenging due to the lack of government regulation or incentives. Without regulatory guidance, the industry's incentive to adopt new contracting models adapted to the needs of BIM collaboration is diminished.

In summation, the Spearman's rho correlation analysis illustrates a multifaceted network of barrier factors impacting BIM adoption. Notably, an increase in costs, whether perceived or actual, is intimately associated with a lack of proper understanding and training related to BIM. Technical issues inherent to BIM software are intricately linked with the human capital and collaborative processes within organizations. Furthermore, the strong correlations among organizational factors highlight the pivotal role systemic changes in policy and educational frameworks play in supporting the adoption of BIM. This comprehensive view of correlated factors suggests that BIM adoption is not solely a technological challenge but a complex change management issue that necessitates coordinated efforts across cost management, technical proficiency, education, and policy support.

5.2 HYPOTHESIS TESTING

In this section, this study will verify the hypotheses presented in the previous sections using SPSS V29 software for all hindering factors in non-parametric rank sum tests in M-W U tests, K-W H tests, and the post-hoc Dunn-Bonferroni pairwise comparisons.

5.2.1 H1: Used or Not Use BIM Technology

The M-W U test on all the impediments showed that none of the barrier factors were statistically significantly different, as their p-values ranged from .310 to .896; see Table 4.11 for details. It can be inferred that the P-value of all the barrier factors is greater than the default significance level (0.05 or 5%) and then retain the null hypothesis of identical distributions. That is, there is no statistically significant difference. It can be concluded that there is no statistically significant difference in the judgment of the importance of these barrier factors based on whether the respondents have used BIM technology.

Although the results of the M-W U test indicate that there is no significant difference in the perception of barrier factors importance between respondents who use BIM technology and those who do not, this does not imply that these barriers are unimportant. On the contrary, these results underscore the critical need to identify and overcome these pervasive barrier factors to successfully implement BIM technology. These barrier factors are prevalent in the promotion of BIM technology and represent challenges that the entire industry must collectively address.

Firstly, respondents, regardless of whether they use BIM technology, may share a common understanding of the barrier factors encountered during its implementation. These barrier factors are likely widely discussed and acknowledged within the industry, such as high technical costs, inadequate training, and lack of uniform standards. These issues are frequently cited in the literature; for instance, Lv (2023) point out that the high initial costs and training requirements of BIM technology are prevalent barriers that affect its adoption in small and medium-sized enterprises.

Furthermore, current education and training in the civil engineering and the CI may already include an introduction and discussion of BIM-related knowledge. Respondents, through education and professional training, might have acquired a basic understanding of the barrier factors to BIM technology. For example, Sun et al., (2023) found that most architectural schools have incorporated foundational BIM knowledge into their curricula, providing students with a comprehensive understanding of BIM barriers upon graduation. This comprehensive understanding results in a convergence of views on these barrier factors, regardless of practical experience.

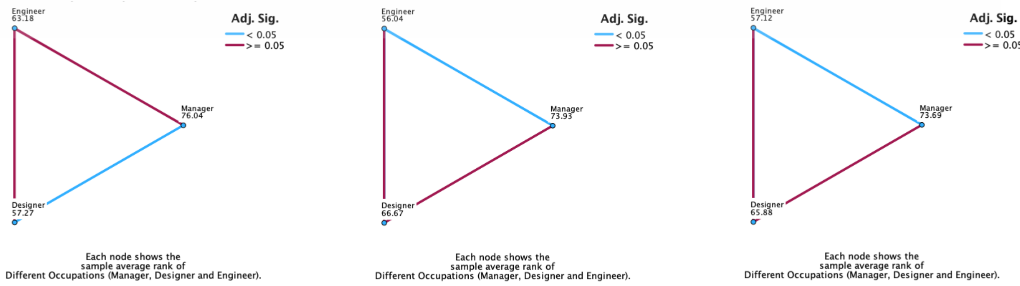
A deeper analysis reveals that these pervasive barriers may stem from several aspects. First are technical and economic factors. The high initial investment and complex software operations of BIM technology require specialized training, which poses a significant obstacle for resource-limited companies. Second are organizational and managerial factors. Many companies lack standardized processes and clear management guidelines for BIM implementation, leading to suboptimal results. Lastly, policy and institutional factors, such as the lack of unified industry standards and government support, hinder the widespread application of BIM technology (Wan & Huang, 2019).

In summary, these pervasive barrier factors and threats warrant high attention from the industry. By actively addressing these barrier factors and challenges, the CI can promote the broad adoption of BIM technology, thereby improving project efficiency and quality. Future research should further explore effective ways to reduce the implementation costs of BIM technology, enhance training effectiveness, and promote the establishment and dissemination of industry standards. These measures will help overcome current barriers and achieve the comprehensive application of BIM technology in the CI.

5.2.2 H2: Different Occupations (Managers, Designers, And Engineers)

The K-W H tests for all the barrier factors showed that only three barrier factors (PF4, TF1, and TF2) had statistically significant differences, because the P-value of barrier factors PF4 (P-value = .023), TF1 (P-value = .019), and TF2 (P-value = .032) are less than the default significance level (0.05 or 5%), then indicating the strongest evidence against the null hypothesis of identical distributions, see Table 4.12 for details. That is, significant differences in how managers, designers, and engineers perceive the three barrier factors. There were no statistically significant differences at the P-value greater than the default significance level (0.05 or 5%) for the other barrier factors.

As can be seen from Figure 5.5, significant differences are highlighted by connecting two distinct groups with a blue line. In addition, the results of the post-hoc Dunn-Bonferroni pairwise comparisons, according to Table 4.13, show that there is a statistically significant difference between the Designer-Manager (Adj. Sig. = .023) for PF4; There is a statistically significant difference between the Engineer-Manager (Adj. Sig. = .019 and .032) for TF1 and TF2, because at P-value less than the default significance level (0.05 or 5%). Meanwhile, P-values for all hindering factors were adjusted for multiple testing by Bonferroni error correction. It can be seen that managers are more likely than designers to believe that there is not enough BIM training; managers tend more than engineers do interoperability and compatibility issues between different BIM software and challenges in collaboration and communication coupled with ambiguity in roles and responsibilities.



(a) PF4 (Designer-Manager) (b) TF1 (Engineer-Manager) (c) TF2 (Engineer-Manager)

Figure 5.5 Post-hoc Dunn-Bonferroni.

5.3 RELATIVE IMPORTANCE INDEX (RII)

Evaluating barrier factors through RII is crucial for understanding the critical challenges faced in implementing BIM technology in Chengdu's MBCPs. As a powerful statistical indicator, RII allows this study to comprehend the Importance degree of each barrier factor as perceived by different stakeholders, thereby facilitating the development of targeted mitigation strategies.

First, the computation and hierarchical arrangement of the RII values for each barrier factor are delineated in Table 4.14. The range of RII values for all barrier factors is .856-.930. Simultaneously, according to Table 3.11, the significance levels for RII ≥ 0.9 and 0.8 ≤ RII < 0.9 are Very High and High, respectively. Therefore, the importance levels of barrier factors TF2 (RII = .930), TF1 (RII = .928), TF3 (RII = .921), PF3 (RII = .915), OF1 (RII = .904), and PF1 (RII = .902) are classified as Very High, making them the top six most significant and critical barrier factors in this survey study. On the other hand, the importance levels of the remaining eight barrier factors are classified as High.

5.3.1 Discussion of Diffident Occupations for the RII

Furthermore, Figure 5.6 vividly illustrates the divergent perceptions among managers, designers, and engineers regarding the barrier factors to BIM implementation, measured by the Relative Importance Index (RII). First, managers are discernibly more concerned with organizational barrier factors than designers and engineers such as the lack of government support and regulatory frameworks, which they rank as having very high importance. This concern likely stems from their strategic role in navigating external forces and their impact on project feasibility and success. Moreover, barrier factor technical, while universally acknowledged as significant, are particularly emphasized by engineers, who are directly affected by interoperability issues and the complexity of BIM tools in their day-to-day operations. Specifically, the issue of BIM interoperability and complexity requires immediate attention, and the homogeneity of such perceptions across all groups suggests that interoperability and complexity are not only technically inconvenient but are fundamental bottlenecks to BIM integration. Designers, while also acknowledging technical barrier factors, display a notable sensitivity to people-related barrier factors, reflecting the impact of these factors on the design process and collaborative efforts.

Meanwhile, although there are certain differences among various groups, some commonalities have also been identified. Specifically, managers, designers, and engineers generally perceive cost barrier factors as less significant and urgent compared to other impediments. Furthermore, these three roles share a similar evaluation of the importance of factor PF3, indicating a consensus in their awareness and emphasis on this factor.

In summary, in the process of promoting the widespread adoption of BIM technology, it is indeed necessary to pay attention to the factors considered important by different roles, in order to develop a more comprehensive and balanced strategy. This implies that the perspectives and needs of various participants such as managers, designers, and engineers should be fully considered. By understanding the expectations and priorities of all parties, it is possible to more effectively identify and address the key challenges in the promotion of BIM technology, while ensuring that each role receives effective support and resources when adopting new technology. Such a strategy not only helps overcome barriers but also fosters cooperation and consensus among stakeholders, laying a solid foundation for the successful promotion and application of BIM technology.

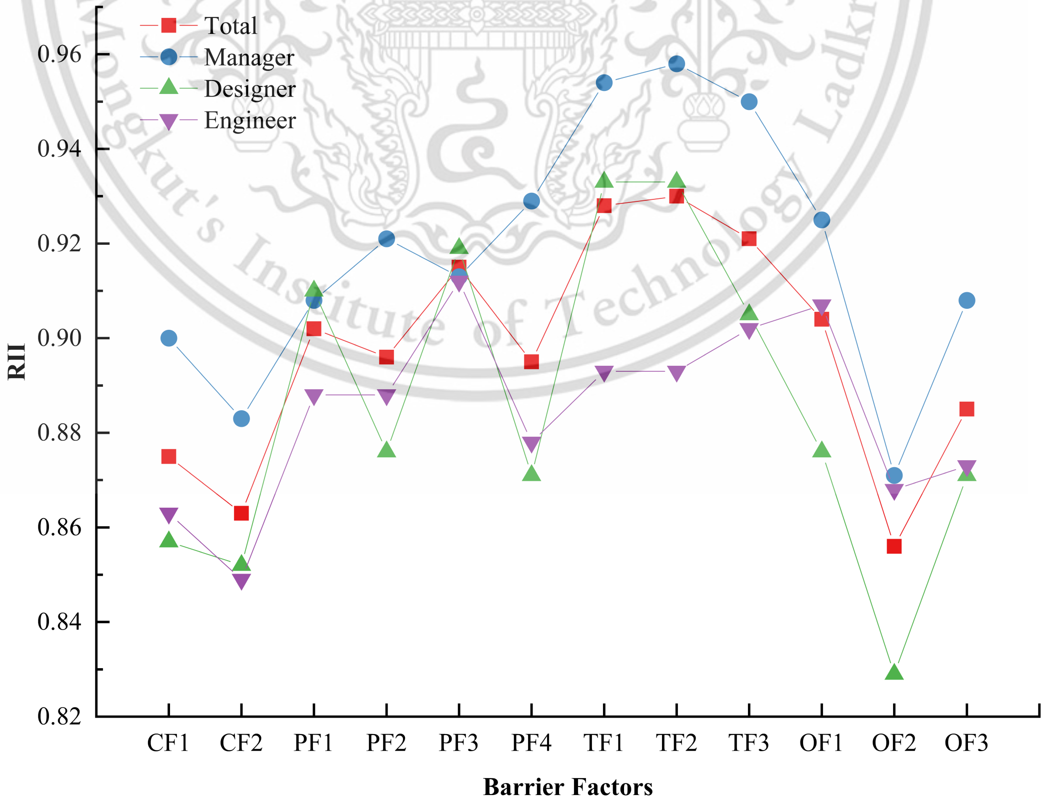


Figure 5.6 RII value of barrier factors.

5.3.2 Comparison of BIM Implementation Barrier Factors

This study, referencing the research findings of other scholars (e.g., Hatem et al., 2018; Ullah et al., 2019b; Zhou et al., 2019; Babatunde et al., 2021; El Hajj et al., 2021), conducted a comparative analysis of the barrier factors to implementing BIM technology in the construction industry across different countries or regions. According to the data in Table 5.1, it can be observed that although the key barrier factors to BIM implementation encountered in the construction process are essentially similar across different countries, the importance ranking of these barrier factors varies. This indicates that while the challenges faced in the promotion of BIM technology have a certain universality, the specific circumstances, cultural backgrounds, technological maturity, and policy environments of each country or region can affect the specific manifestations and priorities of these barrier factors. Therefore, when developing strategies for the promotion of BIM technology, it is also necessary to consider these geographical differences and adopt more customized solutions to address the challenges faced by each region.

Table 5.1 Results of comparison with other countries or regions.

Top six BIM implementation barrier factors	Chengdu's MBCPs	The AEC Industry in other counties or regions				
		China (Zhou et al., 2019)	Iraq (Hatem et al., 2018)	Nigerian (Babatunde et al., 2021)	Estonia (Ullah et al., 2019b)	the Middle East and North Africa (El Hajj et al., 2021)
TF2: Challenges in collaboration and communication coupled with ambiguity in roles and responsibilities.	Rank 1	Rank 5	Rank 6	Rank 6	Rank 17	Rank 10
TF1: Interoperability and compatibility issues among different BIM software.	Rank 2	Rank 9	Rank 17	Rank 13	Rank 16	Rank 5
TF3: The complexity of BIM software and tools, plus time-consuming and cumbersome BIM processes.	Rank 3	Rank 3	Rank 16	Rank 10	Rank 12	Rank 14
PF3: Lack of support from senior management and client demand.	Rank 4	Rank 5	Rank 13	Rank 5	Rank 8	Rank 1
OF1: Traditional contracting methods (BIM requires special bidding conditions and a unique BIM service contract).	Rank 5	Rank 8	Rank 12	Rank 20	Rank 13	Rank 21
PF1: Lack of proper understanding of BIM.	Rank 6	Rank 4	Rank 3	Rank 1	Rank 2	Rank 6

5.4 SUGGESTED COUNTERMEASURES TO IMPROVE THE APPLICATION OF BIM IN CHENGDU'S MBCPS

In July 2020, the National Development and Reform Commission, the Ministry of Construction, the Ministry of Industry and Information Technology, and 13 other departments jointly issued the "Guidelines on Promoting the Coordinated Development of Intelligent Construction and Construction Industrialization," which proposes to use construction industrialization as a carrier and intelligence and digitalization as the driving force to innovate and break through core technologies, to increase the application of intelligent construction in various aspects of project construction, aiming to form an integrated intelligent construction industry system across the whole industry. The initiative advocates for the establishment of an intelligent construction system based on the BIM platform and models to improve the extensive management status of the industry in construction projects (Pan et al., 2022). Within this context, the construction industry urgently needs to undergo transformation and upgrading, and BIM technology provides a key tool to address this challenge. Therefore, actively promoting the widespread application of BIM technology in MBCPs and the CI is of significant importance. This not only facilitates the refined management of construction projects, enhancing the industry image of construction firms but also drives digital reform and technological upgrading within these enterprises.

Moreover, the development of BIM technology in the healthcare construction industry is closely tied to market demand. The demands of owners have fostered the widespread application of BIM technology, which, in turn, has led to the establishment of industry standards, systems, and norms. This is to meet relevant business needs through the application of BIM technology (Gao & Li, 2018).

Meanwhile, according to the results of the RII, the Technical Factor (RII = .923), People Factor (RII = .902), and Organizational Factor (RII = .882) are the main barrier factors to the widespread application of BIM technology in Chengdu's MBCPs. Among the Technical Factor, TF1 (RII = .928), TF2 (RII = .930), and TF3 (RII = .921) are the industry's main concerns; in the People Factor, PF1 (RII = .902), and PF3 (RII = .915) are the industry's main concerns; in the Organizational Factor, OF1 (RII = .904) is a significant concern within the industry. Moreover, according to the results of Spearman's rho correlation analysis, there is a strong positive correlation between the barrier factors OF3 and OF1 (r_s = .667). Therefore, this study also considers OF3 when proposing relevant suggestions.

In light of these findings, this study offers the following seven countermeasure suggestions to mitigate the identified barrier factors and foster the further integration of BIM technology within MBCPs:

5.4.1 Suggested Responses for Technical Factor (TF)

5.4.1.1 Promoting Interoperability in BIM Through Open Standards and User-Centric Development

To mitigate interoperability challenges, it is recommended to advocate for and adopt open BIM standards, such as Industry Foundation Classes (IFC) and BuildingSMART data dictionaries. These standards promote software interoperability, enabling seamless data exchange and collaboration across different BIM platforms (Eastman, 2011). In addition, software developers liberalize restrictions and allow users to develop plug-ins for BIM software according to their own usage needs, enhancing compatibility features that drive incremental improvements in BIM software interoperability.

5.4.1.2 Centralizing BIM Management for Enhanced Collaboration and Efficiency

Implementing a centralized BIM project management platform can significantly enhance collaboration and communication among stakeholders. Such platforms facilitate real-time data sharing and project updates, thereby reducing ambiguity in roles and responsibilities (e.g., Autodesk BIM 360, Glodon Xiezhu and so on BIM project management platform). Additionally, adopting collaborative project delivery methods, like Integrated Project Delivery (IPD), can foster a cooperative culture and shared objectives among project teams (Guide, 2007).

5.4.1.3 Enhancing BIM Competency and Simplification Through Training and Processes Standardization

To address the complexity of BIM software, targeted training programs and continuous professional development initiatives are essential. These educational initiatives must be meticulously structured to accommodate the diverse proficiency levels present within project teams, thereby ensuring that every participant is adept at leveraging BIM tools to their full potential. Additionally, the complexity and time commitment perceived in adopting BIM can be significantly mitigated through the formulation of standardized templates and workflows, particularly for MBCPs (Kassem et al., 2013). This approach not only alleviates the workload of BIM engineers but also fosters a more streamlined and efficient process. By simplifying BIM processes, there is an enhancement in the coherence and collaboration across various project phases, ultimately leading to a more integrated project delivery mechanism (Keskin et al., 2021). Such strategic interventions are crucial for capitalizing on the collective efforts throughout the project lifecycle, thereby unlocking the full spectrum of benefits that BIM technology offers in terms of efficiency, accuracy, and collaborative synergy.

5.4.2 Suggested Responses for People Factor (PF)

5.4.2.1 Fostering BIM Proficiency Through Education and Awareness

Educational institutions and professional bodies should integrate comprehensive BIM training into their curricula and certification programs. This approach ensures that emerging professionals are equipped with the necessary BIM competencies and a proper understanding of BIM technology (Baharuddin et al., 2019; Olanrewaju et al., 2022). Additionally, conducting awareness campaigns highlighting BIM's benefits and strategic importance in MBCPs and construction projects can enhance understanding and acceptance among current practitioners.

5.4.2.2 Proactively and Regularly Show Executives and Clients Excellent Cases of Global MBCP Applying BIM Technology

To cultivate support from senior management and clients, it should proactively and regularly show the excellent cases of global MBCP applying BIM technology to fully demonstrate the advantages of BIM technology, such as cost savings, time efficiency, improved project outcomes, enhanced corporate image, etc. Case studies and evidence-based research showcasing successful BIM implementation can serve as persuasive tools. Furthermore, engaging senior management and clients in strategic planning and decision-making processes related to BIM adoption can foster a sense of ownership and commitment. Gaining the support of management is critical to facilitating the learning of BIM technology within the project team and fostering a culture of collaboration (Villena-Manzanares et al., 2021). When management actively promotes the use of BIM technology and provides the necessary resources and support, team members will be more motivated to learn and apply the technology.

5.4.3 Suggested Responses for Organizational Factor (OF)

5.4.3.1 Advocating for the Use of BIM in Project Tenders to Raise Industry Standards

Advocating for owners to specify BIM technology requirements during the MBCPs bidding phase is crucial for promoting BIM adoption (Majzoub & Eweda, 2021). The bidding documents should detail BIM standards, us8es, and delivery timelines, with a willingness to cover additional expenses to ensure that bidding companies possess BIM capabilities, integrating them into project planning. This approach enhances the industry's BIM awareness and application, ensuring project quality and efficiency. Through meticulous management, it reduces rework errors, lowers costs, and accelerates delivery (Correa & Santos, 2021). Clear requirements also foster early-stage close collaboration and communication, promoting information sharing and collaborative culture, positively impacting project success and the industry's digital transformation and intelligent construction (Stransky & Dlask, 2018). It is an important strategy for spreading BIM and raising industry standards.

5.4.3.2 Government-Led Incentives as Catalysts for BIM Adoption in the Construction Industry

Governments can promote the widespread adoption of BIM technology in construction projects through a series of incentive policies (Li & Mao, 2022). These policies may include, but are not limited to, tax incentives, financial support, and priority in project approval processes (Le et al., 2019). Implementing these incentives can effectively increase the industry's recognition and willingness to adopt BIM technology. Furthermore, the government can prioritize the use of BIM technology in large public building projects, such as MBCPs, and showcase them as benchmark projects. Through such demonstration effects, the significant advantages of BIM technology in improving project quality, optimizing resource allocation, and shortening project cycles can be vividly displayed, further stimulating small- and medium-sized the private sector's extensive attention to and application of BIM technology (Liu et al., 2023). This government-led strategic layout aims to create a more favorable external environment and market conditions for the promotion and application of BIM technology, thereby accelerating the digital transformation process of the CI.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

6.1 SUMMARY OF FINDINGS

6.1.1 Current Research Status of BIM Technology in Chengdu's MBCPs

The current application of BIM technology in Chengdu's MBCPs presents a contrasting scenario. Despite widespread awareness of BIM, its actual usage remains limited. While 54.43% of industry respondents are familiar with BIM, only 19.08% frequently utilize it, highlighting a gap between recognition and practical application. Additionally, despite many recognizing the value of promoting BIM in MBCPs, a notable minority does not see the necessity for special promotion, reflecting mixed views on its practical benefits and implementation challenges. The survey indicates that many BIM users in Chengdu's MBCPs are novices, with a majority either not using BIM or having only 1-2 years of experience. This suggests that BIM adoption is in its early stages, with a focus mainly on basic 2D and 3D modeling, and LOD300. Advanced BIM functionalities like 4D and 5D modeling, along with higher LOD, are yet to see widespread use, signifying the need for deeper engagement with BIM's more sophisticated features. In essence, despite strong awareness and acceptance, BIM technology's thorough and extensive application in Chengdu's MBCP encounters barriers.

In summary, the application of BIM technology within Chengdu's MBCPs is still in the emerging stage and has a lot of room for development. For full benefits in project efficiency, accuracy, and collaboration, Chengdu's MBCPs stakeholders must look towards examples from more advanced countries, engage in international exchanges, and improve local skills to hasten BIM's comprehensive adoption and growth. Such efforts will foster technological innovation, raise industry standards, and secure greater competitiveness and long-term progress for Chengdu's MBCPs.

6.1.2 Potential Barrier Factors in Chengdu's MBCPs Application BIM

This study adopts a systematic literature review approach and conducts semi-structured interviews with seven BIM experts from the management of in Chengdu's

MBCPs, aiming to delve into the barrier factors to the application of BIM technology in project management. Through inductive analysis, the research identifies twelve main barrier factors, further categorizing these into four primary groups: Cost Factor (CF), People Factor (PF), Technical Factor (TF), and Organizational Factor (OF). This classification provides a more detailed and organized perspective for the effective application of BIM technology.

6.1.3 Critical Barrier Factors in Chengdu's MBCPs Application BIM

This study aims to identify the critical barrier factors affecting Chengdu's MBCPs. It involved distributing questionnaires to managers, designers, and engineers of 48 construction firms participating in MBCPs, employing the RII to rank the identified barrier factors, and conducting a thorough analysis. The results revealed the six most critical barrier factors: PF1 and PF3 from the People Factor, TF1, TF2, and TF3 from the Technical Factor, and OF1 from the Organizational Factor.

Furthermore, this study reveals an important observation: management demonstrates a higher level of concern for organizational-related barrier factors, engineers are most affected by technical-related barrier factors in their daily tasks, while designers, despite recognizing technical barrier factors, show a more pronounced sensitivity to people-related barrier factors. This finding highlights the unique challenges faced by different roles in project management, offering a crucial perspective for the development of targeted resolution strategies.

Additionally, by referencing the research findings of other scholars, this study conducts a comparative analysis of the barrier factors encountered in the implementation of BIM technology across different countries or regions within the construction industry. Although the key barrier factors to BIM implementation encountered during construction processes are fundamentally similar across countries, there are differences in the importance ranking of these barrier factors in various countries or regions. This comparative analysis not only enriches the global perspective on the barrier factors to the application of BIM technology but also underscores the importance of adjusting implementation strategies based on the actual conditions of specific areas.

6.1.4 Significance Difference Analysis

6.1.4.1 Analyze Whether the Respondents Have Used BIM Technology or Not

The results of the M-W U test for all the barrier factors showed that there is no statistically significant difference in the judgment of the importance of these all of barrier factors based on whether the respondents have used BIM technology.

6.1.4.2 Analyze the Respondents' Different Occupational Statuses

The results of the K-W H tests and the post-hoc Dunn-Bonferroni pairwise comparisons for all the barrier factors showed that only show that there is a statistically significant difference between the Designer-Manager (Adj. Sig. = .023) for PF4; There is a statistically significant difference between the Engineer-Manager (Adj. Sig. = .019 and .032) for TF1 and TF2. This indicates significant differences in how managers, designers, and engineers perceive the three barrier factors.

6.1.5 Countermeasures and Recommendations

Although BIM technology has revolutionary potential for in Chengdu's MBCPs, realizing its full potential requires a concerted effort to overcome current barrier factors. Moreover, this research not only aims to drive the broad application of BIM technology in Chengdu's MBCPs but also hopes that these strategies and recommendations will foster the application of BIM technology in a wider the CI and other countries or location. By overcoming these barrier factors, the potential of BIM technology can be fully realized, thus driving technological advancement and efficiency improvements in the CI, and Fine management and digital transformation of construction companies.

Therefore, this study aims to by conducting an in-depth analysis of six key barrier factors identified; and coupled with the results from Spearman's correlation analysis, a strong positive correlation between factors OF3 and OF1 was noted (correlation coefficient of .667), hence OF3 was also included in the targeted recommendations. Based on this, the study proposes seven of the above targeted strategies and suggestions to improve the current situation and promote the application of BIM technology.

6.2 FUTURE RESEARCH AND RECOMMENDATIONS

Although the findings of this study are enlightening and of practical value, their applicability may be limited by specific cultural and contextual factors. Therefore, future research should endeavor to expand the geographical coverage of the study to include a more diverse array of construction markets, further validating and deepening the findings of this research. Additionally, employing longitudinal research methods would provide a more in-depth understanding of the potential long-term impacts of BIM on industry standards and practices.

In light of this, future studies should also aim to conduct further quantitative analyses using larger datasets, possibly requiring the use of complex statistical methods or machine learning technologies, to verify the universality and reliability of the qualitative results obtained in this research. Furthermore, exploring the integrated use of BIM technology with cutting-edge technologies such as big data, the Internet of Things (IoT), and artificial intelligence (AI) has the potential to further revolutionize architectural design, green building, construction processes, facility management, and project management methods, thereby optimizing project outcomes.

These research directions would not only deepen our understanding of BIM technology and its application across different cultural and market contexts but also promote technological progress and innovation within MBCPs and the CI, driving the sector towards digital and intelligent transformation. Therefore, continuing in-depth research in these areas will provide valuable insights and guidance for the future development of MBCPs and the CI.

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APPENDIX

Appendix A: Expert Interview Outline.

Appendix B: Questionnaire Example (English Version).

Appendix C: Questionnaire Example (Chinese Version).

Appendix D: The Item Objective Congruence (IOC) Validation Form.

Appendix E: Chengdu Construction Industry Association Membership List.

Appendix F Result of Semi-structured Expert Interview With 7 BIM Experts in Chengdu

Appendix F: The Raw Data of Online Questionnaire Survey.

APPENDIX A

EXPERT INTERVIEW OUTLINE

Expert Interview Outline

Dear experts, greetings! I would like to express my sincere gratitude for your valuable participation in this expert interview. The purpose of this survey is to identify the critical barrier factors hindering the widespread adoption of BIM technology for Medical Building Construction Projects (MBCPs). Your opinions will greatly contribute to this research endeavor. It is important to note that all questions in this survey are strictly confidential and intended for only academic research purposes, with no intention of public disclosure. Alongside some open-ended inquiries, please kindly provide any valuable suggestions you may have. Thank you for your invaluable guidance.

Part I: Personal Information.

Q1. Would you please give a quick introduction about yourself? This may include:

1.1 Name,

1.2 Age,

1.3 Educational background,

1.4 Current company name,

1.5 Job title,

1.6 Years of BIM experience.

2.1 And please give information about your company.

2.2 How many years has the company been in existence?

2.3 How many MBCPs do you have BIM technology applied to?

Part II: Opinions about the potential barrier factors to applying BIM technology in Chengdu's MBCPs.

Q1. What do you perceive as the critical barrier factors to the widespread adoption of BIM technology presently for MBCPs? Please draw upon your professional experience in MBCPs from recent years to give your opinions on aspects such as policy support and technical challenges.

Q2. What Cost Factors (CF) are associated with applying BIM technology in MBCPs? e.g., there are two influential factors as follows:

① The implementation of BIM technology incurs significant costs. (This includes the recruitment of skilled BIM experts and consultants, procurement of a diverse range of BIM software, establishment of robust networks and databases, acquisition of intelligent construction site hardware, and an increase in design fees.)

② Exorbitant training fees for individuals to acquire proficiency in BIM (alongside a steep learning curve).

Please provide your insights based on your work experience in MBCPs. If you have differing opinions on these factors, feel free to alter them or add additional factors you believe are still prevalent.

Q3. What are the Technical Factors (TF) that significantly impact the adoption of BIM technology in MBCPs? e.g.

① The applicability and practicality of BIM software are insufficient due to the limitations of related BIM software, restricted modeling functions, and a scarcity of available software for BIM design.

② Barriers in exchanging BIM information (such as the lack of opened electronic information exchanging platforms for BIM, inadequate cross-platform data exchanging standards, and compatibility issues).

③ Challenges in collaboration and communication coupled with ambiguity in roles and responsibilities.

Please provide your insights based on your work experience in MBCPs. If you have differing opinions on these factors, feel free to alter them or add additional factors you believe are still prevalent.

Q4. What are the People Factors (PT) that are significant in applying BIM technology in MBCPs? e.g.

① Lack of proper understanding of BIM.

② Lack of support from senior management and client demand.

③ Scarcity of proficient BIM experts.

④ Absence of support from company executives and customer demands.

⑤ Limited professional research on BIM technology conducted by companies.

Please provide your insights based on your work experience in MBCPs. If you have differing opinions on these factors, feel free to alter them or add additional factors you believe are still prevalent.

Q5. What are the Organization Factors (OF) to the adoption of BIM technology in MBCPs? e.g.

① The universities of China do not offer a comprehensive professional-level BIM program.

② Conventional contracting methods (BIM necessitates specialized contractual conditions).

③ Societal resistance to change due to ingrained habits.

④ There is an absence of government support, regulations, and incentives, as well as an insufficiency of relevant BIM standards.

⑤ The recruitment of proficient BIM engineers poses a challenge.

⑥ The roles and responsibilities of BIM engineers in a project are not clearly defined.

⑦ Different knowledge backgrounds between teamwork.

⑧ Users of each generation gain different knowledge of technology.

Please provide your insights based on your work experience in medical or healthcare projects. If you have differing opinions on these factors, feel free to alter them or add additional factors you believe are still prevalent.

Part III: Opinions on barrier factors collected from the Literature Review.

As shown in the table below, which barrier factors are not barriers to the application of BIM in Chengdu's MBCPs? Please also add any factors that you believe hinder the implementation of BIM in Chengdu's MBCPs that are not listed in the table.

We are nearing the completion of our interview. Are there any factors you would like to add more? It is possible that we may reach out to you for a follow-up interview, and we kindly request your consent as it might involve discussing certain topics that were not covered in the initial interview. Once I have organized the transcript of our conversation, I may require your signature on the confirmation letter.

Table 1 The list of 15 barrier factors.

Factor Aspect	Code	Obstruct Factor	Opinion
Cost Factor (CF)	CF1	The initial investment costs are too high, including software and hardware expenses.	☐ Yes ☐ No
	CF2	The training costs and learning curve are excessively expensive.	☐ Yes ☐ No
People Factor (PF)	PF1	Lack of proper understanding of BIM.	☐ Yes ☐ No
	PF2	Lack of BIM experts.	☐ Yes ☐ No
	PF3	Lack of support from senior management and client demand.	☐ Yes ☐ No
	PF4	Insufficiency of appropriate training in BIM.	☐ Yes ☐ No
	PF5	Insufficient understanding of BIM benefits.	☐ Yes ☐ No
Technical Factor (TF)	TF1	Interoperability and compatibility issues among different BIM software.	☐ Yes ☐ No
	TF2	Challenges in collaboration and communication coupled with ambiguity in roles and responsibilities.	☐ Yes ☐ No
	TF3	The complexity of BIM software and tools, plus time-consuming and cumbersome BIM processes.	☐ Yes ☐ No
	TF4	There are difficulties in converting data between different BIM platforms.	☐ Yes ☐ No
Organizational Factor (OF)	OF1	Traditional contracting methods (BIM requires special bidding conditions and a unique BIM service contract).	☐ Yes ☐ No
	OF2	Social and habitual resistance to change.	☐ Yes ☐ No
	OF3	Lack of specialized study on BIM technology in higher education curricula.	☐ Yes ☐ No
	OF4	Lack of government support, regulations, and incentive measures coupled with incomplete standards for BIM.	☐ Yes ☐ No

We are nearing the completion of our interview. Are there any factors you would like to add more? It is possible that we may reach out to you for a follow-up interview, and we kindly request your consent as it might involve discussing certain topics that were not covered in the initial interview. Once I have organized the transcript of our conversation, I may require your signature on the confirmation letter.

I would like to inform you that the content of the entire interview, a high degree of summary, mainly the objective facts expressed by the other party, as well as personal views on certain topics, a quick summary to the other party to make the final confirmation, to ensure the effectiveness of communication, to avoid the communication of the wrong understanding of the ideas that the experts want to express.

Contact: Jiahao Chen
Email: 1099036298@qq.com

APPENDIX B

QUESTIONNAIRE EXAMPLE (ENGLISH VERSION)

Questionnaire Example (English Version)

Dear experts, greetings! I would like to express my sincere gratitude for your valuable participation in this questionnaire survey. I'm a KMITL university grade 2022 master's student concentrating in civil engineering, and right now, I'm looking into how to promote BIM technology in Medical Building Construction Projects (MBCPs). I invite you to respond to the following questions from the perspective of practitioners who work in MBCPs and BIM technology. The primary targets of this questionnaire survey are the relevant production and research employees in Chengdu's MBCPs and the BIM technology industry. To specifically target opinions for the information transformation and industrial upgrading of Chinese construction enterprises to enhance BIM technology application, the primary purpose of this questionnaire is to investigate the development of BIM technology in Chengdu's MBCPs and the immediate barrier factors to market promotion. Your opinions will significantly contribute to this research endeavor. It is important to note that all questions in this survey are strictly confidential and intended for only academic research purposes, with no intention of public disclosure. Please kindly provide any valuable suggestions you may have. Thank you for your invaluable guidance.

There are three sections to the questionnaire. The questionnaire was created and divided into three sections: personal information, BIM expertise, and potential barriers to BIM technology adoption in Chengdu's MBCPs.

Screening Question

Do you voluntarily fill out the questionnaire and agree with the authors to use the questionnaire data for academic research?

○ Yes ○ No (If no. Please stop.)

Part I: Personal Information of the Respondents.

1. Gender: (Single choice) *

O Male

O Female

2. Age: (Single choice) *

◯ ≤ 25 years old

◯ 26-35 years old

◯ 36-45 years old

◯ ≥ 45 years old

3. Current level of education (Single choice) *

◯ High school/technical school/technical school and below

◯ College Degree

◯ Undergraduate Degree

◯ Master

◯ Doctor (PhD)

4. Employment position: (Single choice) *

◯ Managers

◯ Designers

◯ Engineers

5. How long do you have years of work experience in the construction industry? (Single choice) *

◯ ≤ 2 years

◯ 3-5 years

◯ 6-9 years

◯ ≥ 10 years

6. Organizations Sector: (Single choice) *

- ○ Public
- ○ Private

7. What is the nature of your organization: (Single choice) *

- ○ Construction Companies
- ○ Design Companies
- ○ Supervision Companies
- ○ BIM Consulting Companies
- ○ Design and Construct
- ○ Engineering, procurement, and construction (EPC)
- ○ Other (Specific) ________________

8. Frequently used BIM software: (Multiple choice question)

- ○ Autodesk AutoCAD
- ○ Autodesk Navisworks
- ○ Fuzor
- ○ Tekla
- ○ Google SketchUp
- ○ Microsoft Excel
- ○ Microsoft PowerProject
- ○ Cinema 4D
- ○ Autodesk Rivet
- ○ Autodesk 3Ds Max
- ○ Rhino
- ○ Graphisoft ArchiCAD
- ○ Bentley MicroStation
- ○ Microsoft Project
- ○ Primavera
- ○ Other (Specific) ________________

Part II: BIM Expertise.

9. Is your level of understanding of BIM technology: (Single choice) *

- ○ Don't know about BIM technology.
- ○ Know about BIM technology but never use it.
- ○ Don't use BIM technology often.
- ○ Use BIM technology regularly.

10. Your attitude to the promotion of BIM technology in the MBCPs: (Single choice) *

○ Not used BIM technology.

○ No need for special promotion

○ More important

○ Very important

11. Years of Using BIM technology: (Single choice) *

○ Not used BIM technology.

○ ≤ 2 Years

○ 3-5 Years

○ 6-9 Years

○ ≥ 10 Years

12. The number of MBCPs in which you have been involved in using BIM technology: (Single choice) *

○ Not used BIM technology.

○ 1 Projects

○ 2-5 Projects

○ 6-9 Projects

○ ≥ 10 Project

13. What kind of BIM models are often used when implementing BIM technology: (Single choice) *

○ Not used BIM technology.

○ 2D Modeling (Usually work with 2D drawings such as CAD in work.)

○ 3D Modeling (Usually use 3D building models in work.)

○ 4D Modeling (Based on the 3D model, incorporate with the construction schedule.)

○ 5D Modeling (Based on the 4D model, incorporate cost elements.)

14. Do you consider the BIM model or the visualization of BIM technology in your day-to-day work to be more important? (Single choice) *

- ◯ Not used BIM technology.
- ◯ Equally important
- ◯ BIM Model
- ◯ Visualization of BIM technology

15. The BIM Level of Details (LOD) level used when building the BIM model: (Single choice) *

- ◯ LOD 100
- ◯ LOD 200
- ◯ LOD 300
- ◯ LOD 400
- ◯ LOD 500
- ◯ Not used BIM technology.

Part III: Possible barrier factors or challenges facing implementing BIM in Chengdu's MBCPs.

16. Please rate the relative importance of the following barrier factors according to your understanding.

Explanation: Please assess the significance of the following barrier factors of BIM technology in Chengdu's healthcare buildings, utilizing a rating scale ranging from 1 to 5. Distinct scores indicate varying levels of impact (1 = Strongly Unimportant, 2 = Unimportant, 3 = Neutral, 4 = Important, 5 =Strongly important).

Barrier Factors	1	2	3	4	5
CF1: The initial investment costs are too high, including software and hardware expenses.					
CF2: The training costs and learning curve are excessively expensive.					

Continued.

Barrier Factors	1	2	3	4	5
PF1: Lack of proper understanding of BIM.					
PF2: Lack of BIM experts.					
PF3: Lack of support from senior management and client demand.					
PF4: Insufficiency of appropriate training in BIM.					
TF1: Interoperability and compatibility issues among different BIM software.					
TF2: Challenges in collaboration and communication coupled with ambiguity in roles and responsibilities.					
TF3: The complexity of BIM software and tools, plus time-consuming and cumbersome BIM processes.					
OF1: Traditional contracting methods (BIM requires special bidding conditions and a unique BIM service contract).					
OF2: Lack of specialized study on BIM technology in higher education curricula.					
OF3: Lack of government support, regulations, and incentive measures coupled with incomplete standards for BIM.					

Additional comments: ....

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The questionnaire is over. Thank you for your support!

If you have any other questions or suggestions, please contact Mr. Jiaohao Chen at 1099036298@qq.com.

APPENDIX C

QUESTIONNAIRE EXAMPLE (CHINESE VERSION)

Questionnaire Example (Chinese Version)

关于成都市医疗建设项目广泛推广 BIM 技术关键阻碍因素的调查研究

尊敬的专家：

您好!衷心感谢您对本次问卷调查的宝贵参与。我是一名 KMITL 大学 2022 级土木工程专业的硕士研究生，旨在研究如何在医疗建设项目中广泛推广 BIM 技术的应用。我诚挚地邀请您以从事医疗建设项目和 BIM 技术从业者的角度回答以下问题。本次问卷调查的主要对象是成都市医疗建设项目及 BIM 技术行业的相关产学研人员。为了提升中国建筑企业信息转型和产业升级，加强 BIM 技术的应用，本问卷调查的主要目的是调查 BIM 技术在成都市医疗建设项目中的发展情况以及阻碍市场推广的关键阻碍因素。您的意见将对这项研究工作作出重大贡献。值得注意的是，本次调查中的所有问题都是严格保密的，仅用于学术研究目的，无意公开披露。如果您有什么宝贵的建议，请提供。谢谢您宝贵的指导。

问卷分为三个部分。该问卷分为三个部分:个人信息、BIM 专业知识和 BIM 技术在成都医疗建设项目中应用的潜在障碍。

筛选问题

您是否自愿填写问卷并同意作者将问卷数据用于学术研究？

○ 是　　○ 否（如果否，请停止。）

第 I 部分:受访者的背景资料。

1. 性别：［单选题］*

○ 男

○ 女

2. 年龄：［单选题］*

○ 25 岁及以下

○ 26-35 岁

○ 36-45 岁

○ 46 岁及以上

3. 您的最高学历是什么（包含目前的在读的学历）？ [单选题] *

○ 高中及以下学历

○ 大专

○ 本科

○ 研究生

○ 博士生

4. 您目前的职位： [单选题] *

○ 经理

○ 设计师

○ 工程师

5. 您毕业以后从事建筑行业的工作年限： [单选题] *

○ 2 年及以下

○ 3-5 年

○ 6-9 年

○ 10 年及以上

6. 您所工作的企业是国营企业还是私营企业： [单选题] *

○ 国营企业

○ 私营企业

7. 您所工作的企业的性质： [单选题] *

○ 建筑施工企业

○ 设计公司

○ 监理公司

○ BIM 咨询公司

○ 设计与施工企业

○ 工程总承包（EPC）

○ 其他 ________________

8. 您工作中常用的 BIM 软件有： [多选题]

☐ Autodesk AutoCAD
☐ Autodesk Rivet
☐ Autodesk Navisworks
☐ Autodesk 3Ds Max
☐ Fuzor
☐ Graphisoft ArchiCAD
☐ Google SketchUp
☐ Bentley MicroStation
☐ Rhino
☐ Tekla
☐ Microsoft Excel
☐ Microsoft Project
☐ Microsoft PowerProject
☐ Primavera
☐ Cinema 4D
☐ 其他 ______________

第Ⅱ部分： BIM 专业知识。

9. 您对 BIM 技术的了解程度： [单选题] *

○ 没有听说过 BIM 技术。
○ 知道有 BIM 技术却从未使用过。
○ 不经常应用 BIM 技术。
○ 经常应用 BIM 技术。

10. 您对在医疗设施建筑行业推广 BIM 技术的态度： [单选题] *

○ 不需要推广 BIM 技术
○ 无需特别宣传 BIM 技术
○ 推广 BIM 技术比较重要
○ 推广 BIM 技术非常重要

11. 您使用 BIM 技术的年限： [单选题] *

○ 从未使用过 BIM 技术
○ 0-2 年
○ 3-5 年
○ 6-9 年
○ 10 年及以上

12. 您参与使用 BIM 技术的医疗建筑建设项目的数量：［单选题］*

○ 0 个项目

○ 1 个项目

○ 2-5 个项目

○ 6-9 个项目

○ 10 个及以上项目

13. 实施 BIM 技术时，经常采用什么样的 BIM 模型：［单选题］*

○ 从未使用 BIM 技术

○ 2D 模型（在工作中通常使用 CAD 等 2 维软件绘图）

○ 3D 模型（在工作中通常会使用 3D 建筑模型）

○ 4D 模型（在 3D 模型为基础，再融入施工进度要素）

○ 5D 模型 （在 4D 模型的基础上，再融入成本要素）

14. BIM 模型 和 可视化谁更重要：［单选题］*

○ 从未使用 BIM 技术

○ 同等重要

○ BIM 模型

○ BIM 技术可视化

15. 建立 BIM 模型时使用的 BIM 详细程度 (LOD) 级别：［单选题］*

○ LOD 100

○ LOD 200

○ LOD 300

○ LOD 400

○ LOD 500

○ 从未使用过 BIM 技术

第 III 部分： 成都医疗建设项目领域实施 BIM 可能面临的阻碍因素或挑战。

16. 请根据您的理解对以下阻碍因素的重要性进行评分。［矩阵量表题］

说明：请用 1 到 5 分来评估以下阻碍 BIM 技术在成都医疗建筑中应用的因素的重要性。不同的分数表示不同程度的影响。（1 = 非常不重要，2 = 不重要，3 = 中立，4 = 重要，5 = 非常重要）。

阻碍因素	1	2	3	4	5
CF1：初期投资成本太高，包括软件和硬件费用。					
CF2：培训成本和学习曲线过于昂贵。					
PF1：缺乏对 BIM 的正确认识。					
PF2：缺乏 BIM 专家。					
PF3：缺乏高管的支持和客户的需求。					
PF4：缺乏适当的 BIM 培训。					
TF1：不同 BIM 软件之间的互操作性和兼容性问题。					
TF2：协作和沟通问题 + 角色和职责明确					
TF3：复杂的 BIM 软件和工具和 BIM 流程既耗时又繁琐。					
OF1：承包方式较为传统（BIM 需要特别的招投标条件和特有的 BIM 服务合同）。					
OF2：高等教育课程缺乏对 BIM 技术的专门研究。					
OF3：缺乏政府支持、法规和激励措施，以及 BIM 标准不完善。					

补充的评论:..

....

问卷调查结束。感谢您的支持！
如果还有其他问题或建议，请联系陈嘉豪先生。邮箱：1099036298@qq.com。

APPENDIX D

THE ITEM OBJECTIVE CONGRUENCE (IOC) VALIDATION FORM

The Item Objective Congruence (IOC) Validation Form

An Investigation into Barriers to Implementing BIM in Medical Building Construction Projects in Chengdu

The Item Objective Congruence (IOC) Form

Researcher: Jiahao Chen

Advisor: Assoc. Prof. Dr. Laemthong Laokhongthavorn

Program: Master of Bachelor's in Civil Engineering (International Program), King Mongkut's Institute of Technology Ladkrabang Business School

Expert name:

Date of IOC Form Checking:

Questionnaire Objectives

The purpose of this survey is to identify the critical barrier factors hindering the widespread adoption of BIM technology for Chengdu's MBCPs.

Questionnaire Structure

Questions	Number
Screening Question	**1**
Part I: Personal Information of the Respondents.	**8**
1.1 Gender.	1
1.2 Age.	1
1.3 Current level of education.	1
1.4 Employment Position.	1
1.5 How long do you have years of work experience in the construction industry?	1
1.6 Organizations Sector.	1
1.7 What is the nature of your organization?	1
1.8 Frequently used BIM software.	1
Part II: BIM Expertise.	**6**
2.1 Your level of understanding of BIM technology.	1
2.2 Your attitude to the promotion of BIM technology in the MBCPs.	1
2.3 Years of Using BIM Technology?	1
2.4 The number of MBCPs in which you have been involved in using BIM technology.	1
2.5 What kind of BIM models are often used when implementing BIM technology?	1

Questionnaire Structure (Continued)

Questions	Number
2.6 Do you consider the BIM model or the visualization of BIM technology in your day-to-day work to be more important?	1
2.7 What BIM Level of Detail (LOD) level was used when building the BIM model?	1
Part III: Possible barrier factors or challenges facing implementing BIM in Chengdu's MBCPs.	**15**
3.1 Cost Factor (CF)	2
3.2 People Factor (PF)	5
3.3 Technical Factor (TF)	4
3.4 Organizational Factor (OF)	4

Description

Thank you for receiving this questionnaire. Please read the questions carefully and give a complete answer according to the actual situation. All your responses will be completely confidential and only used for academic research. Thank you for your participation.

Please fill in the content according to the situation to select the score. You can choose a single choice with each question.

Direction:

Read through the questions in this form. Please indicate the degree to which each item is congruent with the objective of this study. If you have any comments on the congruence of each question, please record them in the space provided. Tick (√) to rate the congruence according to the scale below.

+1 = certain that the question is congruent with themes of opinions with the critical barrier factors hindering the widespread adoption of BIM technology for medical projects.

0 = uncertain that the question is congruent with themes of opinions with the critical barrier factors hindering the widespread adoption of BIM technology for medical projects.

-1 = certain that the question is NOT congruent with themes of opinions with the critical barrier factors hindering the widespread adoption of BIM technology for medical projects.

Part I: Screening Question and Personal Information

Screening Question	Score			Comments
	-1	0	+1	
Do you voluntarily fill out the questionnaire and agree with the authors to use the questionnaire data for academic research? ◯ Yes ◯ No (If no. Stop.)				
Personal Information	**Score**			**Comments**
	-1	0	+1	
1. Gender ◯ Male ◯ Female				
2. Age ◯ ≤ 25 years old ◯ 26-35 years old ◯ 36-45 years old ◯ ≥ 45 years old				
3. Current level of education ◯ High school/technical school/technical school and below ◯ College Degree ◯ Undergraduate Degree ◯ Master's degree ◯ Doctor (PhD)				
4. Employment Position ◯ Managers ◯ Designers ◯ Engineers				
5. How long do you have years of work experience in the construction industry? ◯ ≤ 2 years ◯ 3-5 years ◯ 6-9 years ◯ ≥ 10 years				
6. Organizations Sector ◯ Public ◯ Private				

Part I: Screening Question and Personal Information (Continued)

Personal Information	Score			Comments
	-1	0	+1	
7. What is the nature of your organization? ○ Construction Companies ○ Design Companies ○ Supervision Companies ○ BIM Consulting Companies ○ Design and Construct ○ Engineering, procurement, and construction (EPC) ○ Other (Specific) ________________				
8. Frequently used BIM software ○ Autodesk AutoCAD ○ Autodesk Rivet ○ Autodesk Navisworks ○ Autodesk 3Ds Max ○ Fuzor ○ Rhino ○ Tekla ○ Graphisoft ArchiCAD ○ Google SketchUp ○ Bentley MicroStation ○ Microsoft Excel ○ Microsoft Project ○ Microsoft Powerproject ○ Primavera ○ Other (Specific) ________________				

Additional comments: ....

....

....

Part II: BIM Expertise

Questions	Score			Comments
	-1	0	+1	
9. Your level of understanding of BIM technology ○ Don't know about BIM technology. ○ Know about BIM technology but never use it. ○ Don't use BIM technology often. ○ Use BIM technology regularly.				
10. Your attitude to the promotion of BIM technology in the construction industry ○ Not used BIM technology. ○ No need for special promotion. ○ More important. ○ Very important.				
11. Years of Using BIM technology ○ Not used BIM technology. ○ ≤ 2 Years. ○ 3-5 Years. ○ 6-9 Years. ○ ≥ 10 Years.				
12. The number of projects in which you have been involved in using BIM technology. ○ Not used BIM technology. ○ 1 Projects ○ 2-5 Projects ○ 6-9 Projects ○ ≥ 10 Project				
13. BIM techniques used in construction. ○ Not used BIM technology. ○ 2D Modeling (Usually work with 2D drawings such as CAD in work.) ○ 3D Modeling (Usually use 3D building models in work.) ○ 4D Modeling (Based on the 3D model, incorporate with the construction schedule.) ○ 5D Modeling (Based on the 4D model, incorporate cost elements.)				

Part II: BIM Expertise (Continued)

Questions	Score			Comments
	-1	0	+1	
14. Do you consider the BIM model or the visualization of BIM technology in your day-to-day work to be more important? ○ Not used BIM technology. ○ Equally important. ○ BIM Model. ○ Visualization of BIM technology.				
15. Do you consider the BIM model or the visualization of BIM technology in your day-to-day work to be more important? ○ Not used BIM technology. ○ Equally important. ○ BIM Model. ○ Visualization of BIM technology.				
16. What BIM Level of Detail (LOD) level was used when building the BIM model? ○ LOD 100 ○ LOD 200 ○ LOD 300 ○ LOD 400 ○ LOD 500 ○ Not used BIM technology.				

Additional comments: ....

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Part III: Possible challenges facing implementing BIM in Chengdu's MBCPs.

Barrier Factors		Score			Comments
		-1	0	+1	
Cost Factor (CF)	CF1: The initial investment costs are too high, including software and hardware expenses.				
	CF2: The training costs and learning curve are excessively expensive.				
People Factor (PF)	PF1: Lack of awareness about BIM.				
	PF2: Lack of BIM experts.				
	PF3: Lack of support from executives and customer demand.				
	PF4: Insufficiency of appropriate training in BIM.				
	PF5: Insufficient understanding of BIM benefits.				
Technical Factor (TF)	TF1: Interoperability and compatibility issues among different BIM software.				
	TF2: Challenges in collaboration and communication coupled with ambiguity in roles and responsibilities.				
	TF3: The complexity of BIM software and tools, plus time-consuming and cumbersome BIM processes.				
	TF4: There are difficulties in converting data between different BIM platforms.				
Organizational Factor (OF)	OF1: Traditional contracting methods (BIM requires special bidding conditions and a unique BIM service contract).				
	OF2: Social and habitual resistance to change.				
	OF3: Lack of specialized study on BIM technology in higher education curricula.				
	OF4: Lack of government support, regulations, and incentive measures coupled with incomplete standards for BIM.				

Additional comments: ....

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Jiaohao Chen

27. September 2023

APPENDIX E

CHENGDU CONSTRUCTION INDUSTRY ASSOCIATION MEMBERSHIP LIST

Chengdu Construction Industry Association Membership List

No.	Companies' Identification
1	China Fifth Metallurgical Group Co., Ltd.
2	China Fifth Metallurgical Group First Engineering Division Co., Ltd.
3	China Energy Conservation Construction Engineering Design Institute Co., Ltd.
4	Sichuan Shu Tong Construction Group Co., Ltd.
5	China Railway Second Bureau Sixth Engineering Co., Ltd.
6	China Railway Second Bureau Group Construction Co., Ltd.
7	China West Enterprises Co., Ltd.
8	Sichuan First Construction Engineering Co., Ltd.
9	Sichuan Third Construction Engineering Co., Ltd.
10	Sichuan Sixth Construction Co., Ltd.
11	Sichuan Construction Machinery Engineering Co., Ltd.
12	China Electronics System Engineering Third Construction Co., Ltd.
13	Chengdu Environmental Engineering Construction Co., Ltd. (Sichuan Coal Mine Infrastructure Construction Engineering Company)
14	Sichuan Commercial Construction Co., Ltd.
15	Sichuan Chuanhua Yongxin Construction Engineering Co., Ltd.
16	Chengdu Construction Group Co., Ltd.
17	Chengdu Construction First Building Engineering Co., Ltd.
18	Chengdu Construction Second Building Engineering Co., Ltd.
19	Chengdu Construction Third Building Engineering Co., Ltd.
20	Chengdu Construction Fourth Building Engineering Co., Ltd.
21	Chengdu Construction Fifth Building Engineering Co., Ltd.
22	Chengdu Construction Sixth Building Engineering Co., Ltd.
23	Chengdu Construction Seventh Building Engineering Co., Ltd.
24	Chengdu Construction Eighth Building Engineering Co., Ltd.
25	Chengdu Construction Ninth Building Engineering Co., Ltd.
26	Chengdu Construction Industrial Equipment Installation Co., Ltd.
27	Chengdu Road and Bridge Engineering Co., Ltd.
28	Sichuan Huangxin Construction Group Co., Ltd.
29	Chengdu Huaxia Construction (Group) Co., Ltd.
30	Sichuan Mainland Emerging Construction Co., Ltd.
31	Chengdu Municipal Engineering (Group) Co., Ltd.
32	Chengdu Pufa Construction Engineering Co., Ltd.
33	Sichuan Yuantai Construction Engineering Co., Ltd.
34	Dujiangyan City New Five Construction Co., Ltd.
35	Sichuan Sanyang Construction Co., Ltd.
36	Chengdu Zhihai Building Installation Engineering Co., Ltd.
37	Chengdu Jinhua Construction Engineering Co., Ltd.
38	Chengdu Surveying and Mapping Research Institute

Table Continued.

No.	Companies' Identification
39	Sichuan Lida Construction Engineering Co., Ltd.
40	Chengdu Yellow River Construction (Group) Co., Ltd.
41	Chengdu Beite Building Installation Engineering Co., Ltd.
42	Chengdu Haihong Construction Engineering Co., Ltd.
43	Chengdu Guilin Construction Co., Ltd.
44	Sichuan Jinghui Construction Co., Ltd.
45	Sichuan Chenxing Construction Co., Ltd.
46	Sichuan Chongzhou City Construction Installation Engineering Co., Ltd.
47	Chengdu Huayang Building Co., Ltd.
48	Chengdu Chengfei Construction Co., Ltd.
49	Sichuan Fuguang Jinguan Construction Engineering Co., Ltd.
50	Chengdu Aowei Intelligent System Equipment Co., Ltd.
51	Sichuan Xiaokang Construction Engineering Co., Ltd.
52	Sichuan Qionglai City Qiongzhou Building Engineering Co., Ltd.
53	Sichuan Pixian Building Engineering Company
54	Sichuan Huating Construction Co., Ltd.
55	Sichuan Xinshu Construction Co., Ltd.
56	Chengdu Jintong Construction Engineering Co., Ltd.
57	Sichuan Hongda Construction Engineering Co., Ltd.
58	Sichuan Kaihong Construction Co., Ltd.
59	Sichuan Chongzhou City Shuxi Construction Engineering Company
60	Sichuan Jinhui Construction Engineering Co., Ltd.
61	Chengdu High-tech Zone Construction Management Municipal Engineering Co., Ltd.
62	Sichuan Qingfeng Construction Engineering Co., Ltd.
63	Chengdu Ende Construction Engineering Co., Ltd.
64	Zhongcheng North China Southwest Construction Co., Ltd.
65	Sichuan Oupeng Construction Engineering Company
66	Chengdu Jinyang Construction Co., Ltd.
67	Chengdu Construction Ya'an Construction Co., Ltd.
68	Sichuan Huitong Construction Engineering Co., Ltd.
69	Sichuan Guitong Construction Group Co., Ltd.
70	China Construction Co., Ltd. Southwest Branch
71	Zhongtian Construction Group Co., Ltd. Southwest Company
72	Sichuan Zhenhua Construction Group Co., Ltd.
73	Chengdu Longxi Construction Engineering Co., Ltd.
74	Sichuan Yongfa Construction Engineering Group Co., Ltd.
75	Chengdu Shuangliu Construction Group Co., Ltd.
76	Sichuan Hope Huaxi Construction Engineering General Contracting Co., Ltd.
77	Chengdu Construction Road and Bridge Construction Co., Ltd.
78	Sichuan Shuangxing Construction Engineering Co., Ltd.
79	Chongzhou City Guangyi Construction Engineering Co., Ltd.

Table Continued.

No.	Companies' Identification
80	Zhongxin Guoan Construction Group Co., Ltd. (Shengmao)
81	China Construction Third Bureau Group Co., Ltd. Southwest Branch
82	China Construction First Bureau (Group) Co., Ltd. Southwest Branch
83	China Construction Seventh Engineering Bureau Co., Ltd.
84	China Construction Second Engineering Bureau Co., Ltd.
85	Chengdu Silicon Treasure Technology Co., Ltd.
86	Sichuan Jiayu Construction Installation Engineering Co., Ltd.
87	China Construction Second Bureau Third Construction Engineering Co., Ltd.
88	Sichuan Seventh Construction Engineering Company
89	Hunan Xingda Construction Group Co., Ltd. Chengdu Branch
90	Sichuan Ruiyang Construction Engineering Co., Ltd.
91	Chengdu Xindu Public Utility Construction Engineering Co., Ltd.
92	Sichuan Dongnan Construction Co., Ltd.
93	Sichuan Dafeng Construction Engineering Co., Ltd.
94	Shanghai Construction One Construction Group Co., Ltd. Chengdu Branch
95	Chengdu Xinhe Construction Engineering Co., Ltd.
96	Chengdu Huayan Construction Engineering Co., Ltd.
97	Sichuan Tailong Construction Group Co., Ltd.
98	Chengdu Sanye Construction Co., Ltd.
99	Sichuan Shuyu Construction Engineering Co., Ltd.
100	Chengdu Xinfaxin Construction Engineering Co., Ltd.
101	Sichuan Hongxinda Construction Engineering Co., Ltd.
102	Sichuan Sanxin Construction Engineering Co., Ltd.
103	Chengdu Totem Construction Engineering Co., Ltd.
104	Sichuan Fulong Construction Co., Ltd.
105	China Nuclear Zhonghong Group Co., Ltd.
106	Sichuan Zhengda Construction Engineering Co., Ltd.
107	Sichuan Jinding Construction Engineering Co., Ltd.
108	Sichuan Yahui Construction Installation Engineering Co., Ltd.
109	Sichuan Jiyuan Geotechnical Engineering Survey Co., Ltd.
110	Chengdu Sanpeng Construction Engineering Co., Ltd.
111	Sichuan Tianjiu Construction Engineering Co., Ltd.
112	Sichuan Qionglai Hydropower Engineering Construction Group Co., Ltd.
113	Sichuan Hongde Construction Group Co., Ltd.
114	Sichuan Hongyu Construction Engineering Co., Ltd.
115	Sichuan Guorui Construction Engineering Co., Ltd.
116	Sichuan Jian'an Construction Engineering Group Co., Ltd.
117	Zhejiang Province Sanjian Construction Group Co., Ltd.
118	Sichuan Hongfu Construction Group Co., Ltd.
119	China Railway Long Engineering Group Co., Ltd.
120	Chengdu Pujiang Qijian Engineering Co., Ltd.

Table Continued.

No.	Companies' Identification
121	Sichuan Yuanjian Construction Co., Ltd.
122	Chengdu Huihong Construction Co., Ltd.
123	China Construction Xinjiang Construction (Group) Co., Ltd.
124	Sichuan Zining Construction Co., Ltd.
125	Chengdu Yong'an Construction Group Co., Ltd.
126	Sichuan Tianyuxiang Construction Engineering Co., Ltd.
127	Chengdu Yinping Construction Engineering Co., Ltd.
128	Sichuan Xianzhou Construction Engineering Co., Ltd.
129	Sichuan Changsheng Construction Engineering Co., Ltd.
130	Sichuan Kund Construction Engineering Co., Ltd.
131	Sichuan Zhonglin Construction Co., Ltd.
132	Sichuan Chongzhou City Dahua Construction Engineering Co., Ltd.
133	Chengdu Guangda Construction Group Co., Ltd.
134	Sichuan Chongzhou City Kehui Construction Installation Co., Ltd.
135	Longsheng International Construction Group Co., Ltd.
136	Dujiangyan City Mingxing Construction Installation Co., Ltd.
137	Chengdu Shuangliu Dachang Construction Co., Ltd.
138	Sichuan Dongfang Yuhong Waterproof Engineering Co., Ltd.
139	Chengdu Dengfeng Building Installation Engineering Co., Ltd.
140	Sichuan Xinhua Construction Engineering Co., Ltd.
141	Chengdu Xinhong Construction Engineering Co., Ltd.
142	Chengdu Dongsheng Xingwang Construction Co., Ltd.
143	China Railway Construction Group Co., Ltd.
144	Chengdu Lianbang Medical Technology Co., Ltd.
145	Chengdu Dongxu Construction Engineering Co., Ltd.
146	Sichuan Jufeng Construction Engineering Co., Ltd.
147	Chengdu Dinghang Construction Engineering Co., Ltd.
148	Chengdu Shengxing Construction Co., Ltd.
149	Chengdu Qionglai Third Construction Engineering Co., Ltd.
150	Sichuan Yuyuan Construction Engineering Co., Ltd.
151	Sichuan Tengtu Construction Engineering Co., Ltd.
152	Chengdu Xingda Construction Industry Co., Ltd.
153	Sichuan Mingyi Construction Engineering Co., Ltd.
154	Chengdu Shuangliu Shuangzhong Construction Engineering Co., Ltd.
155	China Construction Fifth Bureau Third Construction Co., Ltd.
156	Chengdu Guihao Construction Industry Co., Ltd.
157	Dujiangyan City Hongda Construction (Group) Co., Ltd.
158	Chengdu Xindu District Jixie Construction Engineering Company
159	Sichuan Shuangyu New Generation Construction Engineering Co., Ltd.
160	Chengdu Wanfu Industrial Engineering Co., Ltd.
161	Sichuan Fangji Construction Co., Ltd.

Table Continued.

No.	Companies' Identification
162	Chengdu Pujiang County Sanjian Engineering Co., Ltd.
163	Sichuan Enda Construction Co., Ltd.
164	Sichuan Huayang Construction Installation Co., Ltd.
165	Sichuan Zhongqi Construction Engineering Co., Ltd.
166	Chengdu Baisha Construction Installation Engineering Co., Ltd.
167	Sichuan Longxin Construction Group Co., Ltd.
168	Chengdu Dayu Hydropower Construction Co., Ltd.
169	Fujian Province Yifang Construction Engineering Co., Ltd. Chengdu Branch
170	Sichuan Xiongdun Construction Engineering Co., Ltd.
171	Sichuan Huaxi Dacheng Construction Co., Ltd.
172	Sichuan Junjie Construction Engineering Co., Ltd.
173	Chengdu Jinhui Construction Engineering Co., Ltd.
174	Sichuan Songyi Construction Engineering Co., Ltd.
175	Chengdu Xindu District Twelfth Construction Engineering Co., Ltd.
176	China Railway First Bureau Group Telecommunications Engineering Co., Ltd.
177	Sichuan Xinjincheng Construction Engineering Co., Ltd.
178	Sichuan Jiahaoxing Construction Engineering Co., Ltd.
179	Chengdu Mingyuan Environmental Engineering Co., Ltd.
180	Sichuan Zhixin Geotechnical Engineering Co., Ltd.
181	Sichuan Yuanming Construction Group Co., Ltd.
182	Chengdu Lianglong Construction Engineering Co., Ltd.
183	Sichuan Heyuan Water Conservancy Engineering Co., Ltd.
184	Sichuan Haihe Construction Engineering Co., Ltd.
185	Sichuan Jianxiang Construction Engineering Co., Ltd.
186	Sino-European International Construction Group Co., Ltd.
187	Sichuan Shuguang Construction Engineering Co., Ltd.
188	Sichuan Chichen Construction Engineering Co., Ltd.
189	Sichuan Huarui Construction Engineering Co., Ltd.
190	Chengdu Baogong Engineering Technology Service Co., Ltd.
191	Sichuan Zhongyao Engineering Management Group Co., Ltd.
192	Sichuan Huayang Construction Installation Co., Ltd.
193	China Construction Science Chengdu Co., Ltd.
194	Zhongwa Construction Group Co., Ltd.
195	Chengdu Xingyuan Science and Construction Co., Ltd.
196	Sichuan Zhongsheng Construction Engineering Group Co., Ltd.
197	Sichuan Jiaxiang Construction Engineering Co., Ltd.
198	Sichuan Fourth Construction Co., Ltd.
199	Sichuan Yuandian Installation Engineering Co., Ltd.
200	Chengdu Jiucheng Construction Engineering Co., Ltd.
201	Guoxin Ecological Construction Co., Ltd.
202	Sichuan Xinao Construction Engineering Co., Ltd.

Table Continued.

No.	Companies' Identification
203	Sichuan Xingjiancheng Construction Engineering Co., Ltd.
204	Sichuan Xinheyuan Construction Engineering Co., Ltd.
205	Sichuan Tianyi Ecological Garden Group Co., Ltd.
206	Zhongqing Hongfa Group Co., Ltd.
207	Sichuan Keyuan Garden Engineering Co., Ltd.
208	Shanghai Baoye Group Co., Ltd.
209	Chengdu Tian Investment New City Construction Investment Co., Ltd.
210	Sichuan Ruihai Construction Engineering Co., Ltd.
211	Sichuan Taikun Construction Engineering Co., Ltd.
212	Sichuan Xiteng Construction Engineering Co., Ltd. (formerly Lu Yin Garden)
213	Sichuan Ruizhu Construction Engineering Co., Ltd.
214	Sichuan Dacheng Construction Engineering Co., Ltd.
215	Sichuan Decai Construction Engineering Co., Ltd.
216	China Construction Hongteng Construction Group Co., Ltd.
217	Sino Great Wall Southwest Construction Engineering Co., Ltd.
218	Sichuan Zhaogang Construction Co., Ltd.
219	Sichuan Yuyu Trade Co., Ltd.
220	China Construction Third Bureau Second Construction Engineering Co., Ltd.
221	Sichuan Chuanxin Construction Engineering Co., Ltd.
222	Sichuan Jincheng Zhixin Construction Engineering Co., Ltd.
223	Chengdu Wuhou Construction Engineering Co., Ltd. (Xinrui)
224	Sichuan Grei Construction Engineering Co., Ltd.
225	Chengdu Urban Investment Construction Technology Investment Management Group Co., Ltd.
226	Sichuan Yiyu Steel Structure Engineering Co., Ltd.
227	Sichuan Changxin Construction Engineering Co., Ltd.
228	China Railway Second Bureau Third Engineering Co., Ltd.
229	Sichuan Zhongjian Jianye Engineering Co., Ltd.
230	Zhongxin Green Construction Holding Co., Ltd.
231	Chengdu Construction Decoration and Renovation Co., Ltd.
232	Chengdu Xindingde Technical Service Co., Ltd.
233	Chengdu Pinzhai Decoration and Renovation Engineering Co., Ltd.
234	Chengdu Xingtiancheng Green Building Technology Co., Ltd.
235	Chengdu Dehe Construction Engineering Quality Inspection Co., Ltd.
236	Sichuan Jinbei Construction Engineering Co., Ltd.
237	Zhongsheng Shengbo Group Co., Ltd.
238	Sichuan Shentong Construction Engineering Co., Ltd.
239	Sichuan Xiangyangtong Construction Engineering Co., Ltd.
240	Sichuan Shuyang Waterproof Engineering Co., Ltd.
241	Chongqing Three Gorges Financing Guarantee Group Co., Ltd. Chengdu Branch
242	Sichuan Junyang Construction Group Co., Ltd.
243	Zhongrong Guocheng Construction Co., Ltd.

Table Continued.

No.	Companies' Identification
244	Sichuan Biaosheng Construction Engineering Co., Ltd.
245	Sichuan Zhixin Construction Engineering Co., Ltd.
246	Sichuan Zhongxin Housing Green Intelligent Building Engineering Co., Ltd.
247	Sichuan Zhiwei Construction Engineering Co., Ltd.
248	Chengdu Ruicheng Highway Survey and Design Co., Ltd.
249	Fuli Construction Group Co., Ltd.
250	Sichuan Desheng Construction Engineering Co., Ltd.
251	Huihong Construction Group Co., Ltd.
252	China Nineteen Metallurgical Group Co., Ltd.
253	China Railway First Bureau Group Construction Installation Engineering Co., Ltd.
254	Wanbiao Construction Group Co., Ltd.
255	China Construction Eighth Engineering Bureau Co., Ltd.

Note: Retrieved September 2023. All information adapted from (CCIA, 2023).

APPENDIX F
RESULT OF SEMI-STRUCTURED EXPERT INTERVIEW WITH 7 BIM EXPERTS IN CHENGDU

Result of Semi-structured Expert Interview With 7 BIM Experts in Chengdu

Result of Interview with Expert Donghe Lv (Company Owner)

Interview Topics: The Study on barrier factors for the application of BIM technology in Chengdu's Medical Building Construction Projects (MBCPs).

Interviewee: Donghe Lv

Data & Location: On September 20, 2023, via the "Tencent Meeting" online meeting platform.

Summary of Interviews

1. Personal Information

Expert Lv's name is Donghe Lv, and he is 31 years old and has a bachelor's degree. He currently serves as the Deputy Director of the Intelligent Construction Center at Hope College of Southwest Jiaotong University. He oversees two companies, Sichuan Lingke Bomu Architecture Technology Co., Ltd. and Sichuan Chuangzhi Future Digital Technology Co., Ltd., both dedicated to advancing BIM technology research and offering technical consulting services to architectural and design entities. With eight years of industry experience, His teams have successfully completed approximately 100 projects, focusing on housing construction, bridges, and BIM technology training. They have significantly contributed to the construction of three large-scale Sino-Hospital projects using BIM technology and have undertaken comprehensive projects like the Semiconductor Industrial Park. Additionally, they provide BIM technology training for university faculty in China and engineers from major state-owned construction enterprises. He also holds a level 2 senior engineer certificate in architecture from BIM.

2. Main Barrier Factors to Applying BIM in Chengdu's MBCPs

The owner's goal of applying BIM technology in the early stage is not clear.

Not applying BIM technology in the whole life cycle; if only BIM technology is involved in the construction stage, it will increase the pressure of using BIM technology.

Difficulties in collaboration between different 3D modeling software and problems in model information transfer.

3. Cost Factors (CF) for barriers to Applying BIM in Chengdu's MBCPs

The investment in software and hardware based on the application of BIM technology in the early stage of the project will be relatively high. These costs are controllable for large projects, but for small and medium-sized projects, these costs are not controllable.

Through about two months of short BIM training, the ability of the relevant students of BIM technology, in fact, cannot only meet part of their professional needs but also need a longer learning time in order to master the entire process of BIM applications.

A large construction project outsourcing BIM technology may cost about three million Chinese Yuan (CNY), which will result in a waste of costs.

4. People Factors (PF) for barriers to Applying BIM in Chengdu's MBCPs

Lack of proper understanding of BIM technology. Most building managers think of BIM technology as flashy and just a simple 3D model.

Lack of experts who understand both BIM technology and construction management to unify and coordinate the overall project process.

Lack of much BIM training. BIM training with depth is now scarce in the community, and almost all courses are of the simplest pure modeling courses.

5. Technical Factors (TF) for barriers to Applying BIM in Chengdu's MBCPs

The synergy and transfer functions between different BIM software programs are inconvenient, resulting in significant interoperability issues.

This inconvenience in the synergy and transfer between BIM software leads to substantial barriers, causing a deficiency in the flow of BIM information.

Incorporating BIM engineers into the existing process management of a construction company marks a significant shift in coordinating multi-party work and introducing complex procedures. This change often results in unclear or confused responsibilities for BIM engineers and poor collaboration among different professions.

No single software fully supports all BIM technology processes, making the application of BIM technology time-consuming and complicated.

6. Organizational Factors (OF) for barriers to Applying BIM in Chengdu's MBCPs

Traditional bidding methods (BIM technology requires special contract formats and bidding conditions).

The structure of BIM courses in Chinese universities is actually imperfect, and there are few BIM courses for each specialized sub-division, which has yet to be corrected.

The application standards and related regulations of BIM technology are actually imperfect, as it takes time to improve gradually.

Result of Interview with Expert Shuchao Xu (Company Owner)

Interview Topics: The Study on barrier factors for the application of BIM technology in Chengdu's Medical Building Construction Projects (MBCPs).

Interviewee: Shuchao Xu

Data & Location: On September 21, 2023, via the "Tencent Meeting" online meeting platform.

Summary of Interviews

1. Personal Information

Expert Xu's name is Shuchao Xu, and he is 29 years old. He has a bachelor's degree, majoring in civil engineering. His current company is Sichuan Golden Tiling Shuhui Technology Co., Ltd. He serves as the general manager. He has the BIM Level 1 Certificate and Level 2 Architectural Specialty Certificate from the China Graphics Society (CGS), and this is my eighth year of working in BIM technology. His company was founded in 2020 and has been established for three years this year. They have done ten construction projects in total and applied BIM technology in two MBCPs.

2. Main Barrier Factors to Applying BIM in Chengdu's MBCPs

Although our country has certain policy support, most of the construction and policy implementation are not in place.

There is a lack of fully specialized BIM experts who understand BIM technology and also have a strong ability to manage the construction site.

The management of many construction companies for the BIM technology is not enough to recognize.

3. Cost Factors (CF) for barriers to Applying BIM in Chengdu's MBCPs

The implementation of BIM technology incurs significant expense costs. For example, the purchase cost of genuine BIM software, customized development of BIM platforms and BIM plug-ins, and hardware costs such as BIM workstations.

BIM users need a lot of time on actual BIM projects before they can master BIM technology, which also increases the cost of learning BIM technology for individual or corporate employees.

4. People Factors (PF) for barriers to Applying BIM in Chengdu's MBCPs

Lack of skilled BIM experts. In other words, there is a lack of composite talents who understand both BIM technology and construction management.

Lack of proper understanding of BIM technology. BIM is a management tool, not only a model.

Lack of BIM training. Currently, only large construction companies have specialized BIM training.

Lack of proper understanding of the benefits of BIM. Thus, the goal and scope of applying BIM technology is not known, and there should be more publicity of real cases.

5. Technical Factors (TF) for barriers to Applying BIM in Chengdu's MBCPs

There are problems with interoperability and compatibility between different BIM software, such as barriers to the exchange of BIM models between various BIM platforms and software.

The roles and responsibilities of BIM engineers in the project may be unclear, leading to collaborative work problems. BIM engineers do not fit well into traditional project management processes or management styles.

Difficulty in converting data between different BIM platforms. Importing and exporting BIM models often encounters problems, either there is not a good file format to import the model, or some components are missing or incompletely displayed.

6. Organizational Factors (OF) for barriers to Applying BIM in Chengdu's MBCPs

Traditional contracting methods are not conducive to the promotion of BIM technology, which requires special bidding conditions.

Resistance to new technologies by old experts in the construction industry, such as old designers, who have gotten used to traditional work habits and are reluctant to change.

China's universities lack professional-level courses on BIM technology. The BIM expertise of most teachers is not yet comparable to that of large buildings.

Poor implementation of government support. Moreover, every region has its own individual BIM standards, and there's no way to try down standardized BIM construction across the country.

Result of Interview with Expert Xiaoping Xiang (Company Owner)

Interview Topics: The Study on barrier factors for the application of BIM technology in Chengdu's Medical Building Construction Projects (MBCPs).

Interviewee: Xiaoping Xiang

Data & Location: On September 25, 2023, via the "Tencent Meeting" online meeting platform.

Summary of Interviews

1. Personal Information

Expert Xiang's name is Xiaoping Xiang. He is 51 years old, and He has a bachelor's degree. His current company is Shenzhen Bodxy Construction Group Co., Ltd, Sichuan Branch. His title is senior engineer, and his position is deputy general manager; he has been engaged in BIM work for five years. He has obtained the Level 1 BIM certificate and the Level 2 BIM certificate of architectural specialty from the Institute of Graphic Arts. The company was founded more than 20 years ago. In total, they have applied BIM technology in more than 20 engineering projects and two MBCPs. One project is in Sichuan, and the other one is in Shaanxi.

2. Main Barrier Factors to Applying BIM in Chengdu's MBCPs

There is insufficient understanding of the benefits of BIM technology.

There are barriers to interaction between different BIM software and problems with interoperability and compatibility between software.

There is also insufficient support from relevant policies, which leads to the poor popularization of BIM technology.

Also, most of the executives of construction companies do not pay enough attention to BIM technology, which leads to a lack of capital investment in BIM technology; he thinks these aspects still need to be strengthened.

3. Cost Factors (CF) for barriers to Applying BIM in Chengdu's MBCPs

The application of BIM technology incurs high costs. For example, the cost of purchasing such software, as well as secondary development for specialized software, network databases, and intelligent hardware facilities on the construction site.

The time cost of learning BIM software is very high. BIM technology is not only a particular software but also requires continuous, in-depth learning.

4. People Factors (PF) for barriers to Applying BIM in Chengdu's MBCPs

Lack of proper understanding of BIM technology. Most people think that BIM is all about the model and don't realize that it's the BIM-added information and data needed to manage the project that is most important.

There is a lack of skilled, all-specialized BIM experts. There are very few people who understand both BIM technology and on-site construction management.

Lack of support from company executives and client needs. A virtuous cycle cannot be created.

Lack of BIM training. With less BIM training, people may not recognize the importance of BIM technology.

5. Technical Factors (TF) for barriers to Applying BIM in Chengdu's MBCPs

Collaboration and communication problems, unclear roles and responsibilities. Because of the integration of BIM into pre-existing workflows, there is also a need to adapt to challenges to legacy and collaborative working models.

The BIM process is relatively time-consuming and cumbersome. Because the modeling and some specific data extractions are still compared with the traditional CAD, the time cost and cost are much higher.

6. Organizational Factors (OF) for barriers to Applying BIM in Chengdu's MBCPs

Chinese universities do not offer comprehensive professional-level BIM technology courses. They are generally simple modeling tutorials. 2.

Traditional bidding methods can hinder the development of BIM technology. There are no special contracts and conditions open to BIM technology.

Social resistance to new technologies. For example, design institutes are very resistant to changing their working model as their design costs have not increased.

Lack of government support. Although the state advocates the application of BIM technology, there are application standards and specifications for the application of BIM technology in various places, and they are all still inconsistent.

Result of Interview with Expert Kun Li (BIM User)

Interview Topics: The Study on barrier factors for the application of BIM technology in Chengdu's Medical Building Construction Projects (MBCPs).

Interviewee: Kun Li

Data & Location: On September 12, 2023, via the "Tencent Meeting" online meeting platform.

Summary of Interviews

1. Personal Information

Expert Li's name is Li Kun, and he is 27 years old. The level of education is a college diploma. Currently working in Sichuan Highland Engineering Design and Consulting Co. Engaged in BIM-related work for five years of time, obtained a BIM level 1 certificate from the Institute of Graphic Arts and a certificate of practice from the second level of construction professionals. Our company was founded in 2010. We have 13 years of experience, and during this period, we have done 33 projects, of which there are 5 MBCPs throughout the application of BIM technology.

2. Main Barrier Factors to Applying BIM in Chengdu's MBCPs

Deep application of BIM technology, the project's upfront cost is relatively high.

Lack of BIM technology for a large number of composite talents.

MBCPs have multiple specialized subcontractors, which makes it more difficult for BIM engineers to communicate with each other at work.

3. Cost Factors (CF) for barriers to Applying BIM in Chengdu's MBCPs

The upfront investment for deep application of BIM technology is high. For example, the cost of BIM software, BIM workstations secondary development of BIM plug-ins, and so on are relatively high.

The cycle of learning BIM technology is relatively long and costly. For most companies, BIM training is only one to two weeks; this cost is almost a hundred thousand dollars. Because BIM is not just software, the follow-up also needs a long time to learn professional knowledge and a series of other specialized software.

4. People Factors (PF) for barriers to Applying BIM in Chengdu's MBCPs

Lack of proper understanding of BIM technology. BIM technology is just a management tool, not just a 3D model and a particular software.

Lack of skilled BIM experts. Most of society either only knows BIM technology or only knows construction management, and few composite talents know both technologies at the same time.

Lack of application needs of company leaders and clients. Customers may have a lack of understanding of BIM technology and related knowledge, and they may not be willing to apply BIM technology. It also indirectly leads to the lack of support from company leaders, which carries on leading to a significantly reduced demand for the application of BIM technology.

Lack of proper BIM training. Currently, the only BIM technology training is in schools and BIM training organizations, which are short and simple tutorials. Only large construction companies conduct more specialized BIM training.

Insufficient understanding of the benefits of BIM technology. Most owners do not know much about BIM technology; they do not know clearly what BIM technology can do. What results can be achieved?

5. Technical Factors (TF) for barriers to Applying BIM in Chengdu's MBCPs

There are problems with interoperability and compatibility between different BIM software; there are many types of BIM software, such as Revit, Tekla, and Bentley modeling software; Fuzor, Lumion, and 3Ds Max animation software; and some local Chinese-related software, such as Quanta, etc. Some BIM software are not compatible with each other. For example, some BIM software data is not interoperable, so Inability to reuse the same BIM model.

As BIM engineers collaborate with other professionals, the roles and responsibilities are not very clear. The current project management process is still the traditional management style, and no changes have been made, so BIM engineers are still in a relatively awkward position, and it will take time to change the status quo.

Complex BIM software and tools, as well as the BIM process, is both time-consuming and cumbersome. If in-depth application is required, BIM modeling, key information collection and analysis, post-rendering, etc. are relatively complex and take a long time.

Data conversion between different BIM platforms, especially lightweight ones, is problematic. These platforms often rely solely on IFC for model parsing, leading to data loss and incomplete model displays.

6. Organizational Factors (OF) for barriers to Applying BIM in Chengdu's MBCPs

Traditional bidding methods are also a hindrance. Because BIM technology requires special bidding conditions and contracts.

Result of Interview with Expert Yuhui Li (BIM User)

Interview Topics: The Study on barrier factors for the application of BIM technology in Chengdu's Medical Building Construction Projects (MBCPs).

Interviewee: Yuhui Li

Data & Location: On September 12, 2023, via the "Tencent Meeting" online meeting platform.

Summary of Interviews

1. Personal Information

Expert Li's name is Yuhui Li, and he is 27 years old with has a bachelor's degree. He has been engaged in BIM-related work for 5 years, and the company I'm currently working for is Sichuan Jingzhi Enterprise Management Limited Liability Company. My position is BIM electromechanical engineer, and now I have obtained the certificate of Level 2 electromechanical professional BIM senior engineer from the Graphic Society. In addition, this year is the third year of the establishment of our company, having done 2 MBCPs and then applying BIM technology.

2. Main Barrier Factors to Applying BIM in Chengdu's MBCPs

Collaboration, communication issues, and unclear roles and responsibilities significantly. Complicate the installation of Mechanical and Electrical (M&E) pipelines in medical buildings. The complexity arises when various professional subcontractors fail to accurately convey technical instructions to on-site workers, leading to deviations from the construction plan. Such missteps result in construction errors that disrupt the work of other specialties and necessitate rework due to misaligned construction sequences. Consequently, this undermines the effective implementation of plans issued by BIM engineers, thereby diminishing the perceived advantages of BIM technology.

3. Cost Factors (CF) for barriers to Applying BIM in Chengdu's MBCPs

The application of BIM technology incurs relatively high upfront costs. For example, hiring relevant BIM staff, purchasing relevant BIM software and BIM workstations, and other hard expenses.

4. People Factors (PF) for barriers to Applying BIM in Chengdu's MBCPs

Lack of proper understanding of BIM technology. More people think that BIM is just ornamental 3D modeling.

Lack of all-around BIM experts. BIM experts may be better at customizing BIM implementations. At the same time, the cost of recruiting such BIM talent is still relatively high.

Lack of support from the company's leadership or customer needs.

Lack of proper BIM training. Currently, only large construction companies have specialized BIM training.

5. Technical Factors (TF) for barriers to Applying BIM in Chengdu's MBCPs

Poor interoperability and compatibility between different BIM software. For example, Platforms BIM models imported into lightweight BIM platforms can result in the loss of some components or other problems, such as the original polysurface model becoming deformed.

BIM engineers often encounter challenges in collaboration and communication, compounded by unclear roles and responsibilities. It is not uncommon for engineers initially responsible for structural and architectural aspects to be tasked with creating BIM models for MEP (Mechanical, Electrical, and Plumbing) or facade systems, impacting the effectiveness of BIM technology implementation. Additionally, the MEP sector's complexity, encompassing specialties like HVAC, water supply and drainage, and low-voltage systems, places considerable pressure on BIM engineers due to the need for coordination with multiple specialty leads.

Complex BIM software and tools, plus the BIM process, are both time-consuming and cumbersome. If one wants to apply BIM technology deeply, one needs not only modeling software but also a series of subsequent software to cooperate with each other to achieve the goal of a good application.

6. Organizational Factors (OF) for barriers to Applying BIM in Chengdu's MBCPs

The traditional project bidding model can hinder the application of BIM technology. This is because BIM continues to require special bidding conditions and contracts.

Social and customary resistance to change and innovative technologies. Some old experts still prefer the traditional working model.

China's higher education lacks specialized courses in BIM technology. The university programs are simple tutorials that, if improved, could also increase the employment rate of students.

Lack of national support and relevant laws and regulations or incentives. Because each region has unique BIM standards, it is hard to achieve uniformity, and it's hard to really go for standardized construction across the country.

Result of Interview with Expert Shiheng Guo (BIM User)

Interview Topics: The Study on barrier factors for the application of BIM technology in Chengdu's Medical Building Construction Projects (MBCPs).

Interviewee: Shiheng Guo

Data & Location: On September 18, 2023, via the "Tencent Meeting" online meeting platform.

Summary of Interviews

1. Personal Information

Expert Guo's name is Shiheng Guo, and he is 26 years old. His level of education is a college diploma. The current company is Shanghai Huizhijian Construction Consultant Co. The position is an electromechanical major BIM engineer. Then, I have five years of experience in BIM. At present, I hold a junior BIM level 1 certificate. Our company was founded 12 years ago, and our company has been applying BIM technology for about two years, so our company is now applying BIM technology for only two MBCPs.

2. Main Barrier Factors to Applying BIM in Chengdu's MBCPs

He believes that the main obstacle at present is the application of BIM technology needs to be invested in the early stage of the prohibitive cost, for example, the staff of the BIM technology training, as well as some of the genuine BIM software, BIM plug-ins, and BIM workstations as procurement.

3. Cost Factors (CF) for barriers to Applying BIM in Chengdu's MBCPs

The initial investment in applying BIM technology is too high. In addition to the point just mentioned, there is also the issue of personnel salaries. The cost of recruiting some skilled BIM experts and consultants will be higher.

In addition to the training required for BIM technology, the cost is higher, and the learning time is longer. Because it takes a long time to learn and gain experience with BIM technology.

4. People Factors (PF) for barriers to Applying BIM in Chengdu's MBCPs

Lack of proper understanding of BIM technology. Most people think that BIM is just a model for promotional purposes.

Lack of skilled BIM experts. Such talents are still scarce, and it is hard to find people who understand BIM and construction management.

Lack of customer demand and company executive support. Because clients and executives do not know enough about BIM technology, it leads to a lack of demand for its use.

Lack of proper BIM training. Currently, in-depth BIM training is only available in large state-owned construction companies.

5. Technical Factors (TF) for barriers to Applying BIM in Chengdu's MBCPs

Collaboration and communication, plus unclear roles, and responsibilities. Most of the projects still adhere to the traditional construction management process, so it leads to BIM engineers in the work their own work positioning, and their responsibilities are not particularly clear, easy to confusion; there is still room for improvement.

Complex BIM software and tools + processes are both time-consuming and cumbersome. Because BIM technology is not just a certain software, it is necessary to use multiple specialized software with each other to achieve the goal, so it will be more time-consuming and cumbersome.

There are some barriers to the exchange of information in BIM technology. Currently, he uses the BIM platform, and the model and related data can only be uploaded; if you want to export from the platform to other modeling software, there are some barriers.

6. Organizational Factors (OF) for barriers to Applying BIM in Chengdu's MBCPs

The traditional way of bidding for projects can hinder the application of BIM technology, which requires special bidding conditions and contracts. This problem can be overcome at the source by a policy of adding a few points to the score of construction companies that use BIM technology at the bidding stage.

Chinese universities do not offer more comprehensive courses on BIM technology, and most of the courses offered are extremely basic, focusing more on how to do basic modeling with BIM software.

Lack of government support and stimulation of relevant laws and regulations, as well as insufficient BIM standards. Because the current national level is more to advocate the application of BIM technology, each province will have its own corresponding regional BIM specification; it is difficult to form a unified standard within the industry.

Result of Interview with Expert Gang Wang (University Teacher)

Interview Topics: The Study on barrier factors for the application of BIM technology in Chengdu's Medical Building Construction Projects (MBCPs).

Interviewee: Gang Wang

Data & Location: On September 23, 2023, via the "Tencent Meeting" online meeting platform.

Summary of Interviews

1. Personal Information

Expert Wang's name is Gang Wang, he is 46 years old, and he has a master's degree. He is currently working in the School of Civil and Architectural Engineering of Panzhihua College as an associate professor, and he is also the head of Panzhihua BIM Engineering Technology Research Center, which is a scientific research platform in Panzhihua City. He is usually engaged in scientific research on BIM technology, and he has been involved in BIM technology research for five years now. The university was founded in 1983 and has a history of 40 years. They have done about fifteen construction projects in total, and they have applied BIM technology in 4 MBCPs.

2. Main Barrier Factors to Applying BIM in Chengdu's MBCPs

He identifies the primary challenge in adopting BIM technology as stemming from the project management team's perspectives. Many project managers believe that their current professional capabilities and management teams are sufficient for completing MBCPs without the additional expense of hiring BIM teams. Furthermore, even when BIM teams are employed, the aim often is not to leverage BIM technology to its fullest potential but rather to meet owner requirements or pursue awards.

3. Cost Factors (CF) for barriers to Applying BIM in Chengdu's MBCPs

The implementation of BIM technology increases direct costs, such as paying the salaries of the BIM team or paying for BIM services. Thus, the perception of BIM technology's high implementation cost remains a significant barrier despite its potential for long-term efficiency and improvement.

The training costs and learning curve are too high. Learning BIM technology does not happen overnight; Studying BIM software skills and expertise takes a long time.

4. People Factors (PF) for barriers to Applying BIM in Chengdu's MBCPs

Lack of proper understanding of BIM technology. For example, most project managers think that BIM technology is dispensable because they do not understand the importance of BIM technology.

Lack of all-round BIM experts: BIM engineers need to be able to create BIM models, integrate BIM models and related data perfectly, use BIM technology to solve practical problems on the construction site, and have strong management and coordination skills.

Lack of support from executives and client needs. Most project managers believe that existing technologies and management processes can already meet management needs, leading to reluctance to use innovative technologies.

Lack of proper BIM training. At present, most people who learn BIM technology are still in the introductory courses known in the university; advanced courses in the community are also challenging to have the opportunity to learn.

5. Technical Factors (TF) for barriers to Applying BIM in Chengdu's MBCPs

Interoperability and Compatibility Issues. Different BIM software often struggles with seamless integration, complicating the analysis or calculation of 3D models across various specialized platforms.

BIM Engineer Collaboration and Communication + Roles and Responsibilities. Integrating BIM engineers into conventional project management frameworks is challenging, necessitating modifications to management practices for enhanced collaboration and clarity in roles.

The complexity of BIM Software/Tools and Processes. The extensive time requirements for BIM modeling, post-rendering, program design, and adjustments stem from the complexity of the software and the necessity for in-depth knowledge for practical application. Despite these challenges, BIM technology can significantly reduce design errors at the source.

6. Organizational Factors (OF) for barriers to Applying BIM in Chengdu's MBCPs

Traditional contracting methods can hinder the promotion of BIM technology, which requires special bidding conditions and contracts at the bidding stage. Nowadays, some large-scale public infrastructure projects in China, especially those focusing on airport projects, require bidders to provide implementation plans for BIM technology during the bidding stage.

Chinese universities lack professional-level courses on BIM technology. Even though some universities offer specialized courses related to BIM technology, they are general introductory BIM courses and do not vary according to the specialties studied.

Lack of government support, relevant regulations and incentives, and inadequate BIM standards. Moreover, BIM standards are not harmonized across regions.

APPENDIX G

THE RAW DATA OF ONLINE QUESTIONNAIRE SURVEY

The Raw Data of Online Questionnaire Survey

The following table shows the 131 valid questionnaires recovered from (Manager, Design, and Engineer) of 48 companies for this study.

No.	Part I																						Part II							Part III											
	1	2	3	4	5	6	7	8															9	10	11	12	13	14	15	16											
								1	2	3	4	5	6	7	8	9	10	11	12	13	14	15								CF		PF				TF			OF		
																														1	2	1	2	3	4	1	2	3	1	2	3
1	1	2	3	3	3	1	2	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	2	1	1	1	1	6	4	4	5	5	5	5	5	5	5	5	5	5
2	2	3	4	3	3	1	5	1	1	0	1	1	0	0	0	0	0	0	0	0	1	0	4	4	3	3	3	2	3	4	4	4	5	4	4	5	4	5	5	5	5
3	1	2	3	3	2	2	2	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	2	2	1	1	1	1	6	4	4	4	3	4	4	5	5	5	1	3	3
4	1	2	3	3	3	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	1	1	1	6	4	4	4	4	4	4	5	5	5	4	4	4
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6	1	3	3	1	4	1	5	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	4	3	3	2	3	2	3	5	5	3	5	3	5	5	5	5	5	5	5
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9	1	2	2	2	2	1	5	1	1	1	1	1	0	0	1	0	1	0	0	0	1	0	4	4	3	4	5	4	5	4	4	5	4	5	5	5	5	4	4	4	4
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14	2	2	3	2	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	1	1	1	6	4	4	5	4	5	4	5	5	4	4	4	4
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Table Continued.

No.	Part I																						Part II							Part III											
	1	2	3	4	5	6	7	8															9	10	11	12	13	14	15	16											
								1	2	3	4	5	6	7	8	9	10	11	12	13	14	15								CF		PF				TF			OF		
																														1	2	1	2	3	4	1	2	3	1	2	3
17	1	3	4	1	3	1	5	1	1	1	0	1	0	0	0	0	1	0	0	0	0	0	3	3	3	3	4	2	4	4	4	2	3	3	3	4	3	4	4	4	3
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Table Continued.

No.	Part I																						Part II							Part III											
	1	2	3	4	5	6	7	8															9	10	11	12	13	14	15	16											
								1	2	3	4	5	6	7	8	9	10	11	12	13	14	15								CF		PF				TF			OF		
																														1	2	1	2	3	4	1	2	3	1	2	3
37	1	2	3	3	2	2	4	1	1	1	1	1	0	0	0	1	0	1	1	1	0	0	3	4	2	3	3	4	3	4	4	4	4	4	4	4	4	4	4	4	4
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52	2	2	3	2	2	2	2	1	1	1	1	1	0	1	0	1	0	1	1	1	0	0	3	4	2	2	3	3	3	3	4	4	3	4	4	5	5	5	3	3	3
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Table Continued.

No.	Part I																						Part II							Part III											
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																														1	2	1	2	3	4	1	2	3	1	2	3
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69	1	3	3	3	4	1	6	1	1	1	1	0	0	1	0	1	1	1	1	0	0	0	4	4	4	4	5	2	4	4	4	5	4	4	4	4	4	4	5	4	5
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72	1	3	4	3	3	1	6	1	1	1	0	1	0	1	0	1	1	1	1	0	0	0	4	4	3	3	5	3	4	4	4	5	5	5	5	4	4	4	4	4	4
73	1	4	5	1	4	1	6	1	1	1	0	1	0	1	0	1	0	1	1	0	0	0	3	3	3	3	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5
74	1	3	4	2	3	1	6	1	1	1	0	0	1	1	0	1	1	1	1	0	0	0	4	4	3	3	4	2	4	5	4	5	4	5	5	4	4	4	5	4	5

Table Continued.

No.	Part I																						Part II							Part III											
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																														1	2	1	2	3	4	1	2	3	1	2	3
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80	1	3	3	2	4	2	1	1	0	0	0	0	1	0	0	0	0	1	1	0	0	0	2	2	1	1	1	1	6	4	5	5	4	5	4	5	5	5	5	4	5
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No.	Part I																						Part II							Part III											
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																														1	2	1	2	3	4	1	2	3	1	2	3
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105	1	2	3	3	3	1	6	1	0	0	0	0	0	0	0	0	0	1	1	1	0	0	2	2	1	1	1	1	6	3	4	3	4	4	5	3	1	3	5	5	5
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Table Continued.

No.	Part I																						Part II							Part III											
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																														1	2	1	2	3	4	1	2	3	1	2	3
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