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APPLICATION OF BIM IN MEDICAL BUILDING CONSTRUCTION PROJECTS: BARRIER FACTORS AND SOLUTION STRATEGIES: A CASE STUDY OF CHENGDU MEDICAL BUILDING CONSTRUCTION PROJECT

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Research Paper

Abstract: *In recent years, the use of BIM software in clinical building tasks has been paid greater and extra attention. Taking Chengdu's scientific development mission as an example, this paper discusses the utility of BIM in scientific building projects and researches the impediment elements and answer strategies. This paper makes use of semi-structured interviews and literature evaluations to evaluate every influencing aspect earlier than by conducting quantitative research. After amassing facts via qualitative methods, an online questionnaire survey was once built in accordance with the interview consequences and previous lookup papers, and a number of factors blanketed in the online questionnaire had been comprehensively explained, and the software state of affairs and present issues of Building Information Modeling (BIM) in scientific development tasks have been summarized. The consequences of the lookup exhibit that the predominant boundaries to the positive adoption of BIM technological know-how in Medical Building Construction Projects (MBCPs) departments in Chengdu are multifaceted. First, issues from collaboration and verbal exchange stand out. These challenges are compounded with the aid of doubtful roles and obligations inside the mission team. This ambiguity now not solely hinders fantastic teamwork but also prevents BIM from seamlessly integrating with present workflows. Second, there are full-size boundaries to interoperability and compatibility problems between exclusive BIM software program applications. This incompatibility creates limitations to the clean alternate of records and data, leading to inefficiencies and plausible blunders in challenge execution. The large range of software programs used at one-of-a-kind degrees*

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of MBCPs exacerbates this problem. Finally, the inherent complexity of BIM software programs and tools, coupled with the time-consuming and cumbersome BIM process, poses a big challenge. This complexity frequently leads to a reluctance amongst stakeholders to embody BIM technology. Given these findings, this study learns about the stage for future lookup and sensible interventions aimed at advertising wider acceptance and the tremendous use of BIM in the Medical Building Industry (MBI) and Construction Industry (CI).

Keywords: *BIM; Medical Building Construction Projects; Barrier factors.*

1. Introduction

The "13th Five-Year Plan" marks a crucial phase for China's goal of achieving a comprehensive well-off society, necessitating the development of a robust basic medical and health system. This initiative is vital for optimizing the allocation of medical resources and influencing the design of medical facilities. As living standards rise, so does the demand for health services, exacerbated by China's large and aging population. This situation presents significant challenges, such as insufficient health resources, an imbalanced structure and distribution, and limited basic service capabilities. Furthermore, Changing illness patterns, environmental factors, lifestyle modifications, and medical technology improvements, in addition to China's economic development, increasing urbanization, industrialization, and an aging population, necessitate substantial medical reform (Migilinskas et al., 2013).

Since the inception of the COVID-19 pandemic in early 2020, there has been a substantial rise in demand for hospital facilities, particularly intensive care units (ICUs), due to its profound influence on the Medical Industry (MI) (Lin et al., 2021). Despite moving into the post-pandemic phase, guidelines from the Joint Prevention and Control Mechanism of the State Council (JPCMSC), issued on January 19, 2023, underline the ongoing need to standardize and prepare ICUs (JPCMSC, 2023). The aforementioned advancements have elevated the standards for the planning, execution, and refurbishment of Medical Building Construction Projects (MBCPs), an essential and swiftly growing industry. MBCPs are responsible for the development of facilities that offer comprehensive medical services (JPCMSC, 2023) These facilities are distinguished by their intricate nature, the need for effective long-term asset management, and the ability to adapt by means of functional restructuring and expansion. This circumstance requires an innovative information management strategy customized to medical projects' particular requirements, including design, building, operation, and maintenance (Bryde et al., 2013).

Furthermore, the satisfaction levels of medical staff (physicians, nurses, and assistants) and stakeholders are significantly impacted by the design of the medical facility, which is, therefore, vital to the success of a campaign (Lin et al., 2018). Moreover, patients' physical and mental recovery is influenced by the architectural and functional design of MBCPs, as well as the energy consumption of hospitals and the productivity of medical staff (Hareide et al., 2016; Mackrill et al., 2017). Conventional design techniques dictate that design teams convey medical design intents to stakeholders and medical practitioners through the use of two-dimensional (2D) CAD drawings and associated materials (Eastman, 2011; Somboonwit & Sahachaisaeree, 2012). Medical experts and stakeholders may find it challenging to comprehend the principles and information illustrated in these two-dimensional drawings due to a lack of technical expertise and experience (Okada et al., 2017). Delays, cost overruns, substandard work quality, design disagreements, and failure to update blueprints are all potential outcomes of ineffective communication, which may also result in design flaws throughout construction. Building specialists are perpetually on the lookout for novel approaches and instruments so that they may successfully address these issues.

The utilization of BIM, which visualizes the entirety of a project's lifecycle from design to construction to operation, has garnered considerable interest in recent times(Mesároš et al., 2020). BIM technology enables collaboration among all project participants, enabling effective information sharing among all project stakeholders (Y. Chen et al., 2020). The significant capacity for improving project quality and efficiency, specifically in the planning and design stages, has been exemplified by the integration of BIM technology into MBCP management. Optimizing overall performance, BIM technology promotes communication and collaboration among project teams (Zhan et al., 2022). Concurrently, a group of researchers constructed a medical FM system that interprets Key Performance Indicators (FM-KPIs) and performs data queries using Big Data Analysis (BDA), BIM, and NoSQL (Not Only SQL) databases (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.

Additionally, Chengdu, the sixth largest city in China with a total population of 21.192 million, is also facing the same problems mentioned above, such as a serious aging population and uneven distribution of quality medical resources (Zou et al., 2024). Therefore, on February 21, 2023, the First Session of the 18th People's Congress of Chengdu City emphasized in the government work report that in order to create a happy Chengdu, 27 major medical projects such as the Downtown Hospital and the Municipal Brain Science Hospital will be started, 10 high-level clinical key specialties will be created, and 15 new district (county) medical sub-centers will be built (Qin, 2015). At the same time, in recent years, Chengdu City has also issued a number of projects to promote the application of BIM technology-related policies actively. The introduction of a series of positive policies highlights Chengdu CI's determination to reform and innovate for development (CBURDB, 2023).

Globally, BIM technology is celebrated for boosting construction project efficiency, with many governments endorsing its use (Liu et al., 2019; Zhou et al., 2019). The primary reasons for the limited integration of BIM into MBCPs in China are the high costs and complexity associated with deployment (Ahmed, 2018). Although the application and study of BIM in healthcare are increasing, there is still a lack of a comprehensive evaluation of the obstacles preventing its widespread adoption among MBCPs. However, the urgent need for contemporary MBCPs in China and the established benefits of BIM in overseeing complex building projects make it a crucial instrument for the Medical Building and Construction sectors. This circumstance emphasizes the crucial importance of investigating the obstacles to the widespread implementation of BIM in Chengdu's MBCPs, a subject with substantial research value.

Therefore, through an in-depth analysis of MBCPs in Chengdu, combined with an online questionnaire for managers, designers, and engineers involved in the projects, this study aims to identify the main barriers affecting the application of BIM technology in local MBCPs. Relative Importance Index (RII) methodology. Finally, the study will propose targeted solutions to guide the diffusion and deeper application of BIM technology in MBCP as well as in the broader Architecture, Engineering, and Construction Industry (AECI) and CI, thus contributing to the digital transformation and industrial upgrading of AECI and CI.

2. Application of BIM in MBCPs

2.1 BIM Overview

BIM technology belongs to a class of advanced three-dimensional (3D) digital technology models; the use of this technology can make the entire project construction and operation of all the data information generated together. All technical engineers of the project unit can use this technology to build an exclusive information platform, so as to use the platform to complete the sharing and exchange of resource data and timely respond to all problems encountered in the construction and operation of the project (Olsson & Hansen, 2010).

2.2 Characteristics of BIM Technology

1) Visualizaton. Nowadays, traditional graphic design can no longer meet the needs of construction projects; BIM technology can model the main body of the building, and then present a more three-dimensional and intuitive model, and then simulate the entire building construction process with strong visualization.

2) Coordination. BIM technology can simulate different schemes and possible risk factors in the entire construction process, which can promote the evaluation of construction project management to be more accurate and scientific and play a certain coordinating role in dealing with the conflict between construction and construction management (Othman & Ahmed, 2013).

3) 5D form BIM technology can not only realize 3D models, but also realize 5D information simulation with time and process to present the life cycle simulation of the entire construction project, which is also impossible to achieve in the past project management (Doulabi & Asnaashari, 2016).

2.3 Application of BIM Technology in All Stages of Engineering

1) Decision-making stage. Project units can use BIM technology to convert the original abstract two-dimensional drawings into three-dimensional visual drawings, and more intuitively understand the medical process and surrounding traffic routes, so as to judge whether the layout design and functional arrangement of the project are scientific and reasonable, promote the

communication and cooperation between the main bodies of the project activities, and improve the design scheme (Khanji et al., 2019).

2) Design phase. The final measurement basis of the whole design stage is still the design blueprint. If only based on the design blueprint, it will limit the cooperation between various majors. In addition, because the amount of engineering drawing data is very large, strict requirements, once a small adjustment will very likely affect other majors, it is difficult for the project unit to carry out effective global management (Reed, 2005). If the traditional project management mode is used for management, the project, as the constructor of the unit, is difficult to directly reflect the functions required by the construction of the phase I project of Chongqing Medical Device Quality Inspection Center into the design drawings when undertaking complex construction projects, so there are obstacles in communication with the designer (Haiduven, 2009). In the past, when the project unit encountered this problem, it was necessary to design the corresponding model room for the key functional rooms in advance. In the course of repeated visits, analysis, and discussion, the various organization personnel of the hospital constantly adjusted the layout process of the model room, which seriously delayed the construction period and increased the workload (Kapelusz-Poppi, 2001). However, if BIM technology is used, all professional models can be directly integrated, and the omissions in cooperation between professionals can be directly identified, and timely modifications can be made (Al-Momani, 2000).

3) Project preparation and implementation phase. The following points are included in the project preparation and implementation phase:

(1) Cost control, that is, the project unit uses BIM technology to plan the construction route and allocate the construction process in advance and can also calculate the equipment and materials required for construction in advance, scientifically allocate all construction contents, and strictly control the application of equipment and materials in the construction process (Al-Momani, 2000).

(2) Quality and safety control. Because the project contains multiple professional projects, which are highly professional, the division of labor in each region is clear, the installation and connection problems in each region are inconsistent, and close linkage between various departments is required. If BIM technology is used, various resources can be effectively coordinated, and all work can be arranged in advance (Al-Momani, 2000).

(3) Schedule control. Project units using BIM technology for management can effectively link up various work, scientifically allocate the construction period of each process, pay attention to optimization, and make the design scheme more scientific and efficient.

(4) Site construction guidance. In the case of complex projects, it is often difficult for construction personnel to understand and easy to make mistakes. However, BIM technology can be used to construct corresponding models through visualization technology, promote the visualization of pre-shift disclosure, and facilitate the orderly development of various works (Al-Momani, 2000).

3. Research on obstacles to the application of BIM in MBCPs

3.1 Study Design

3.1.1 Research framework

The study's research framework is shown in Figure 1.

3.1.2 Research purpose

This study has been carefully designed to provide a comprehensive and clear exploration of the application of BIM technology in the MBCPs, with a focus on finding key barrier factors of Chengdu's MBCPs application BIM technology and propose robust technical strategies for adoption in the industry. The goals of the study are multifaceted:

(1) The study aims to identify and describe the challenges and obstacles encountered in the deployment of BIM technology in MBCPs in Chengdu. This will be achieved through a questionnaire designed systematically to provide a comprehensive understanding of key barriers.

(2) Effective integration of BIM technology in Chengdu's MBI to formulate and put forward pragmatic-oriented strategic suggestions. This will include tailored strategies to overcome identified challenges and harness the benefits of the technology, thus paving the way for its successful implementation.

3.2 Research methods

A combination of qualitative and quantitative methods was used to achieve the objectives of the study. The specific application is as follows.

3.2.1 Qualitative research

The qualitative research component of this study employed a literature review to examine the potential barriers to BIM technology in the medical building and Architecture, Engineering, and Construction (AEC) industry. Additionally, semi-structured interviews were conducted online with seven BIM experts in Chengdu's MBI to identify potential obstacles affecting the application of BIM technology in Chengdu's MBCPs. After collecting information through qualitative methods, survey studies were constructed based on interview results and past research papers.

3.2.2 Quantitative research

In the quantitative research phase of this study, data was collected through survey questionnaires with the aim of gaining a deeper understanding of the perspectives of managers, designers, and engineers from 48 construction companies that have participated in MBCPs in Chengdu on the barriers to the application of BIM technology in Chengdu's MBCPs. This method facilitates an accurate grasp of industry professionals' true attitudes and views on the obstacles to the promotion and application of BIM technology, providing valuable primary data for the research.

3.3 Questionnaire design

The online questionnaire consists of three sections :(1) the respondents' personal information, (2) BIM expertise, and (3) potential barriers, as shown in Table 1 for questionnaire details. The study used a five-point Likert scale to quantify the importance of hindering factors, ranging from 1= strongly unimportant to 5= strongly important, as shown in Table 2. In this study, these factors were categorized into factor of cost (FC), factor of personal (FP), factor of Technical (FT), and factors of organizational (FO). Each category of factors was translated into specific questionnaire entries to ensure coverage of all the barriers identified by the study.

3.3.1 Research object

The online survey targeted managers, designers, and engineers from 48 construction companies that participated in MBCPs in Chengdu, Sichuan Province, China. A total of 168 individuals from these companies participated in the survey. Chengdu was chosen as the research site because it is an economic and cultural center in southwest China with a rapidly developing MBI. The region faces major challenges in the development of healthcare infrastructure, mainly due to the large scale of projects, the diversity of healthcare facilities, and the fierce competition. Therefore, Chengdu provides an ideal case for an in-depth exploration of the characteristics and challenges of implementing BIM technology in local MBCPs.

3.3.2 Sampling method

The sampling method is purposeful sampling. This non-probabilistic sampling technique is optimal when a large number of individuals have knowledge in the field of study (Tongco, 2007). Purposeful sampling is also compatible with qualitative and quantitative research. Its advantages include accessible and fast data, while its limitations include potential non-representation of the entire population and possible bias of respondents (Barratt et al., 2015).

3.3.3 Data collection methods

The survey was distributed to participants via email and the way the snowball rolls (WeChat). Before filling out the questionnaire, participants are required to read and agree to the following statement: "Your participation is voluntary; Therefore, the information obtained will be kept confidential and used only for research purposes." The Ethics Statement ensures compliance with research ethics. A total of 168 questionnaires were distributed to managers, designers, and engineers of 48 construction companies undertaking MBCPs in Chengdu. All 144 questionnaires were collected, then deleted 13 invalid questionnaires (years of CI's work experience≤ 2 years). 131 valid questionnaires remained, with a recovery rate of 77.98%.

In September 2023, this study meticulously searched for the keywords "Chengdu, hospital, construction, bid-winning" on the "Sichuan Public Resource Trading Information Network." Through this search, a total of 48 construction companies were found to have successfully won bids for MBCPs in the Chengdu area (Sichuan Province General Office of the People's Government, 2023), as shown in Appendix. The “Sichuan Public Resource Trading Information Network,” as a government website in Sichuan Province, China, specifically used for the public tendering of construction projects, provided an important data source for this study. Furthermore, by analyzing the member list of the Chengdu Construction Industry Association, it was determined that there were 280 member construction companies in Chengdu (Chengdu Construction Industry Association, 2023); it ended in September 2023.

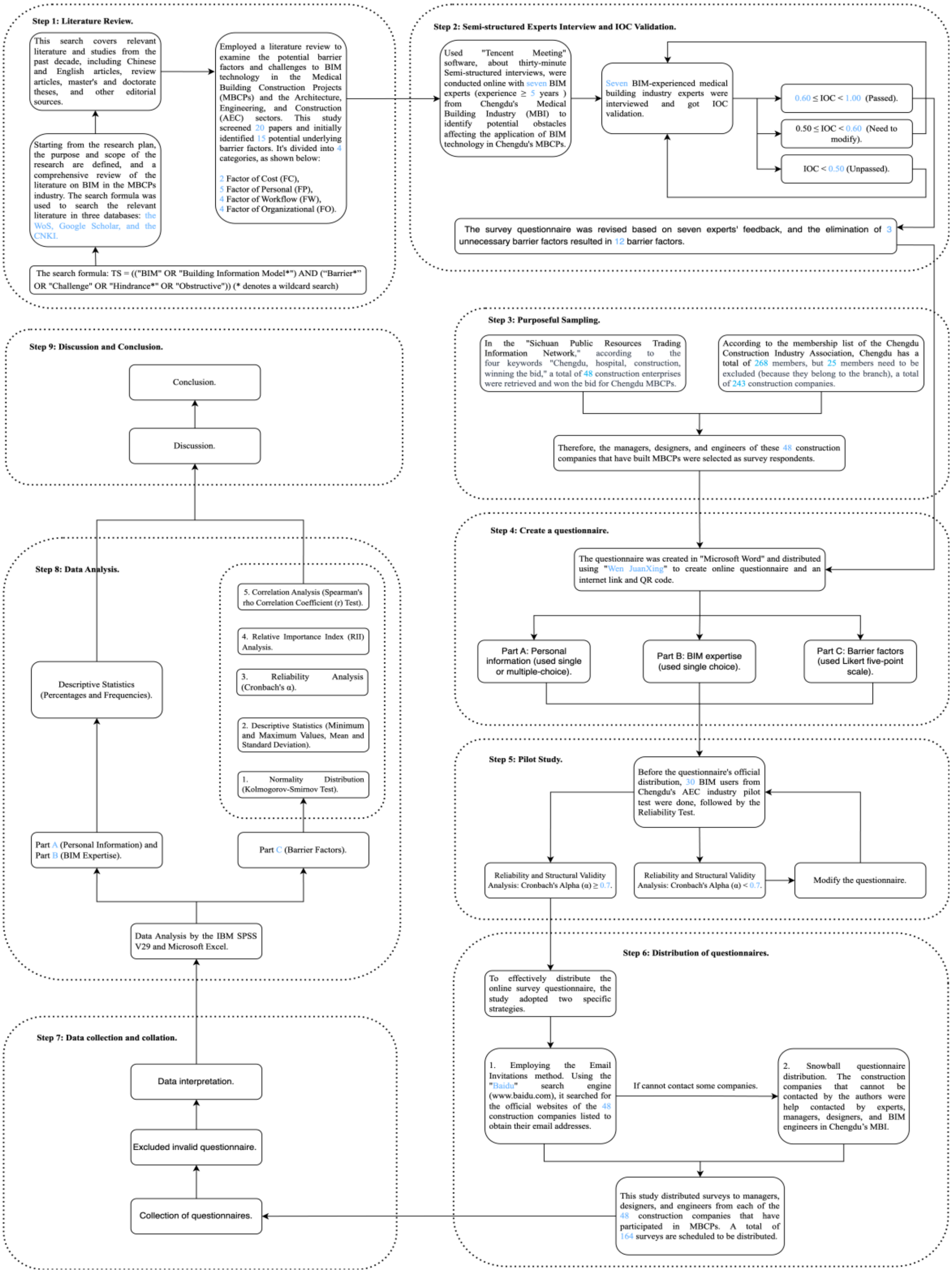

Figure 1. Research framework of the study.

Table 1: 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 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
2.3 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.	15
3.1 Factor of Cost (FC)	2
3.2 Factor of Personal (FP)	5
3.3 Factor of Technical (FT)	4
3.4 Factor of Organizational (FO)	4

Table 2: The Likert five-point scale.

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

However, after excluding 25 members that belonged to branches of the Construction Industry Association, 255 qualified construction companies were ultimately identified. Notably, the majority of these companies are state-owned construction enterprises, and most of them have their own BIM teams or departments, such as BIM centers. These construction companies cover all subdivisions of the CI, including rail transit, municipal engineering, residential construction, and medical building, among others. Therefore, these data can serve as a foundational reference for assessing the BIM technological capabilities of construction companies.

3.3.4 Data analysis methods

In this study, the Social Science Statistical Software Package (SPSS 29) was used, and Microsoft Excel was used for data processing and calculation. The quality of the questionnaire was measured by validity and reliability.

Reliability was assessed using the Cronbach Alpha coefficient, whereas validity was verified using the Implement-objective consistency (IOC). When determining the degree to which all items in a test assess the same concept or construct, Cronbach's Alpha is frequently employed as a reliability coefficient and is a measure of internal consistency (Cronbach, 1951). Indicating better reliability are alpha coefficient values that fall within the range of 0 to 1 and with higher (> 0.60) (Tavakol & Dennick, 2011). Assuring that every item corresponds to the particular cognitive objectives or skills it intends to assess, IOC validation employs expert judgment to assess the content validity of test items (Turner & Carlson, 2003). The Kolmogorov-Smirnov (K-S) test was employed to assess if the data followed a normal distribution and Spearman's rho correlation examined the relationship between each element. Analyzing descriptive data using descriptive statistics like mean, standard deviation, and percentage. Moreover, barrier variables in the questionnaire were ranked utilizing the Relevance Importance Index (RII) (Park et al., 2018)

Cronbach Alpha coefficient was used to evaluate reliability and project-objective consistency (IOC) was used to verify validity. Cronbach's Alpha is a measure of internal consistency, often used as a reliability coefficient to assess the extent to which all items in a test measure the same concept or construct (Cronbach, 1951). The range of the alpha coefficient is from 0 to 1, with higher values indicating greater reliability (Tavakol & Dennick, 2011). IOC validation involves expert judgment to evaluate the content validity of test items, ensuring each item aligns with the specific cognitive objectives or skills it aims to measure (Turner & Carlson, 2003). In addition, the Kolmogorov-Smirnov (K-S) test was used to test for the normal distribution of the data, and Spearman's rho correlation analyzed the association between each factor. Descriptive statistics such as mean, standard deviation, and percentage are used to analyze descriptive data. In addition, the Relevance Importance Index (RII) was used to rank barrier factors in the questionnaire (Park et al., 2018).

3.3.5 Initial identification of possible barrier factors

Figure 1 illustrates the main process of conducting the survey. Currently, there is a scarcity of literature specifically addressing the factors hindering the application of BIM in MBCPs. However, studies on the obstacles to using BIM technology in the CI have been initiated earlier and are more comprehensive. Therefore, this study expands its scope of literature search to not only focus on the MBI but also to refer to related studies in the construction sector.

The study has opted to retrieve literature from three reputable databases: the China National Knowledge Infrastructure (CNKI), Web of Science (WoS), and Google Scholar. Each of these databases possesses unique advantages. The WoS database is a repository recognized for its enormous collection of high-quality English literature (Ding & Yang, 2020). Moreover, the CNKI database was chosen due to its exceptional depth of coverage in the realm of Chinese database offers (Gan et al., 2022). At present, Google Scholar is acknowledged as an outstanding and readily available resource for locating and accessing scholarly information (Jacsó, 2005). The platform provides researchers, educators, and students with an extensive collection of scientific articles, theses, books, and conference papers, thereby promoting the progress of knowledge in a variety of fields. As a collection, these databases provide an extensive and varied assortment of materials, rendering them optimal for the research requirements of this study.

Therefore, this research utilizes the search string: TS = (("BIM" OR "Building Information Model*") AND ("Barrier*" OR "Challenge" OR "Hindrance*" OR "Obstructive")) (* denotes a wildcard search), to conduct a literature search in three databases: WoS, Google Scholar, and the CNKI. This search covers relevant literature and studies from the past decade, including articles and review articles.

This study meticulously screened each piece of collected literature, documenting the key barriers described therein. Based on their frequency of occurrence and the diversity of factors involved, 15 potential hindrances affecting the implementation of BIM in Chengdu's MBI were identified. These have been categorized into four main groups: Factor of Cost (FC), Factor of Personal (FP), Factor of Technical (FT), and Factor of Organizational (FO). The preliminary collation and summary of these factors are presented in Table 2.

3.4 Study and implement

3.4.1 Semi-structured interview

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). 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 interview questions focused on the four dimensions of barrier factors to applying BIM technology in MBCPs (e.g., FC, FP, FT, and FO) 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).

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 (Liu et al., 2019). In conclusion, this study has carefully selected 7 experts with rich experience in applying BIM technology in Chengdu's MBI, including 3 managers, 3 BIM engineers, and 1 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 provided in Table .

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.

3.4.2 Questionnaire survey

A questionnaire survey is a key tool for collecting quantitative data in this study, aiming to identify the main obstacles to the widespread application of BIM technology in MBCPs in Chengdu.

In order to achieve these goals, the methods of semi-structured interviews and literature reviews were used to gather as much in-depth and comprehensive information as possible to address the research questions, and each influencing factor was reviewed before quantitative research was conducted. After collecting information through qualitative methods, survey studies were constructed based on interview results and past research papers. The online questionnaire consists of three sections: (1) the respondents' personal information, (2) BIM expertise, and (3) potential barriers.

The questionnaire is accompanied by a cover letter explaining the purpose of the study and data security to encourage a high response rate. Appendices A and B contain copies of the survey in both English and Chinese (Yu Chen et al., 2020). The questionnaire includes widely used single-choice and multiple-choice questions designed to address the research objectives and gather all key information to support the discussion, results, and recommendations of the research Interview implementation.

3.4.3 Quality control

The quality of the questionnaires will be tested by submitting sample questionnaires to 7 BIM experts in Chengdu's MBI who have more than 5 years of experience in applying BIM technology in MBPCs. They will assess the completeness of the questions and what the questionnaire covers, as well as the respondents' adequate understanding of the topics being measured (Wang et al., 2020). This includes ensuring that the language is readable and understandable to the interviewee. The questionnaire will then be tested for (a) content validity and (b) reliability.

(1) Content validity

Each question in the questionnaire was evaluated by seven experts. For each question, the scores are averaged to calculate the IOC. An IOC of 0.6 or higher for each question is desirable.

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 (Wang et al., 2021).
Content validity formula:

$$IOC = \frac{\sum R}{N} \quad (1)$$

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. How to judge the validity of content. As shown in Table .

As shown in Table 6, following the review by seven BIM experts, the original barrier factors FP5, FT4, and FO2 were removed due to their RII values being less than 0.5. Consequently, a total of 12 potential barrier factors remain.

(2) Measurement Reliability

One of the fundamental requirements of any research paper is to maintain accurate measurements and acceptable results. To achieve this, we 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). It is calculated as follows.

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

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, as shown in Table .

(3) Spearman's rho Correlation Coefficient(r) Test

One of the primary objectives of any research is to maintain accurate results. Therefore, before starting the data analysis, the K-S test was used to test for normal distribution using the statistical software SPSS 29. However, the significance value calculated for the respondents was less than 0.001, which is below the default level of significance (0.05 or 5%). as indicated in Table . Consequently, non-parametric statistical tests will be conducted further.

For this purpose, the research was Spearman's rho correlation coefficient test was utilized to ascertain the results of internal consistency and the strength and direction of the relationship, a number ranging between −1 and +1, as indicated in Table . In this study, the correlation coefficient value ranged from 0.142 to 0.667, suggesting that all items are consistent and valid, indicative of a positive correlation. When one variable changes, the other variables also change in the same direction (Schmid & Schmidt, 2007).

Table 3. The selected BIM barrier factors are based on previous research and expert interviews.

Barriers / **References**		Factor of Cost (FC)		Factor of Personal (FP)					Factor of Technical (FT)				Factor of Organizational (FO)			
		FC1	FC2	FP1	FP2	FP3	FP4	FP5	FT1	FT2	FT3	FT4	FO1	FO2	FO3	FO4
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 & Xu, 2019)				*				*	*				*	*	
8	(Tan et al., 2019)	*	*	*		*		*	*	*	*		*		*	*
9	(Wang, 2019)	*	*	*	*	*	*	*		*	*		*		*	*
10	(Qiu & LI, 2019)	*	*	*	*		*		*	*		*	*	*	*	*
11	(Mahdi & Mawlood, 2020)	*	*	*	*	*		*					*		*	*
12	(Jin et al., 2020)	*	*	*	*			*	*	*	*				*	*
13	(El Hajj et al., 2021)			*	*	*		*	*	*	*		*		*	*
14	(Vigneshwar et al., 2022)	*	*	*	*	*	*	*		*					*	
15	(Olanrewaju et al., 2022)	*		*	*	*	*	*	*			*			*	
16	(Wu et al., 2021)	*	*	*	*	*	*		*	*	*	*		*	*	*
17	(Zhang, 2022)	*	*	*	*	*	*		*	*	*		*	*	*	*
18	(Takyi-Annan & Zhang, 2023)	*	*	*	*	*	*		*	*	*	*		*	*	*
19	(Zaia et al., 2023)	*	*	*	*	*	*	*	*		*		*	*		*
20	(Fu, 2022)	*	*	*	*	*		*	*	*	*	*	*	*	*	*
Frequency of Factors		18	16	17	18	16	12	12	16	14	11	8	11	10	19	16
The Second step: Post-expert interview		*	*	*	*	*	*		*	*	*		*		*	*
The Third step: After final revision		*	*	*	*	*	*		*	*	*		*		*	*

Note: **FC1**: The initial investment costs are too high, including software and hardware expenses. **FC2**: The training costs and the learning curve are prohibitively expensive. **FP1**: Lack of proper understanding of BIM. **FP2**: Lack of BIM experts. **FP3**: Lack of support from senior management and client demand. **FP4**: Insufficiency of appropriate training in BIM. **FP5**:

Insufficient understanding of BIM benefits. **FW1**: Interoperability and compatibility issues among different BIM software. **FW2**: Challenges in collaboration and communication coupled with ambiguity in roles and responsibilities. **FW3**: The complexity of BIM software and tools, plus time-consuming and cumbersome BIM processes. **FW4**: There are difficulties in converting data between different BIM platforms. **FO1**: Traditional contracting methods (BIM requires special bidding conditions and a unique BIM service contract). **FO2**: Social and habitual resistance to change. **FO3**: Lack of specialized study on BIM technology in higher education curricula. **FO4**: Lack of government support, regulations, and incentive measures coupled with incomplete standards for BIM.

Table 4. 7 MBI BIM experts' personal information.

Profession	Name	Age	Job Position	Company	Certificate	Experience
Owner	Donghe Lv	31	Manager	Sichuan Lingke Bomu Construction Technology Co., LTD	Level 2 BIM Senior Engineer Certificate in Architecture	8 Years
	Shuchao Xu	29	Manager	Sichuan Jinling Shuhui Technology Co., LTD	Level 2 BIM Senior Engineer Certificate in Architecture 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 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	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.

Table 5. Criteria for content validity.

The item with IOC score	Result
0.6 < IOC < 1.00	Pass
0.5 < IOC < 0.6	Need to modify
IOC < 0.5	Not Pass

Table 6. IOC Validation.

Factor Group	Code	Factor Name	Experts' Rating							∑R	IOC	Analysis Result
			1	2	3	4	5	6	7			
Factor of Cost (FC)	FC1	The initial investment costs are too high, including software and hardware expenses.	+1	+1	+1	+1	+1	+1	+1	7	1.000	Passed
	FC2	The training costs and learning curve are excessively expensive.	0	+1	+1	+1	+1	+1	+1	6	0.857	Passed
Factor of Personal (FP)	FP1	Lack of proper understanding of BIM.	+1	+1	+1	+1	+1	+1	+1	7	1.000	Passed
	FP2	Lack of BIM experts.	+1	+1	+1	+1	+1	+1	+1	7	1.000	Passed
	FP3	Lack of support from senior management and client demand.	+1	+1	+1	0	0	+1	+1	5	0.714	Passed
	FP4	Insufficiency of appropriate training in BIM.	+1	+1	+1	+1	+1	+1	+1	7	1.000	Passed
	FP5	Insufficient understanding of BIM benefits.	0	+1	0	0	+1	0	0	2	0.285	Unpassed
Factor of Technical (FT)	FT1	Interoperability and compatibility issues among different BIM software.	+1	+1	0	+1	+1	0	+1	5	0.714	Passed
	FT2	Challenges in collaboration and communication coupled with ambiguity in roles and responsibilities.	+1	+1	+1	+1	+1	+1	+1	7	1.000	Passed
	FT3	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
	FT4	There are difficulties in converting data between different BIM platforms.	0	+1	+1	+1	0	0	0	3	0.429	Unpassed
Factor of Organizational (FO)	FO1	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
	FO2	Social and habitual resistance to change.	+1	0	0	0	+1	+1	0	3	0.429	Unpassed
	FO3	Lack of specialized study on BIM technology in higher education curricula.	+1	0	+1	+1	+1	+1	+1	6	0.857	Passed
	FO4	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 7. Criteria for Cronbach's alpha.

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

The reliability test for the 12 barrier factors conducted by the researcher showed that Cronbach's alpha coefficient was 0.844, which is considered reliable because it is in the acceptable range, as shown in Table .

Table 8. Reliability Analysis.

Factor Group	Code	Cronbach's Alpha	N of Items
Factor of Cost (FC)	FC1 FC2	0.747	2
Factor of Personal (FP)	FP1 FP2 FP3 FP4	0.800	4
Factor of Technical (FT)	FT1 FT2 FT3	0.798	3
Factor of Organizational (FO)	FO1 FO2 FO3	0.784	3
Total		0.844	12

Table 9. Normality distribution test.

	Kolmogorov-Smirnov[a]		
	Statistic	DF	Sig.
FC1	.279	131	<.001
FC2	.319	131	<.001
FP1	.369	131	<.001
FP2	.341	131	<.001
FP3	.388	131	<.001
FP4	.323	131	<.001
FT1	.423	131	<.001
FT2	.413	131	<.001
FT3	.398	131	<.001
FO1	.371	131	<.001
FO2	.346	131	<.001
FO3	.365	131	<.001

Note: a. Lilliefors Significance Correction

Table 10. Five levels of importance.

Levels	Value of number
High (H)	$0.8 \leq RII \leq 1$
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)	$0 < RII < 0.2$

(4) The Relative Importance Index (RII)

In this study, the relevance importance index will be employed to rank each barrier factor in the questionnaire. The Relative Importance Index (RII) of the resulting data is calculated using Saleh's formula (Heijnen et al., 2012):

$$RII = \frac{\sum W}{A*N} \quad (0 \leq RII \leq 1) \quad (3)$$

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, totaling 131.

The Relative Importance Index (RII) ranges from 0 to 1. According to (Akadiri & Wolverhampton, 2011), the RII values are converted into five levels of importance, as shown in Table . The higher the RII value, the greater the impact of the attribute. Nonetheless, RII does not reflect the interrelationship among various attributes.

Table 11. Correlation Analysis Results

	FC1	FC2	FP1	FP2	FP3	FP4	FT1	FT2	FT3	FO1	FO2	FO3
FC1	1											
FC2	.595**	1										
FP1	.297**	.339**	1									
FP2	.279**	.302**	.360**	1								
FP3	.396**	.294**	.612**	.433**	1							
FP4	.230**	.273**	.372**	.395**	.419**	1						
FT1	.220*	.231**	.234**	.275**	0.142	.182*	1					
FT2	.205*	.303**	.256**	.304**	.206*	.314**	.657**	1				
FT3	.208*	.291**	.326**	.392**	.299**	.345**	.530**	.623**	1			
FO1	.438**	.394**	.324**	.322**	.300**	.257**	.274**	.310**	.290**	1		
FO2	.280**	.337**	.214*	.373**	.213*	.361**	.193*	.258**	.185*	.491**	1	
FO3	.373**	.359**	.376**	.229**	.296**	.189*	.265**	.222*	.239**	.667**	.494**	1

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

3.5 Result

3.5.1 Characteristics of interviewees

Table lists the characteristics of the respondents according to their gender, age, education level, job title, and experience in the CI.

Table 12. Personal information

Variables	No. of Respondents	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	15.27
Education Level		
Associate degree	12	9.16
Undergraduate degree	77	58.78
Master	32	24.43
Doctor (PhD)	10	7.63
Employment Position		
Managers	48	36.64
Designers	42	32.06
Managers	41	31.30
How long do you have years of work experience in the construction industry?		
3-5	50	38.17
6-9	41	31.30
≥ 10	40	30.53
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	24.43
Total	131	100

3.5.2 BIM technology

To accomplish the study objectives, participants were asked the following questions. As shown in Table . As can be seen from the table, the application status of BIM technology in MBCPs in Chengdu shows certain diversity and development potential. However, there are also problems of insufficient understanding and limited application. This provides important reference information for the promotion and in-depth application of BIM technology in the future.

Table 13. BIM expertise.

BIM Expertise	Count	Percentage %
Your level of understanding of BIM Technology:		
Don't know about BIM technology.	3	2.29
Know the technology but never use it.	58	44.27
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
How many years of experience do you have working with BIM Technology?		
Never utilized BIM Technology	61	45.56
≤ 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	45.56
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	37.40
LOD 400	17	12.98
LOD 500	3	2.29

3.4.2 Commonly used working software

Table below shows the software respondents commonly use at work. As can be seen from the table, most construction companies still choose to apply BIM technology.

Table 14. Common software for working.

Group	Software Name	Count	Percentage %	Rank
CAD Drawing	Autodesk AutoCAD	131	100	1
	Graphisoft ArchiCAD	9	6.87	12
BIM Modeling Software	Autodesk Revit	70	53.44	4
	Bentley MicroStation	5	3.82	13
	Rhino	40	30.53	9
	Tekla	20	15.27	11
BIM Visualization	Autodesk Navisworks	53	40.46	5
Assistance Software	Fuzor	44	33.59	7
Rendering Software	Google SketchUp	49	37.40	6
	Autodesk 3Ds Max	44	33.59	7
	Cinema 4D	5	3.82	13
Project Management Software	Primavera	9	6.87	12
	Microsoft Excel	102	77.86	2
	Microsoft Project	102	77.86	2
	Microsoft Powerproject	31	23.66	10

3.4.3 BIM implementation barrier ranking

The RII calculation results of barrier factors in this study are shown in Table . This research ranks the 12 barriers to BIM implementation by RII. The average score for barrier factors ranged from 4.282 to 4.649. This research used the same threshold approach to evaluate significant variables (Huang et al., 2021). The threshold is set at 0.9 to identify key barrier factors. As a result, only six BIM implementation barrier factors were higher than 0.9. These barriers include FT2 (RII = 0.930); FT1 (RII = 0.928); FT3 (RII = 0.921); FP3 (RII = 0.915); FO1 (RII = 0.904); and FP1 (RII = 0.902).

4. Solving strategies for obstacle factors applied by BIM in MBCPs

Based on the six key barriers above, the study suggests the following improvements.

1) Clarify the roles and responsibilities of the construction management team and BIM team members and adopt collaborative platforms to improve communication. Regular team meetings should be held to ensure transparency and timely information sharing. Consider using BIM collaboration tools, such as BIM 360 or Revit Work-sharing, to enhance team collaboration efficiency.

2) Establish standardized BIM software interfaces and data exchange formats. Encourage BIM software providers to participate in the development of open standards to facilitate better data exchange between software. At the same time, increase the project team's familiarity with different BIM tools through training and practice to address compatibility issues.

3) Provide specialized BIM training and technical support to improve team members' proficiency with BIM tools. Optimize BIM processes by simplifying operations with customized workflows and templates. Additionally, it explores the use of artificial intelligence and automation technologies to reduce manual workload.

4) Convince senior management and clients of the long-term value and return on investment (ROI) of BIM by presenting case studies demonstrating BIM's successful application in other projects, thereby enhancing confidence and support.

5) Promote updates to standard contract templates within the industry, including requirements for BIM technology. Actively share the benefits of BIM with owners and contractors to encourage the inclusion of BIM use in tender conditions.

6) Strengthen education and awareness to enhance the industry's understanding of BIM. Increase BIM-related courses in universities and vocational training. Organize seminars and workshops to enable more professionals to understand the advantages and application methods of BIM.

Table 15. The Ranking of barriers to BIM implementation.

Group	RII	No.	Items	Mini	Max	Mean	SD	RII	Rank
Factor of Cost (FC)	0.869	FC1	The initial investment costs are too high, including software and hardware expenses.	1	5	4.374	.660	.875	10
		FC2	The training costs and the learning curve are prohibitively expensive.	3	5	4.313	.596	.863	11
Factor of Personal (FP)	0.902	FP1	Lack of proper understanding of BIM.	1	5	4.511	.778	.902	6
		FP2	Lack of BIM experts.	3	5	4.481	.599	.896	7
		FP3	Lack of support from senior management and client demand.	1	5	4.573	.668	.915	4
		FP4	Insufficiency of appropriate training in BIM.	1	5	4.473	.636	.895	8
Factor of Technical (FT)	0.923	FT1	Interoperability and compatibility issues among different BIM software.	3	5	4.641	.569	.928	2
		FT2	Challenges in collaboration and communication coupled with ambiguity in roles and responsibilities.	1	5	4.649	.607	.930	1
		FT3	The complexity of BIM software and tools, plus time-consuming and cumbersome BIM processes.	3	5	4.603	.550	.921	3
Factor of Organizational (FO)	0.882	FO1	Traditional contracting methods (BIM requires special bidding conditions and a unique BIM service contract).	1	5	4.519	.705	.904	5
		FO2	Lack of specialized study on BIM technology in higher education curricula.	3	5	4.282	.572	.856	12
		FO3	Lack of government support, regulations, and incentive measures coupled with incomplete standards for BIM.	2	5	4.427	.832	.885	9

5. Conclusion

This study focuses on the challenges and barriers to implementing BIM technology in the MBCPs in Chengdu, China. This survey is based on a comprehensive literature review and enriched by interviews with BIM experts active in the MBI in Chengdu and a questionnaire survey of managers, designers, and engineers of 48 construction companies in Chengdu that have undertaken MBCPs. The analysis of the survey results shows that the main obstacles to the effective adoption of BIM technology in Chengdu MBI departments are multifaceted. First, challenges stemming from communication and teamwork become apparent. The uncertain roles and responsibilities of the project team serve to worsen these challenges. Insufficient elucidation on this subject hinders not only effective collaboration but also the smooth incorporation of Building Information Modeling (BIM) into established procedures. Irrespective of this, significant barriers hinder compatibility issues and hinder interoperability among various BIM software programs. Incompatibility impedes the smooth passage of data and information, resulting in inefficiencies and the potential for errors throughout the project's execution. This issue is exacerbated by the wide variety of software deployed during the various phases of MBCPs. Furthermore, when considering the time-consuming and arduous nature of the BIM process, the inherent complexity of BIM software and tools eventually poses a significant barrier. Stakeholders often exhibit reluctance to embrace BIM technology due to the complex and nuanced nature of this matter.

Based on these recent findings, stakeholders in Chengdu's MBI must implement specific measures to overcome these obstacles. Chengdu's MBCPs stand to be significantly transformed by BIM technology, yet the complete advantages of this transformation may solely be realized by collectively surmounting the hurdles that have been identified. Beyond Chengdu, and perhaps in other places confronting comparable obstacles, this study establishes the groundwork for subsequent investigations and pragmatic interventions that foster broader adoption and efficient utilization of BIM in MBCPs.

Primarily, the concentrated examination of the Chengdu MBCPs in this study introduces research limitations that may restrict the applicability of the results to different sectors or regions. Moreover, subjectivity is introduced into the research process through expert interviews and questionnaire responses; the viewpoints and experiences of a select few participants may not accurately represent the whole sector. Ongoing research is also necessary to capture the most recent developments and problems in the sector, as the study's findings may be superseded by the swift evolution of BIM technology and construction processes.

Subsequent investigations ought to strive to broaden the geographic extent of this research in order to encompass a variety of construction markets, so augmenting the applicability of the results in distinct regulatory and cultural contexts. Furthermore, longitudinal investigations may yield significant knowledge regarding the progressive influence of BIM technology on construction methodologies as time passes. Further quantitative research using bigger datasets, maybe with the help of sophisticated statistical methods or machine learning approaches, is urgently required to confirm the validity of the qualitative findings obtained from this work. Further optimization of design processes, construction processes, and project results could be achieved by investigating the integration of BIM with new technologies like the Internet of Things (IoT) and artificial intelligence (AI).

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Appendix: List of 48 Construction Firms Winning Bids for MBCPs in Chengdu.

No.	Company's name
1	Beijing Zhongjianhua 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
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 (Zhao et al., 2024).