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The Efficacy of Building Information Model in Cost Control of Green Buildings in Shanghai

Shi Yangle[1], Khoo Terh Jing[1,*], Chen Siyao[1], Ha Chin Yee[1], Deng Zihao[1], Lei Hao[1], Sun Hui[1]

[1] Department of Construction Project Management, School of Housing, Building, and Planning, Universiti Sains Malaysia, 11800 Minden, Penang, Malaysia

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ABSTRACT

With the rapid development of modern cities, green buildings have become an important way to reduce energy consumption and environmental impact. The focus of the industry has shifted towards controlling the costs associated with these green buildings. As a solution, Building Information Modelling (BIM), an integrated digital tool, has gained widespread usage in the cost control of green buildings, including in the city of Shanghai. As a centre city of China, Shanghai has both prospects and challenges in the field of green building cost control, it is extremely important to conduct this comprehensive study in Shanghai. Therefore, the primary objective of this study is to delve into the impact of BIM on the cost control of green buildings in Shanghai and unveil its effect during the implementation process of green building projects. To achieve this goal, the author used qualitative research and conducted in-depth interviews with engineers who have used BIM technology in various green building projects. The interviews explored the application of BIM and its effect on controlling costs. The findings of this study reveal that BIM has had a significantly positive impact on the cost control of green buildings in Shanghai. By implementing BIM, the efficiency of cost control has been enhanced throughout the entire life cycle of these environmentally friendly structures. This improvement stems from the ability of BIM to provide accurate and detailed information about the building's design, construction, and operation, enabling better decision-making and resource allocation. The implications of this study are twofold. First, it helps to theoretically understand the impact of BIM on green building cost control, especially in the context of Shanghai. This adds to the existing body of knowledge and furthers research in the field. Secondly, this study also fills the research gap of BIM in the cost control of green building projects in Shanghai.

1. Introduction

The data indicates that on a global scale, industrial structures account for approximately 40% of the overall energy output, utilize 12-16% of the total water resources, utilize 32% of both non-renewable and renewable materials, consume 25% of the world's wood, utilize 40% of raw materials,

* *Corresponding author.*
E-mail address: terhjing@usm.my

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produce 30-40% of the total solid waste, and release 35-40% of carbon dioxide emissions. This has prompted a heightened global recognition of the significance of integrating sustainability into the realm of construction [1]. This has led to a growing global awareness of the importance of sustainability in the construction sector.

Considering growing sustainability concerns, such as reducing CO2 emissions and energy dependence on fossil fuels, the construction industry has been pushed to adopt green building strategies [2]. Green building and sustainable building are a subset of sustainable development [3]. The advantages of green building are well known, and the disadvantages are obvious. The high investment in green buildings discourages most property developers. There is no denying that the upfront investment costs for green buildings are high, but green building is the right decision in terms of the whole life cycle [4].

Being a groundbreaking innovation and methodology, Building Information Modelling is widely regarded as a significant prospect for the Architecture, Engineering, and Construction (AEC) sector [5]. BIM has arisen as an answer that enables the seamless integration and supervision of information across the complete lifespan of a structure, thereby enabling the comprehensive utilization of accessible data for cost management purposes [6]. Building Information Modelling has emerged as a transformative force within the Architecture, Engineering, and Construction (AEC) industry, revolutionizing the way projects are conceived, executed, and maintained. By facilitating the seamless integration of information and enabling stakeholders to harness data throughout a building's lifecycle, BIM empowers the industry to achieve unparalleled levels of cost control, collaboration, and project success. Its enduring impact is poised to shape the future of construction and solidify its position as a cornerstone of modern AEC practices [6].

1.1 Problem Statement and Research Aim

With the continuous application and promotion of BIM in the green building industry, research on the effects and impacts of BIM in actual green projects has received increasing attention [7]. In this study, a visual knowledge mapping analysis of relevant literature in the Web of Sciences (WOS) database was conducted using bibliometric methods and Cite Space visualization software. It mainly analyses the status and research trends of international academic research on the effects of BIM in green building projects. By systematically reviewing the existing literature, a lack of relevant research on the effects of BIM in the application of actual green building projects in China was identified. This study aims to analyse whether the implementation of BIM technology in green building projects throughout the lifecycle can help cost controls and to explore what cost control strategies can be enhanced by BIM. To convince stakeholders that BIM is a trustworthy technology in green building cost control.

1.2 Research Objective

This study is to fulfill two main objectives in the field of green building in Shanghai. First, it assesses the efficacy of Building Information Modeling (BIM) as a tool for controlling costs. Specifically, the study will investigate whether BIM can be able to help green building projects cost control during the green building cost control process. Secondly, it explores the role of BIM in enhancing cost control in green buildings. In particular, the study aims to explore which strategies of cost control for green building projects in Shanghai can be enhanced by BIM technology.

i. To assess the effectiveness of BIM application for cost control in green building in Shanghai.

ii. To exploring green building cost control strategies can be enhancement by BIM.

2. Literature Review

2.1 Introduction

The purpose of this section is to review the practical applications of BIM for cost control in green buildings, with a focus on its application in Shanghai. This section covers the existing research on theories, concepts, and models of BIM for green building cost control [8]. It summarizes and analyses the status of BIM for green building cost control globally, commonly used cost control methods, and the challenges and limitations of BIM for green building cost control theory. The aim is to identify gaps in existing research and to lay the foundation for subsequent cost studies.

2.2 Literature Search

To systematically understand and explore the application of Building Information Modelling (BIM) in green building cost control, an extensive literature search was conducted in this paper. The objective of the literature search was to obtain relevant literature such as academic journals, conference papers, books and technical reports that are closely related to the research topic.

First, the authors conducted a full-text search using online academic databases, Google Scholar, and Web of Sciences. In the search process, the keywords include "building information modelling", "BIM", "green building "BIM", "green building", "cost control" and so on. The authors limited the timeframe of the search by focusing on literature published within the last 10 years to ensure access to the latest research results.

Through the above method of literature search, the authors successfully acquired a few academic literature and research results related to BIM in green building cost control, which provides sufficient theoretical and practical support for the research of this paper. In the next sections, this study would review and analyse these literatures to explore the specific application effects and impacts of BIM in green building cost control [9].

2.3 Literature Selection

The literature was further screened based on the following criteria:

i. Relevance: the authors first checked the title and abstract of each literature and screened for literature directly related to the research topic.
ii. Time frame: The authors mainly focused on literature published within the last 10 years to ensure access to the latest research results.
iii. Source credibility: the authors selected some well-known academic journals, conference papers and books to ensure the quality and reliability of the literature.
iv. Research methodology: the authors pay more attention to the literature that adopts quantitative or qualitative research methodology, so that more reliable and comprehensive research results can be obtained.

2.4 Concept Definition

2.4.1 Green buildings

There are many different definitions of what constitutes a green building, with most researchers agreeing that green buildings are designed to achieve optimum energy efficiency and are constructed using natural, recycled materials [4]. These buildings provide occupants with a healthier, more comfortable, and efficient indoor environment by maximizing the use of resources such as energy, rainwater, and recycled materials [10]. According to the US Environmental Protection Agency (USEPA), green building is "the practice of creating structures and using environmentally responsible and resource efficient processes throughout the life cycle of a building" [11].

The subsequent description offers a relatively comprehensive outline of environmentally friendly construction in the context of China: In accordance with the delineation provided in China's national standard for green building, "Green Building Evaluation Standard", it refers to a building that maximizes the conservation of resources (energy, land, water, and materials), protects the environment, and reduces pollution during the whole life cycle of the building, and provides people with healthy, suitable, and efficient [12]. The building is in harmony with nature. An alternative characterization lies in the assertion that green buildings are designed to furnish individuals with living and working environments that are not only healthy and comfortable, but also safe [13]. Simultaneously, throughout the complete lifespan of the structure — encompassing the stages of building material production, transportation, architectural planning, design, construction, maintenance, and eventual material reuse during demolition — the objective is to realize a resourceful utilization of assets, energy, land, water, and materials. This pursuit minimizes the ecological footprint of the building, having the least possible impact on the environment [14].

2.4.2 Cost control

Cost control refers to guiding, limiting, and supervising all production and operation activities in the process of cost formation [15], detecting errors in time, controlling all specific costs and production costs always within the original design by adopting appropriate solutions, continuously reducing costs, and ensuring that the specified cost targets are met and exceeded [16].

Traditional building projects only consider the initial cost of the project and seldom consider the future cost, while green building is a full life cycle building, it is inevitable to analyse the cost composition of green building based on the height of the full life cycle and to gain a deeper understanding of its cost composition [17].

Total life cycle costs are the sum of all costs involved in a project, product, or asset throughout its life cycle. These costs include, not limited to, the costs of all phases of the project or product such as design, construction, operation, maintenance, and disposal [18].

The concept of total life cycle cost emphasizes the consideration of costs over the entire life cycle, not just the investment in the construction phase of the project or product. It recognizes the need for integrated consideration of costs at all stages of the decision-making process to make decisions that are economically, environmentally, and socially sustainable [18]. This includes design and construction costs, operation and maintenance costs, renewal, and improvement costs, and decommissioning and disposal costs [19].

2.4.3 Building Integrated Modelling (BIM)

BIM is Building Information Modelling. It is a digital, integrated approach to building design and management that enables the management and coordination of the entire process of a construction project through the creation, maintenance, and utilization of a virtual model of the building. The functions of BIM cover the following, digital modelling, collaboration and integration, efficiency and accuracy, data-driven decision making, and total lifecycle management [20].

During green building construction, BIM makes an important contribution to improving project quality [21]. The implementation of BIM can effectively ensure the quality of scheduling and project management in green building construction. BIM can enhance construction schedule management for stakeholders [22].

This comprehensive analysis reveals that Building Information Modelling is strategically fine-tuned to elevate project quality, efficiently retain, and manage life cycle data, promote collaborative optimization, and oversee planning and scheduling within the construction phase of environmentally friendly structures. The discourse ultimately culminates in the inference that BIM's application extends seamlessly across the entirety of green building construction, spanning from the preliminary stages to the culmination of post-construction [21].

Building Information Modelling (BIM) is an effective tool to facilitate green building assessment [21]. Information about a building is usually fragmented and distributed across different sources. BIM and BIM-related tools can effectively handle multidisciplinary information about a building from the perspective of the entire project life cycle [23].

2.5 BIM Application in Cost control

Through digital modelling, collaboration and integration, and data-driven decision-making, BIM provides powerful support for cost control [24]. In the architectural design phase, the application of BIM models enables the design team to simulate and analyse the costs of different design alternatives to select the most cost-effective solution. In the construction phase, BIM's virtual coordination capabilities help reduce conflicts and on-site rework, improve construction efficiency, and thus reduce construction costs. In the operation and maintenance phase, BIM integrates equipment and facility information to support facility management teams in predicting equipment maintenance costs, optimizing maintenance schedules, and reducing operating costs [25]. In addition, BIM's full lifecycle management features make it a powerful tool for full-process cost control, providing project managers with the ability to monitor cost changes in real time, helping to better control project costs. However, implementation of BIM still needs to overcome challenges such as technical and training costs, as well as the acceptance of BIM technology by construction industry stakeholders [26].

2.6 BIM in green building cost control

The cited research encompasses a diverse array of subjects pertaining to the utilization of Building Information Modelling across various facets within the construction sector. Jin *et al*., [27] aims to showcase the latest design technology's ability to accurately analyse daylight in buildings. [28] investigates the degree to which the adoption of BIM has yielded documented advantages across diverse construction endeavours. Li *et al*., [29] focus on quantifying BIM's benefits in building construction resource management and real-time cost control through a case study approach, comparing it with traditional non-BIM technologies.

Hardin *et al*., [30] contribute by demonstrating how their integrated model provides construction managers with a comprehensive tool that surpasses solely utilizing BIM. Oduyemi *et al*., [31] examine and categorize the merits and impediments, encompassing both technological and non-technological factors, associated with the incorporation of BIM in the realm of sustainable building design. Lou *et al*., [32] establishes a cost management process for prefabricated buildings based on BIM technology. Long *et al*., [33] propose an energy-efficient building design framework that combines BIM and artificial intelligence technologies, analysing their use in designing energy-efficient buildings.

Looking ahead, Liao *et al*., [34] propose potential avenues for future research, encompassing inquiries such as analysing the mutual development between collaborative networks and BIM artifacts, refining the Caliber of intricate networks grounded in BIM, comprehending the post-adoption behaviours of BIM within intricate environmental scenarios, and formulating strategies for mitigating complexity through BIM-centric approaches. In addition to these studies, other influential work by Mostafa *et al*., [35] has also contributed to the growing body of knowledge on the application and benefits of BIM in the construction industry. Overall, these studies collectively contribute valuable insights into the potential and benefits of incorporating BIM technology into various construction processes, ranging from design and resource management to energy-efficient building design and cost control.

2.7 Cite Space Visual Analytics

The dataset analysed in this subsection was retrieved from Web of Science (WOS), which provides comprehensive citation searching and supports referencing of interdisciplinary research. WOS was originally launched by the Institute for Scientific Information (ISI) as a scientific citation indexing service covering a wide range of citation databases. The data collected in this paper were analysed using Cite Space (version 5.1.R8.SE), which is a software for analysing literature in the scientific field. The input to Cite Space is mainly bibliographic information, especially citations from WOS. Data sources include authors, publications, keywords, and citations, which can be analysed and generate interactive visualizations (citations) of knowledge graphs for specific scientific domains.

2.7.1 Chronological Distribution of Literature

After screening, the authors were provided with 614 relevant core literature, and this part is all analysed based on these 614 documents. After statistics and analysis, the authors came up with a quantitative distribution of the number and percentage of publications. The results show that the amount of literature on BIM application in green building cost control is consistently increasing over time until 2019 when it tends to equalize. The most relevant literature was published in the year 2022 with a percentage of 26.04%

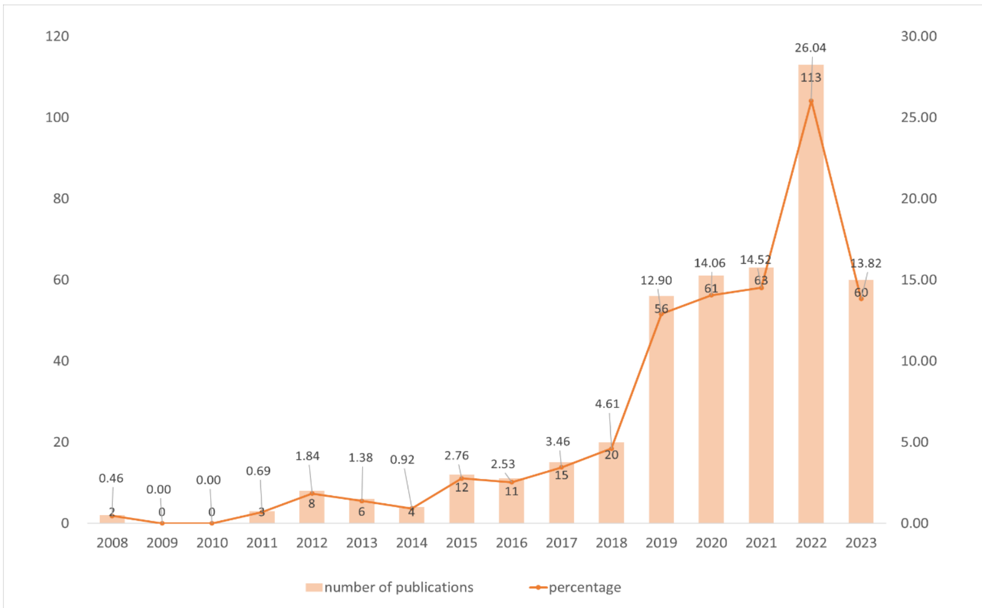

Fig. 1. Chronological Distribution of Literature on BIM in Green Building Cost control

2.7.2 Keyword-based research hotspots

Table 1 shows the top 15 keywords with the strongest citation explosion in the Cite Space analysis. A citation explosion is defined as a significant increase in the number of citations for a keyword in each time, indicating that the keyword has a high level of research interest and importance in that time. The greater the median centrality, the greater the influence of a particular keyword, which plays the role of a "connector" among keywords of different topics. The keywords with median centrality greater than 0.3 are green building, systems, and technologies, indicating important concepts in BIM and green building cost control publications. The keyword Green Bim is relevant to this study and as can be seen from the graph, Green Bim is extremely hot from 2015-2021, proving that this study is a hot study.

Table 1
BIM's top 15 emergent terms in green building cost control research

Top 15 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2008 - 2023
green building	2015	3.86	**2015**	2017	
green bim	2015	2.76	**2015**	2021	
simulation	2017	3.05	**2017**	2018	
system	2018	2.59	**2018**	2019	
framework	2017	2.37	**2018**	2019	
sustainability	2017	2.18	**2019**	2019	
leed	2020	2.21	**2020**	2020	
climate change	2020	2.02	**2020**	2021	
systems	2021	3.13	**2021**	2023	
indoor environmental quality	2021	2.56	**2021**	2023	
energy savings	2021	2.19	**2021**	2021	
comfort	2021	2.19	**2021**	2021	
technology	2022	3.11	**2022**	2023	
benefits	2022	2.26	**2022**	2023	
prediction	2022	2.16	**2022**	2023	

3. Methodology
3.1 Introduction

This chapter describes the research methodology for cost control in green buildings based on BIM, and the methodology used is qualitative analysis. The research questions focus on the effectiveness of BIM in green building cost control and what green building cost management strategies can be enhanced by BIM. The study area was Shanghai, China, the data collection method was semi-structured interviews, and the data analysis included coding the data collected from the semi-structured interviews and the use of thematic analysis. Ethical aspects were also considered and informed consent was obtained from all participants, and strict confidentiality was maintained throughout the study. Throughout the study, the authors took steps to minimize any possible harm or discomfort to participants.

3.2 Research Design

This study has two objectives：

i. To assess the effectiveness of BIM application for cost control in green building in Shanghai.
ii. To exploring BIM enhancement cost control strategies in green buildings in Shanghai.

Based on the research questions and objectives, the researchers developed a research design.

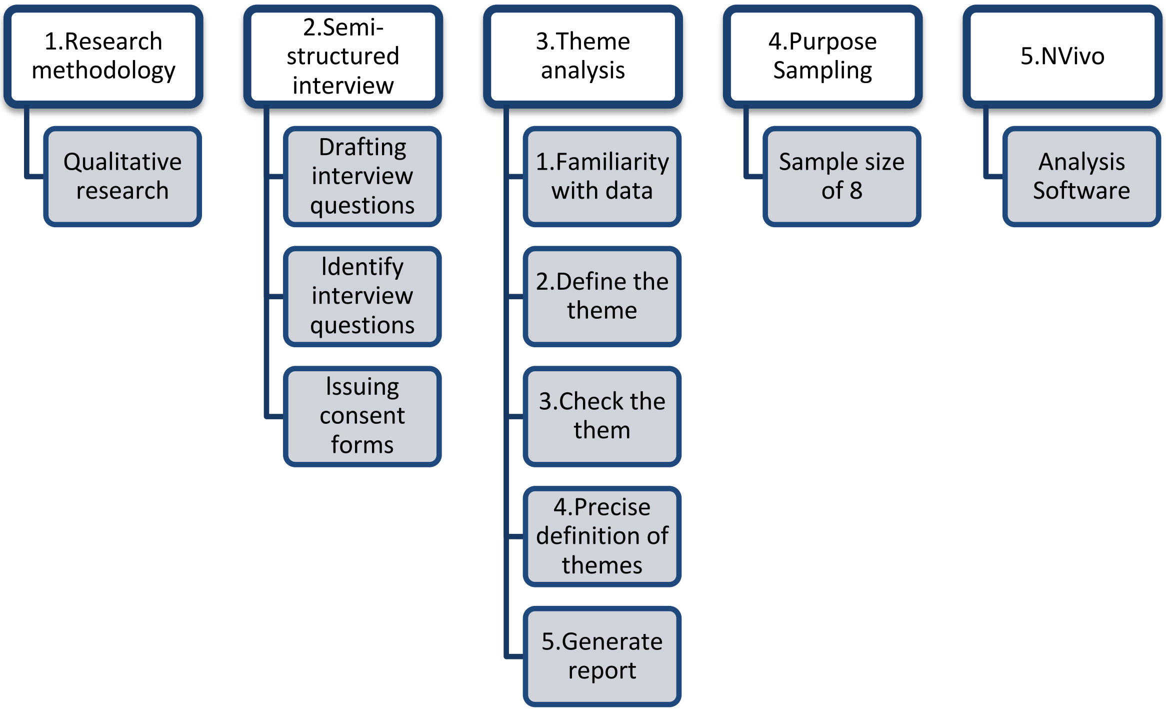

Fig. 2. Research Flow Chart

3.3 Interview Process

This study recruits' participants through a combination of social media platforms and email communications. Information materials were released through these channels to provide comprehensive details of the study, including the research objectives, research questions, research background and status of green building development.

The flow chart of the semi-structured interview research in this chapter is as follows:

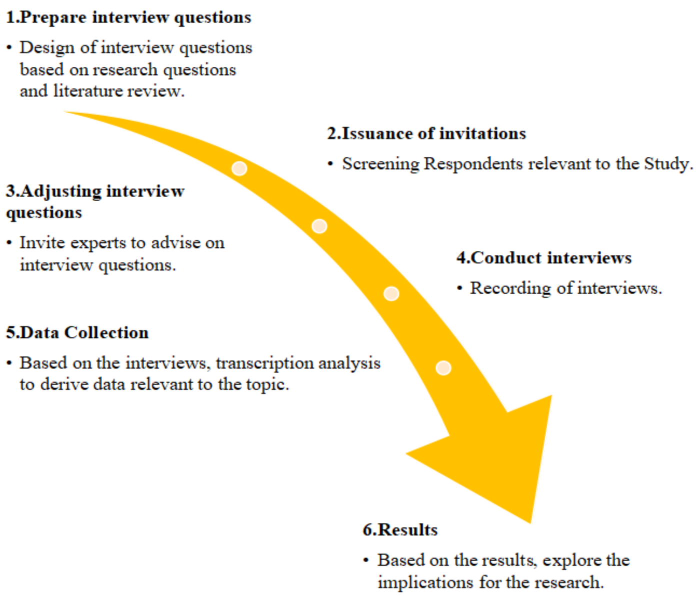

Fig. 3. Semi-structured interview research

3.3.1 Interview questions

The sources of the interview questions were carefully designed and selected to provide insight into the research topic and answer the research questions. Question formulation was optimized based on the purpose of the study, literature review and prior research, as well as the characteristics and backgrounds of the participants. Interview questions were open-ended, allowing participants to express their views and experiences freely and ensuring access to in-depth and detailed data.

Table 2
Interview Question Setting

Question	Source
Q1: Do you think BIM has cost controls for green building projects?	[28,36]
Q2: How does BIM help cost controls in green building projects?	[37]
Q3: How is BIM used in cost control strategies?	[38]
Q4: What green building cost strategies can BIM enhance?	[21,35]

3.3.2 Target Group

By harnessing the power of social media platforms and employing a targeted email recruitment strategy, the study team aimed to maximize participant engagement in an ethical and transparent manner. To ensure that participants were well informed about the study, comprehensive informational materials were provided that provided information about the purpose of the study, research questions, and relevant details about participation. In addition, the research team obtained informed consent from each participant through a designed consent form that emphasized their autonomy and ensured their voluntary participation.

This study will involve interviews with a total of eight experienced practitioners. The selection criteria for the interviewees will meet the following three requirements. First, the interviewees should be directly or indirectly involved in green building. Second, interviewees must have been involved in 1-2 green building projects. Finally, based on a predetermined sample size, all interviewees must have used BIM in their green building cost control efforts. To ensure a thorough exploration of the research topic, each interview session is expected to last approximately 30 minutes.

3.3.3 Data collection

The data collection method used in this chapter consisted of conducting semi-structured interviews to generate textual data. The data collected through this method was then transcribed and analyzed to identify emergent themes and patterns. As such, textual data became the primary data type used in this chapter.

The qualitative data collected in this study can be divided into two categories:

i. Primary data: textual data collected directly from participants through semi-structured interviews, including participants' opinions, experiences, and perceptions.
ii. Secondary Data: This refers to data collected from sources other than the participants. Secondary data in this study includes academic papers related to BIM and controlling costs in green buildings.

3.3.4 Sample Size

Sample size refers to the number of participants or observers included in a study. It represents the subset of the target population selected by the researcher to collect data and draw conclusions about the larger population [39]. The size of the sample is an important consideration in research because it affects the statistical power, generalizability, and precision of the findings. A total of eight participants were selected for this study and these eight participants were chosen for the following reasons:

i. "Saturation" is a widely recognized and highly valuable concept in qualitative research that plays a key role in determining appropriate sample sizes [40]. As the field has evolved, the term "data saturation" has become increasingly important in addressing the question, "How many qualitative interviews are enough?" This long-standing question has become increasingly salient. This reflects the understanding and application of these concepts in a broader context. Traditionally, 6-7 interviews have been shown to be sufficient to capture most themes in a homogenous sample, with an impressive 80% saturation level achieved in approximately 6 interviews [41]. Drawing from academic research, this study takes a flexible approach to sample size and argues that a sample of eight participants is sufficient to reach data saturation in qualitative research work.
ii. In some research contexts, it may be impractical or unnecessary to select an excessively large sample size [42]. In such cases, the goal of the researcher is to strike a balance between obtaining a sufficient sample size to produce reliable results and optimizing the efficient use of resources. Therefore, in this case, the authors chose 8 individuals as the sample size.

3.4 Data Analysis

Thematic analysis is a research tool that is diffuse, compatible, and more flexible than other qualitative techniques [43]. Thematic analysis allows for a deeper exploration of the underlying meanings and interpretations in the data, capturing the subjective experiences and insights expressed by the participants. The authors believe that thematic analysis is the more appropriate method for this study.

Theme Analysis Process:

i. Familiarization with the data
The first step is to translate the spoken language from the interviews into text.
ii. Preliminary coding
Look at the preliminary codes and identify patterns or links between them. Group similar codes into broader categories or themes.
iii. Identify Themes.
Define each theme by providing a concise explanation that describes its content, nature, and characteristics within the context of the study.
iv. Examining Themes.
At this stage, candidate codes that do not match any of the themes emerge from the previous analysis. Themes are continually reviewed and modified by revisiting the data, comparing, and contrasting codes, and considering alternative interpretations. Define themes accurately.
v. Generate a report.

The written discourse must go beyond the mere presentation of data and incorporate that data into the analytic narrative.

3.4.1 Analysis software

NVivo is a powerful qualitative data analysis software widely used by researchers across a wide range of disciplines [44]. Developed by QSR International, NVivo provides a comprehensive set of tools and features that facilitate the coding, organization, and analysis of qualitative data.

3.5 Limitations of Research Methodology

Qualitative research using purposive sampling, interviews, and thematic analysis offers valuable insights but has limitations. It focuses on specific phenomena in specific contexts, making generalization difficult due to small sample sizes and lack of statistical representation. Subjective interpretation introduces researcher bias in participant selection, interview questions, and data coding. Additionally, it can be time-consuming and resource-intensive, limiting sample size and scope. While it captures rich narratives, the lack of quantifiable data hinders precise and objective statements. Thematic analysis's interpretive nature may also lead to variations in identified themes and potential bias among different researchers.

4.Result

4.1 Respondents in this study

4.1.1 Respondent Background

Details of the respondent background is tabulated in Table 3.

Table 3
Respondent's detailed background

Respondent Position	Years of work	company size	Company Type	Management level
Technicians	11 years	2814 people	Construction Company	Middle
Technicians	10 years	2814 people	Construction Company	Middle
Consultant	9 years	28 people	Consulting Company	Low-level
Consultant	12 years	28 people	Consulting Company	Low-level
Designers	10 years	214 people	Design Company	Middle
Designers	12 years	214 people	Design Company	Middle
Researchers	21 years	1814 people	University	High
Researchers	14 years	1814 people	University	High

4.1.2 Background analysis

According to the figure below, it can be found that the interviewees are mostly middle managers, and the main personnel of BIM in controlling costs in green buildings are also concentrated in middle managers, so the interviews with the interviewees can better emphasize the value of the study.

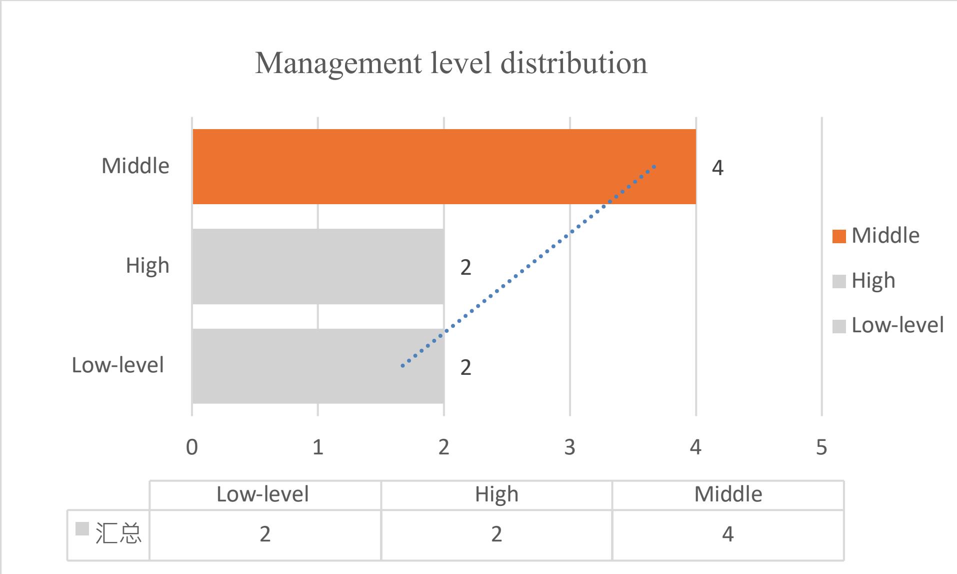

Fig. 4. Map of respondents' management levels

4.2 Content analysis of interviews

4.2.1 Coding results

The interview data were carefully read and analyzed according to the purpose of the study and the research questions. In the process of analysis, some recurring key words, phrases, or themes, are summarized. Coding is the systematic analysis and interpretation of interview data. In the table, each code is followed by the corresponding number of the respondent.

Table 4
Codes and respondents

RO1 Code	Respondent
BIM-CC-01: Practical Application of BIM in Shanghai Green Building Project	1.3.5.7.8
BIM-CC-02: Advantages and shortcomings of BIM application in green building cost control	1.2.3.4.5
RO2Code	Respondent
BIM-GBC-01: The Enhancing Effect of BIM Implementation on Green Building Energy Strategies	1.3.4.5.7
BIM-GBC-02: BIM Enhancement for Green Building Design Strategies	2.3.4.6
BIM-GBC-03: Effectiveness of BIM in Green Building Materials and Resource Management Strategies	3.4.5.6.8
BIM-GBC-04: Enhancing the Effectiveness of BIM in Maintenance Cost Strategies for Green Buildings	4.5.6.7
BIM-GBC-05: Enhancement of BIM for green building construction process cost strategy	1.3.5.7.8
BIM-GBC-06: Practical Effects of BIM in Green Building Equipment Management Strategies	5.6.7

4.2.2 Coding analysis

4.2.2.1 BIM-GBC-01

The use of BIM technology in green building energy strategies has had a positive impact on cost reduction. With BIM technology, design teams can simulate and analyse the impact of different material choices on energy costs, optimize the design of heating and cooling systems, evaluate the application of renewable energy sources, and assess the effectiveness of energy-saving measures. Respondents 1 and 3 noted: *BIM technology also enables continuous optimization of energy efficiency* *during the operational phase of a building to achieve continuous cost reductions. Respondent 4.5.7 narrates that through data-driven decision support, BIM provides a more efficient and environmentally friendly solution for green buildings, which in turn achieves the goals of cost control and sustainability.* Therefore, the application of BIM in green building energy strategies has proven to be an effective means to provide strong support for cost control in green building projects.

4.2.2.2 BIM-GBC-02

BIM technology plays a key role in green building design strategies to reduce costs. *Respondent 2 said that BIM provides comprehensive support to design teams through enhancements in accurate simulation and analysis, data-driven decision making, collaboration and communication, environmental assessment and optimization, and overall lifecycle management. Design teams can make decisions based on accurate data, optimize energy performance and material selection, and avoid unnecessary energy waste. The collaborative features of BIM technology promote efficient communication between teams, reducing errors and conflicts. Respondent 6 recounts that BIM also supports environmental assessment and optimization of buildings, selecting the optimal environmental strategy and reducing operating costs. Through the whole process of data management and analysis, the design team can monitor and cost controls in real time, make corresponding adjustments, and achieve continuous cost optimization.* Therefore, the application of BIM technology significantly improves the efficiency and cost control of green building design strategies and promotes the goal of sustainable development.

4.2.2.3 BIM-GBC-03

The application of BIM technology to green building materials and resource management strategies has had a significant impact on cost reduction. *Respondent 3 narrated that with BIM technology, project teams can accurately manage the process of purchasing, using, and recycling construction materials and resources, thereby avoiding over-purchasing and waste and reducing the overall cost of the project. The data and information integrated in the BIM model allows the team to better optimize the material purchasing plan, select environmentally friendly and economical materials, and thereby reduce the cost of materials. Respondent 8 said that BIM can also help assess the environmental impact of different materials, promote sustainable procurement, and resource management, and further reduce the life-cycle costs of projects.*

4.2.2.4 BIM-GBC-04

The application of BIM technology in the design and construction phases provides a more accurate and comprehensive data base for maintenance cost strategies for green buildings. *Respondent 4 said that with BIM modeling, design and construction teams can accurately record and integrate information about equipment and materials, including equipment models, installation locations, and maintenance intervals. This enables the maintenance team to locate, troubleshoot and repair equipment more efficiently in the later stages of maintenance work, thus reducing unnecessary maintenance time and costs. Respondent 6 stated that the continued application of BIM technology in the operational phase of green buildings provides real-time data monitoring and management tools. Through BIM modeling, facility management teams can stay on top of the status and performance of building equipment and update maintenance schedules in real time. This enables maintenance teams to respond more quickly to equipment failures and maintenance needs, reducing* *maintenance response time and lowering maintenance costs.* BIM technology provides strong support for optimizing and improving maintenance cost strategies. Through the data analysis and simulation functions of the BIM model, the maintenance team can evaluate the effectiveness of different maintenance strategies and find the most cost-effective maintenance solution. This enables the maintenance team to continuously improve the maintenance cost strategy and increase the effectiveness of cost control.

4.2.2.5 BIM-GBC-05

The application of BIM technology in the construction planning phase brings more efficient resource management and construction process optimization. *Respondent 1 suggests that BIM models, construction teams can perform detailed virtual construction simulations, predict potential problems, and optimize construction sequencing and scheduling. This helps to avoid wastage of resources and conflicts and improves construction efficiency, thereby reducing construction costs. Respondent 7 narrates that BIM technology facilitates construction site coordination and real-time monitoring. With BIM models, construction teams can quickly access construction drawings and technical information on site, reducing errors and omissions and saving time and labor costs. BIM technology plays an important role in construction change and problem management. With BIM modeling, the construction team can record and manage construction changes in a timely manner to avoid unnecessary delays and additional costs.*

4.2.2.6 BIM-GBC-06

BIM technology supports the facility management team with accurate facility information and data. *Respondent 5 said that with BIM modeling, the facility management team can easily access information such as equipment parameters, maintenance records and operating status to help with equipment maintenance and management. This improves the service life of the equipment and reduces equipment failures and damages, which in turn reduces repair and replacement costs. Respondent 7 says that BIM technology can help facility management teams predict equipment maintenance costs. By simulating and analyzing the operation of equipment, the team can predict the maintenance needs and costs of the equipment and plan maintenance schedules wisely, avoiding unplanned repairs and maintenance costs.*

4.3 Validity and reliability

Internal consistency refers to the degree of consistency in coding, interpreting, and analysing the same data between different researchers in qualitative research [45]. In qualitative research, the researcher's subjective factors and personal views may affect the understanding and interpretation of the data, so it is important to assess internal consistency to ensure the credibility and reliability of the study [46].

In this study, the authors primarily used the consultative discussion method to assess the internal consistency of the study. During the data analysis stage, to ensure the credibility of the findings, the authors formed a group, which consisted of all the authors of this paper, to discuss coding during the data analysis process. By brainstorming, the authors were able to gain a fuller understanding of the meaning behind the data and reduce the impact of subjective bias.

4.4 Research limitations

Limitations exist in all studies, including this one. First, due to the nature of the study, data were coded, and themes were identified by one person, which may introduce subjective bias. Despite the methodological consistency adopted in the coding process, this single perspective analysis may not fully capture the multiple perspectives of different expertise. Further research could consider using multiple researchers for independent coding and analysis to increase the credibility and reliability of the findings.

5. Conclusions

5.1 RO1

This paper explores the effect of BIM (Building Information Modeling) application in cost control of green building projects in Shanghai through a systematic qualitative study. By collecting and analyzing and interviewing stakeholders with some experience, it is found that the application of BIM technology has a positive impact on the cost control of green building projects. The comprehensive analysis shows that BIM effectively reduces the cost of green building projects and improves the sustainability and overall efficiency of the projects through design optimization, clash detection, resource management, construction optimization, and operational forecasting. However, to fully utilize the benefits of BIM technology, it is recommended that project teams fully understand and master BIM technology and provide training and support to ensure its effective application. Future research can further explore the effectiveness of BIM application in different types of green building projects and provide insights into the development trend of BIM technology in the green building field.

5.2 RO2

This study conducted comprehensive research on the integration of Building Information Modeling (BIM) to enhance cost control strategies in green building projects in Shanghai. The results of the study show that the application of BIM greatly enhances the cost management strategies in all dimensions of green building projects in Shanghai. BIM mainly enhances energy strategy, material strategy, and design strategy in Shanghai green building cost control strategies.

i. Energy Strategy
   Design teams using BIM can evaluate multiple energy efficiency alternatives through energy simulation and analysis. This reduces operating costs.
ii. Design Strategy
   The visualization capabilities of BIM minimize errors and omissions in the design process, so its use has a significant impact on design strategy.
iii. Material Strategy
   BIM can work seamlessly with supply chain systems to minimize over-purchasing and waste, thus helping to reduce overall project costs.

6.Discussion

6.1 Interpretation of results

When analyzing the results of this study, it is evident that the results are largely in line with the authors' expectations, validating the positive role of BIM in green building cost control. This has been confirmed in the literature review [47]. The literature review shows the enhanced role of BIM in several green building cost control strategies [7]. However, the authors found some unexpected results that this study enhanced only some of the strategies and not all of them in the specific context of Shanghai, which is different from the broad coverage in the literature review.

When analyzing the literature review, many BIM-enhanced green building cost control strategies have been mentioned in the literature, covering the linkages between building construction resource management, building daylighting capabilities, building construction resource management and real-time cost control aspects, collaborative networks, and BIM [48]. However, the results of this study showed that BIM played a significant role only in material strategies, energy strategies and design strategies. This discrepancy may be due to geographical reasons, human-political factors, and other localized factors [49]. Although the results of this study could not cover all the strategies mentioned in the literature, it reflects the diversity of BIM applications in different regions and environments. It is worth noting that the results of this study are highly consistent with the literature review in terms of energy strategies, which suggests that the application of BIM in this area is indeed highly effective and adaptable in Shanghai. This is worth further exploring and emphasizing.

6.2 Comparison to existing studies

This study provides in-depth research on the issue of controlling costs in green building projects based on the combination of Life Cycle Costs (LCC) theory. Unlike previous studies that simply considered the stages of design, construction, and maintenance, the authors expanded the application of Life Cycle Costs (LCC) theory in their study. As mentioned by the authors in the literature review, the application of BIM in different phases has had a positive impact. In the building design phase, the application of BIM models enabled the design team to simulate and analyze the costs of various design options [50]. This application helped in choosing the most cost-effective solution among the many options. And in the construction phase, BIM's virtual coordination capabilities reduced conflicts and on-site rework, increasing construction efficiency, and thus reducing construction costs [51]. Therefore, this study breaks through the limitations of these three typical phases and considers all the factors affecting cost control, such as energy, technology, and materials, involved in the entire green building project. This comprehensive analysis makes our study more realistic and enables us to evaluate the role of BIM in controlling costs more comprehensively.

6.3 Contribution and Recommendations

This study expands the application of LCC theory in the field of green building cost control. By combining LCC theory with BIM green building practices, the researchers provide a new perspective and methodology that enables a more comprehensive assessment of the role of BIM in the cost control of green building projects. This is important for the theoretical development of the green building field.

This study uses the interview method to conduct in-depth discussions and summaries with frontline staff. By communicating with practitioners, the researcher can gain a deeper understanding of the actual situation, challenges, and opportunities of BIM in green building cost control in real projects. This will help bridge the gap between academia and practice, promote the integration of theory and practice, and improve the practicality and operability of the study.

These limitations provide opportunities for further research. Therefore, the results of this study open the way for future research and provide directions for future research. Future studies could adopt more diverse research methods, such as mixed-methods research, case studies, or empirical research, to obtain more comprehensive and holistic data. In addition, widening the sample size and increasing the time span of the research data could also help improve the reliability and generalizability of the findings.

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