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Impact of BIM Technology in Enhancing the Quality Control of Project Management in China

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ABSTRACT

BIM technology introduced and applied in the global construction industry; the construction sector of China has followed the pattern of innovation in this respect. BIM technology improves project management and quality control by the incorporation of smart digital technologies thus enhancing efficiency, collaboration, and cost-effectiveness of construction projects. Even though the adoption of BIM has created numerous benefits, for instance, decreased design errors, enhanced project quality and productivity among others, the level of its application is not clear, the systematic studies evaluating practical effects are lacking. This research intended to introduce the current status of BIM applications, particularly its role in quality control, explains the factors affecting the quality control by using BIM in project management of China through Systematic Literature Review from the year 2014 to 2023 and a further analysis and discussion through the results of questionnaire. The database are Scopus and Web of Science. After analysis, it shows that these past few years have witnessed a growth of BIM technology and its applications in quality control of project management by efforts and active responses of industry in China. Although the problems of technological integration, industry standardization as well as professional training still existed, small-to-large scale construction projects, have displayed a good potential to increase the quality control starting from design up to completion process. Meanwhile, it shows that the factors affecting the quality control by using BIM are technological innovation and development, information sharing and collaborative mechanisms, 3D modelling and visualization capabilities, and support throughout the project lifecycle respectively. By the applying of specific cases in literature review, it contributes the elaboration of academic theory and practices in the field of BIM as well as communication and mutual understanding between the architecture, engineering, and IT field and further discussion for the factors affecting the quality control of project management by using BIM.

Keywords:
BIM; quality control; project management; smart digital; BIM influenced factors

1. Introduction

Building Information Modeling (BIM) technology is one of disruptive technologies, which has been changing the whole construction industry worldwide especially in China. It is acknowledged that

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BIM has been a core element of improving quality of work in project management, which gives a precise design, efficient allocation of resources, and effective collaboration between partners, dramatically decreases making errors and financial overruns [1]. Nonetheless, the full use of BIM in China is still not realized because of the challenges like the integration with the existing systems and the lack of standardization, which are major barriers to its effective implementation [2].

The in-depth research of Chinese construction industry regarding the application of BIM technology is not precisely carried out, the literature concerning this issue lacks the specifics on how the customized BIM technology can cover local needs. This gap most clearly lies in the case of the delivery of projects and quality checking, processes of the construction work which are the principal ones on the way to the success of projects [3]. These problems could be tackled if known what the factors affecting the quality control by using BIM project management in China.

The main objectives of the research are to introduce the current status of using BIM in quality control, also explains the influenced factors affecting the quality control by using BIM in project management, which compare with the selected references and the result of questionnaire. The result will also highlight which would be applicable to enhance the use of BIM in the quality control of project management in China.

1.1 SLR Method

This part emphasizes the systematic literature review (SLR) process as one of the foundations, which provides an analysis of BIM's role across industries, which outlined includes defining objectives and selection criteria, conducting a comprehensive search using databases in Scopus and Web of Science. Research questions were raised as Table 1.

Table 1
The research questions

Research divisions	Questions	Perspectives
Current status	What is the status of using BIM in quality control of project management?	Theory
Influenced factors	What are the factors of using BIM affecting the quality control of project management?	Technologies

1.1.1 Process of SLR

SLR (systematic literature review) process in this research precisely narrows the area of useful literature by applying a systematic procedure for obtaining reliable information. The searches are carried out through the authoritative databases as Scopus and Web of Science, focusing on the fields of engineering to get a broad sample of articles. The keywords include BIM, Project Management and Quality Control, the time limitations between the years 2014 and 2023. Next is selecting journal articles to guarantee the level of depth of the research and requiring these in English and open access to guarantee global accessibility. The last step is to deduplicate the literature across databases to keep the articles from being studied twice. Final references from Scopus and WOS are as follows in Table 2.

Table 2
The final selected references

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Scopus	0	2	1	4	2	4	3	8	11	8
WOS	0	1	2	1	6	6	10	9	10	14

1.1.2 Data analysis

The Figure 1 shows the number of publications per year from 2014 to 2023, which can be seen that there were 3 publications in both 2015 and 2016. After that, the number of publications yearly increased. Overall, the number of publications shows a steady upward trend, especially after 2020, where the growth is more significant, indicates that during this period, research increased significantly, which outcomes were continuously emerging.

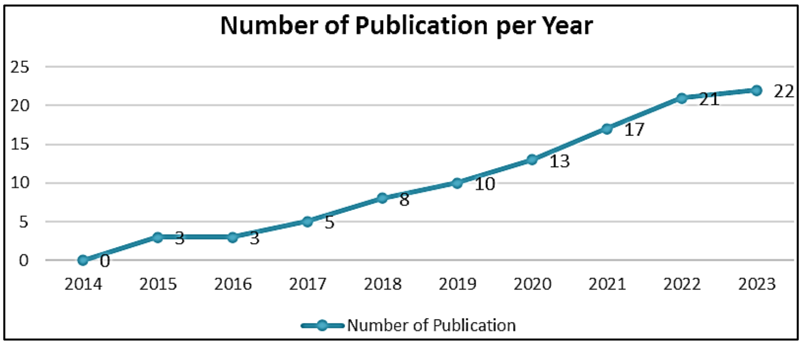

Fig. 1. Number of publications

The Table 3 lists 13 journals along with the article numbers and ranks. The top three journals are "Buildings" with 17 articles, "Automation in Construction" with 13 articles, and "Applied Sciences" with 12 articles. Both "Advances in Civil Engineering" and "IEEE Access" published 4 articles each, while "Journal of Information Technology in Construction" and "IWRED" each published 3 articles, which evident that "Buildings," "Automation in Construction," and "Applied Sciences" contribute significantly to the body of research.

Table 3
Article numbers of selected journal

No.	Journal	Article numbers	Rank
1	Buildings	17	1
2	Automation in Construction	13	2
3	Applied Sciences	12	3
4	Advances in Civil Engineering	4	4
5	IEEE Access	4	4
6	Journal of Information Technology in Construction	3	6
7	IWRED	3	6
8	Journal of Building Engineering	2	8
9	International Journal of Construction Management	2	8
10	Computers in Industry	2	8
11	Journal of Sensors	2	8
12	Sustainability	2	8
13	IPICSE	2	8

The Table 4 displays the number of publications and ranks for various countries. China leads with 25 publications, followed by the United Kingdom with 12 publications. Australia and Spain each has 8 publications, placing them with the third place. The United States and South Korea both have 7 publications, ranking fifth. Canada, Germany, Italy, Portugal, and Poland each have 4 publications, sharing the seventh rank. China in terms of publication numbers indicates a strong focus in research within this field. The high publication counts in the United Kingdom, Australia, and Spain suggest active research communities and robust academic frameworks supporting these studies. The presence of multiple countries with similar publication numbers highlights the global interest and collaborative efforts in this area.

Table 4
Publications of selected countries

No	Country	Publications	Rank
1	China	25	1
2	United Kingdom	12	2
3	Australia	8	3
4	Spain	8	3
5	United States	7	5
6	South Korea	7	5
7	Canada	4	7
8	Germany	4	7
9	Italy	4	7
10	Portugal	4	7
11	Poland	4	7

The VOS viewer as Figure 2 illustrates the relationships in the field of research, which the most topics include "quality control," "BIM", and "project management." Surrounding these core topics are related terms such as "three-dimensional computer graphics," "risk management," "automation," and "virtual reality," which reveals that quality control and BIM are central to the research discourse, reflecting their critical role in advancing construction industry practices. The key words suggest a significant focus on enhancing efficiency, accuracy, and management in projects management. The related terms highlight the interdisciplinary nature of this research area, incorporating elements of technology, management, and engineering to address contemporary challenges in construction development.

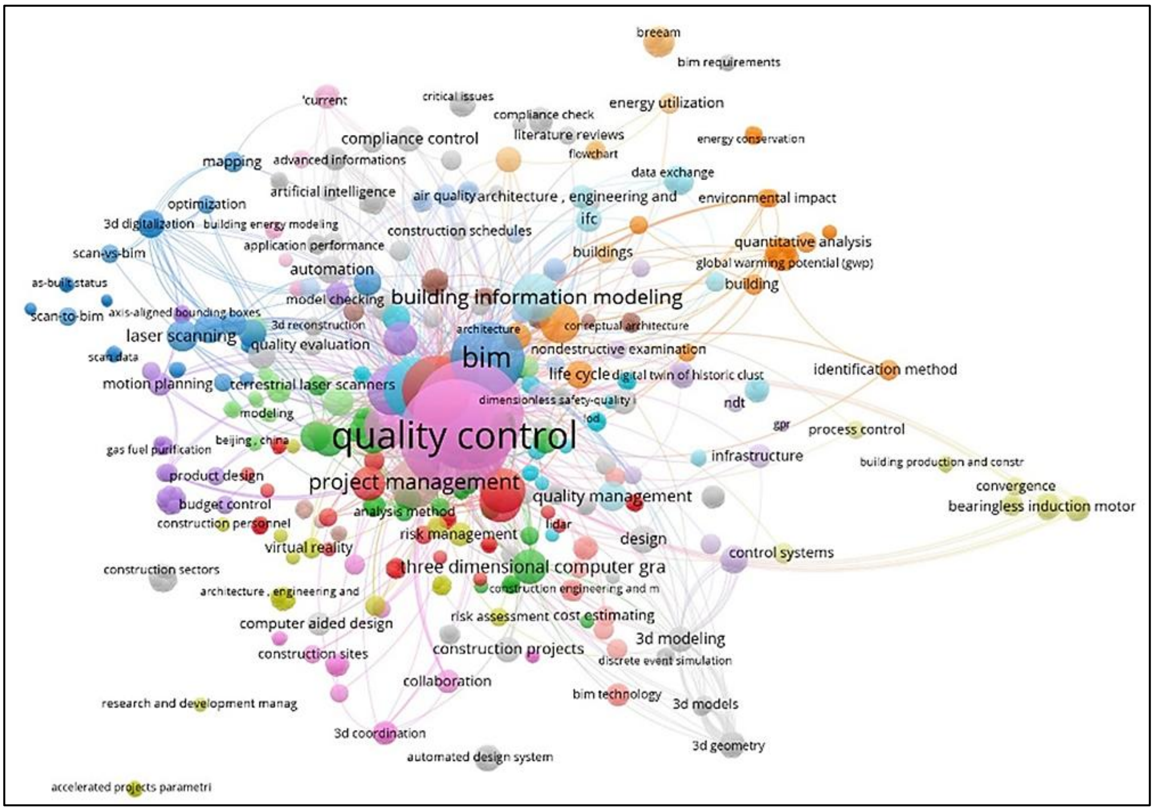

Fig. 2. VOS viewer

1.2 Current Status of BIM in Quality Control from Selected References

BIM is shifting the quality control of project management, increasing efficiency, collaboration, and cost-effectiveness through advanced technologies like IoT, RFID, and UAVs globally. The implementation of its policy in the field of infrastructure and green building advocated by the UK, USA, and China stresses its applicability worldwide [4,5]. BIM not only helps produce exact and precise 3D models and optimize processes but also deals with other construction activities such as geometrical quality assurance and environmental impact assessments [6-8]. The worldwide use of BIM is shown through its compatibility with digital twin technologies and widespread use in major countries, making the projects more effectively managed. They can be clearly witnessed in infrastructure projects and green building initiatives where BIM become vital in moving forward the construction industry [9,10]. BIM can also bridge the communication gap and technical integration problems in areas such as China and Poland even though those tasks remain challenging, continuing to make strides in raising quality control levels on a global scale [11,12].

The implementation of BIM in China introduced in 2002 and since then it was changing construction industry largely due to initiatives for standardization of the practices and rapid adaptation of the approach by contractors. The national improved project management and quality control is clearly visible in large-scale infrastructure projects where the precision and efficiency of BIM are extremely important [13-15]. The China BIM Union was established in 2012, and the implementation of national standards has alleviated the methodological deficiency situation, helping in the general application of BIM across the industry [16,17]. Local government undertake BIM guidelines customizing to the regional needs which leads to flexibility and efficiency across diverse communities [18,19]. The recent policy encouraged the integration of BIM with the advanced technologies like AI and machine learning, extending the boundaries of project management and operational efficiency [20-22]. Technological integrations like IoT, VR/AR, GPS, and RFID have changed the BIM application, which advance asset management, monitoring, and field verification. With integration of AR into BIM, new technologies are developing, enhancing quality assurance and infrastructure management through advanced visualization and real time data analysis [9,23].

1.3 Influenced Factors Affecting the Use of BIM in Control Quality

BIM has become an indispensable tool in the construction industry, transforming project management and operations. By transitioning from traditional 2D to advanced 3D modelling, it enables more precise designs, enhances collaboration, and improves operational efficiency through innovative applications. Its capabilities and integration with other cutting-edge technologies highlights the model's impact on enhancing accuracy, facilitating communication, and supporting comprehensive project lifecycle management.

1.3.1 Technological innovation and development

The use of BIM has dramatically enhanced the management and the operational of practices through performance of transition from the previous 2D to 3D digital modeling systems which enable new innovative ideas like automatic HVAC control, TLS data for performance of fire disaster evacuation simulation and BIM based traffic analysis. It has improved the precision of the design, the organization of the information, and the increase of the real-time collaboration, especially in such areas as Hong Kong and Spain [24-28]. The incorporation of BIM into work processes has been changing conventional practices with the protection of regard to fuel design of traffic intersection where the improvement of the design procedures is through dynamic simulations that accord precision to the planning phases of a project [26]. Similarly, the use of BIM and TLS data in disaster management has revolutionized evacuation planning, offering quick and reliable simulations, a substantial improvement over traditional technique [28]. BIM's role in HVAC systems not only supports automated control and optimization but also leads to significant operational cost reductions and energy conservation [24]. All these improvements indicate BIM's application on managing projects by improving on existing operations methods, collaboration data, costs and time of delivering across the world [29].

1.3.2 Information Sharing and Collaborative Mechanisms

BIM serves as a vital open platform in the construction industry, enhancing collaboration through effective visualization and information sharing among engineers, inspectors, and maintenance teams. Its integration with technologies like 3D point cloud and RFID improves data analysis and quality inspection, aiding in applications such as underwater bridge deterioration assessment [30]. The combination of BIM with RFID technology enhances collaborative construction by facilitating real-time updates and sharing of information across various disciplines, optimizing collaborative processes and overcoming communication barriers within the industry. This central repository function of BIM not only streamlines the communication among diverse stakeholders but also supports complex project management, including heritage buildings guided by Heritage BIM (H-BIM), illustrating its crucial role in fostering effective collaboration and optimizing project management.

1.3.3 3D Modelling and visualization capabilities

BIM significantly enhances construction project management by improving accuracy, facilitating communication, and enabling efficient design modifications, which integrates technologies like 3D point cloud, RFID, and NDTs to create detailed parametric models that visualize and manage data effectively, aiding in tasks such as underwater bridge deterioration assessment and real-time quality control [31,32]. These models not only reduce errors but also enhance the understanding of complex project components. Advanced visualization tools like RFID integrated within BIM facilitate real-time updates and communication among stakeholders, improving the management and quality control throughout the project's lifecycle [33]. Furthermore, the incorporation of VR and AR technologies into BIM provides intuitive and interactive environments that help stakeholders visualize, interact with, and better understand project designs and statuses. BIM's dynamic nature allows for ongoing design updates and modifications, responsive to changing demands, thus enabling early detection and resolution of conflicts, particularly in complicated project areas such as pavement construction [34]. Overall, BIM fosters effective collaboration and decision-making, minimizing costly errors and delays, thereby enhancing overall project efficiency and outcomes.

1.3.4 Support throughout the project lifecycle

BIM plays a crucial role in enhancing the planning, design, and construction phases of building projects by providing detailed and accurate modeling capabilities. In the planning stage, it facilitates complex tasks such as rebar modeling for variable section columns, efficiently addressing geometric and structural challenges to ensure high-quality conceptual plans, reducing the need for rework, and enabling precise financial estimations [35]. This accuracy promotes effective site analysis, detailed structural planning, and integration into broader project plans. During the design and construction stages, its collaborative and integrated approach with 3D modeling capabilities enhances architectural and engineering planning, encouraging cooperation among diverse stakeholders, which not only minimizes errors but also aids in resource planning, safety management, and proactive problem-solving, ensuring projects are well-organized and adaptable to challenges [36,37]. BIM's application across these phases improves efficiency, planning accuracy, and collaborative processes, making it an indispensable tool in the construction industry.

1.4 Quality Control of Project Management

BIM enhances various aspects of construction projects from planning and design to maintenance and cost control. Through the integration of innovative technologies such as real-time image comparison, laser scanning, Digital Twins, and Scan-to-BIM, which significantly increases accuracy, reduces errors, and supports dynamic, iterative design processes. These capabilities not only streamline the construction phases but also extend into operational efficiency and sustainability during the maintenance phase. By optimizing project planning, design quality, process monitoring, and management, BIM plays a critical role in improving cost effectiveness and time management across construction projects. This part outlines BIM's transformative impact on project efficiency, quality control, and sustainability, demonstrating its essential role in project management.

1.4.1 Project planning and design quality

BIM significantly transforms planning and design in construction by enhancing accuracy and fostering innovation. In China, BIM reduces design errors and aligns construction more closely with original plans through technologies like real-time image comparison and laser scanning, which facilitate defect detection and efficient time usage [12,38]. This accuracy improves planning feasibility, enabling the construction industry to maintain high-quality conceptual plans and manage costs effectively. Additionally, BIM supports modular construction, allowing for rapid design changes and innovative solutions, thereby minimizing errors, and avoiding delays. The integration of BIM with modular and industrialized construction methods not only improves project efficiency and innovation but also enables dynamic, iterative design processes that adapt to changing needs and conditions [39,40]. Overall, BIM's role in enhancing the planning, design, and construction stages ensures that projects are executed more efficiently, accurately, and innovatively, making it an essential tool for well-organized and successful construction projects.

1.4.2 Construction process monitoring and management

BIM remarkably enhances construction site management by integrating with technologies such as Digital Twins and Scan-to-BIM, facilitating real-time monitoring and proactive problem-solving, which improves safety and process management. This technology is crucial for managing large-scale engineering data and coordinating cross-professional efforts, thus boosting operational efficiency through early detection of issues via 3D modelling and 4D simulation models [41-43]. BIM's application in modular construction allows for rapid design adjustments and innovative solutions, enhancing project accuracy, feasibility, and adherence to building regulations. Furthermore, the integration of BIM with MBD technology enhances quality control standards, supporting efficient cost and time management across construction phases [44,45]. BIM's deployment optimizes site delivery, quality, health, and safety management, marking it as an essential tool for improving construction project efficiency, accuracy, and innovation.

1.4.3 Operational efficiency and sustainability in maintenance phase

BIM improves the sustainability and efficiency of facility operations and maintenance by integrating advanced technologies such as geometric dimensioning, which fills a critical gap in the construction industry by extending its utility beyond the design and development phases to operations and maintenance (O&M), facilitating real asset management and efficient building operations. This integration ensures that BIM models are not only theoretical designs but functional systems applicable for onsite use, supporting quality management and long-term asset performance tracking [5]. Meanwhile BIM contributes to energy management by improving material efficiency and accuracy during construction, which enhances the overall energy efficiency of buildings. The use of geometric dimensioning and tolerancing (gDTs) in BIM for quality control helps to eliminate rework and minimize energy consumption throughout the building's lifecycle, promoting sustainable building practices and energy conservation [46]. BIM's application in facility management and energy efficiency exemplifies its role in promoting green building practices and improving the operational phase of buildings, highlighting its comprehensive benefits in enhancing building sustainability and operational effectiveness.

1.4.4 Project cost and time control

BIM enhances cost and time management in construction by optimizing cost forecasting, budgeting, and schedule management. By streamlining cost estimation processes and effectiveness, BIM reduces errors and ensures precise schedule adherence, particularly in modular construction, which prevents reworks and delays [10,47], which also integrates project timelines with budget estimates, supported by government policies and industry support, leading to better planning, execution, and resource coordination in projects including green buildings. Several articles demonstrate BIM's capacity to enhance cost control and project efficiency, highlight BIM's role in effective time management and schedule control by addressing construction incompatibilities and optimizing engineering scheduling [42,48-50]. The frame of influenced factors is shown in Figure 3.

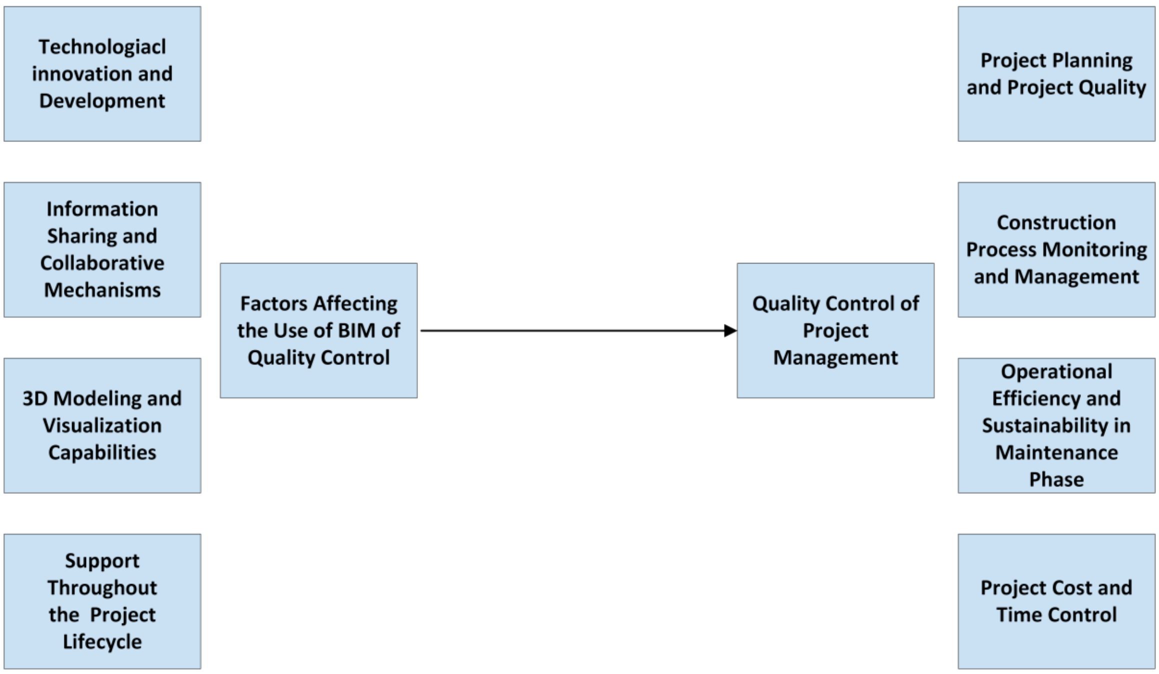

Fig. 3. Frame of influenced factors

2. Methodology

This part highlights the integral role of deductive reasoning in generalizing from theoretical frameworks to specific instances. The creation of questionnaires is an interactive process, involving design, execution, and data analysis, which ensures the reliability and practical applicability of the findings to the construction industry [51-55]. Focusing on Shanghai's construction industry, the research investigates BIM's effects on project quality, efficiency, and customer satisfaction through extensive surveys involving diverse stakeholders, including managers, experts, and workers, with 428,300 persons being the total number based on the data of 2022, which published in December, 2023 [56]. To make sure that the sample population is a true representation of the survey and accurate, 384 respondents were decided based on the Morgan formula. The questionnaire section of the research meticulously outlines the design and application of survey instruments as critical tools for collecting detailed data on the implementation and impacts of BIM technology throughout various stages of project management.

By investigating BIM's technological advancements, the questionnaire aims to illuminate how these innovations enhance project effectiveness and quality, identifying challenges like technical training, user acceptance, and data security that are critical for BIM's integration into projects [57-59]. Through gathering data on the challenges encountered at various stages of the project lifecycle, the questionnaire contributes to developing effective strategies to overcome these barriers, thereby promoting the broader adoption and optimization of BIM technology, which segment effectively encapsulates the multifaceted role of BIM in enhancing construction project management, emphasizing how it supports better quality control, increases efficiency, and fosters collaboration. It highlights the need to address implementation challenges to ensure BIM's effective integration and optimization within the industry.

3. Results

This part analyses the result and meet the objectives of the research. Through the analysis of the test results of validity and reliability, respondent demographics, and other aspects that are related to the research objectives. In this part, the application of BIM technology in Chinese project management and its impact in quality control by using BIM are revealed. The reliability and validity of the questionnaire are checked out to make sure that the data collected is of good quality. It is significant to present the characteristics of the respondents, such as gender, age, education, work experience, occupation, salary, and BIM usage duration, to provide the necessary background for the analysis. The PCA's rotated component matrix and other necessary results are also included which provide a wide range of results and analysis for the research.

3.1 Validity and Reliability Test Results

Before conducting data analysis, rigorous tests were performed to ensure the accuracy and consistency of the questionnaire data. The following sections provide a detailed description of the test results.

3.1.1 Reliability test results

The reliability is done by using Cronbach's Alpha coefficient, which measures the level of agreement among the items on the questionnaire. In Table 5, Cronbach's Alpha (sometimes called the correlation coefficient) is a very common analysis resilience approach that helps to check how the different items of the questionnaire correlate with each other to found out the trustworthiness of the questionnaire at the end. The reliability coefficient for the test administered are as follows:

Table 5
Reliability statistics of questionnaires

Reliability statistics		
Cronbach's Alpha	N of Items	Variables
0.889	5 (a1-a5)	A: Technological innovation and development
0.881	5 (b1-b5)	B: Information sharing and collaborative mechanisms
0.868	5 (c1-c5)	C: 3D modeling and visualization capabilities
0.883	5 (d1-d5)	D: Support throughout the project lifecycle
0.879	5 (e1-e5)	E: Project planning and design quality
0.883	5 (f1-f5)	F: Construction process monitoring and management
0.880	5 (g1-g5)	G: Operational efficiency and sustainability in maintenance phase
0.880	5 (h1-h5)	H: Project cost and time control

3.1.2 Validity test results

The Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of Sphericity were used to assess the structural validity and suitability of the survey data for factor analysis. In Table 6, the KMO value of 0.0937 indicated that the sample data was adequate for analysis, and Bartlett's Test confirmed significant correlations among the variables with a Chi-square value of 9467.209 and a p-value of <0.001, suggesting a strong factor structure. These tests demonstrated that the questionnaire has high internal consistency and structural validity, making it a reliable tool for measuring variables critical to the research. The results indicate that the questionnaire is well-developed and can effectively capture the dimensions of BIM efficiency in project management and quality control.

Table 6
KMO and Bartlett`s test of the questionnaires

KMO and Bartlett's test		
Kaiser-Meyer-Olkin measure of sampling adequacy.		.937
Bartlett's test of Sphericity	Approx. chi-square	9467.209
	df	780
	Sig.	.000

3.2 Demographic of Respondents

The demographic information of respondents in Table 7 is crucial for understanding the context and background of the survey participants. This section provides a detailed analysis of the demographic characteristics of the respondents who participated in the study, including gender, age, working years, occupation, salary, educational background, and duration of BIM usage. These characteristics help to provide a comprehensive understanding of the sample population and offer valuable insights into the relationship between these variables and the application of BIM technology in construction projects.

In Table 7, most respondents are male (80.21%), indicating a significant gender imbalance in this field. The age distribution shows a concentration in the 21-40 years range, making up 54.42%, suggesting that the sector appeals to and is dominated by a relatively younger workforce. Those with 1-10 years of work experience are the largest group, accounting for 39.84%, reflecting a possibly high turnover rate or a growing industry attracting newer professionals. Most respondents work as engineers (40.1%) or project managers (39.21%), highlighting the technical and managerial focus within the sector. Regarding salaries, the range between RMB 15,000 and RMB 25,000 encompasses 29.95% of respondents, which indicate the industry-standard compensation for mid-level professionals in this field. As for educational backgrounds, 50% have a bachelor's degree, emphasizing the requirement for a higher education level in this industry. In terms of BIM usage, 3-5 years is the most common duration (25%), suggesting that BIM technology has been gradually adopted, reflecting ongoing technological integration in the sector. The next group, 5-8 years (20.05%), shows continued usage and possibly increasing expertise among users.

Table 7
Demographic of respondents

Demographic item		Frequency	Percentage
Gender	Male	315	80.21%
	Female	69	19.79%
Age	21-30	115	29.95%
	31-40	97	25.26%
	41-50	76	19.79%
	51-60	58	15.10%
	Above 60	38	9.90%
Working years	1-10	153	39.84%
	11-20	117	30.47%
	21-30	76	19.79%
	Above 30	38	9.90%
Occupation	Engineers	154	40.10%
	Project manager	116	30.21%
	Lecturers	38	9.90%
	Designers	38	9.90%
	Others	38	9.90%
Salary (K)	<RMB8,000	38	9.90%
	RMB8,000-RMB15,000	96	25.00%
	RMB15,000-RMB25,000	115	29.95%
	RMB 25,000-RMB35,000	78	20.3%
	>RMB35,000	57	14.85%
Background	Diploma	38	9.90%
	Bachelor	192	50%
	Master	115	29.95%
	Doctorate	39	10.16%
Duration of BIM usage (years)	Below 3	97	25.26%
	3-5	96	25%
	5-8	77	20.05%
	8-10	57	14.84%
	Above 10 years	57	14.84%

3.3 Results and Analysis of Current Status of Application of BIM Use

As can be seen that eight factors are relevant about the status of BIM applications, which are identified in different variables as follows in Table 8. The Table 8 displays the average scores and rankings for eight variables of questions from a survey on the status of BIM usage. The highest-ranked factor is "technological innovation and development" with a mean value of 2.907, followed closely by "project cost and time control" at 2.901. "Support throughout the project lifecycle" ranks third with a mean of 2.891, while "Project Planning and Design Quality" is fourth at 2.868. Other significant factors include "information sharing and collaborative mechanisms" (2.848), "construction process monitoring and management" (2.834), and "3D modelling and visualization capabilities" (2.763).

In addition, the top ranking of technological innovation and development highlights its crucial role in enhancing project outcomes. Effective cost and time control are also essential, emphasizing the importance of efficient resource management. Continuous support throughout the project lifecycle and high-quality planning and design are vital for maintaining project momentum and ensuring successful delivery. Other factors, such as information sharing and 3D modelling capabilities, indicate areas where further improvements could be beneficial.

Table 8
Mean of influenced factors

Influenced factors	Mean	Rank
A: Technological innovation and development	2.907	1
H: Project cost and time control	2.901	2
D: Support throughout the project lifecycle	2.891	3
E: Project planning and design quality	2.868	4
B: Information sharing and collaborative mechanisms	2.848	5
G: Construction process monitoring and management	2.834	6
F: Construction process monitoring and management	2.814	7
C: 3D modeling and visualization capabilities	2.763	8

3.4 Results and Analysis of Influenced Factors

This part discusses the analysis of influenced factors affecting the application of BIM in project management through the survey data. The analysis focuses on the communalities table, which is used to identify the underlying relationships between observed variables.

3.4.1 Communalities table analysis

The communalities table represents the variance in each variable by the extracted factors shown in Table 9. The initial communalities are all 1.000, indicating that each variable has all its variance considered in the factor analysis. The extraction communalities are the estimates of the variance in each variable by the factors after extraction.

The communalities table provides key insights into the influenced factors affecting BIM in project management. High extraction values for variables like a1 (0.833) and b1 (0.831) emphasize the importance of integration and data management for successful BIM use. Similarly, values for e1 (0.839) and g1 (0.837) point to the critical roles of user expertise and training. Moderate values for c1 (0.807) and d1 (0.855) highlight the necessity for effective inter-departmental communication and collaboration, while lower values like a3 (0.617) and c2 (0.613) indicate that technical challenges, though less dominant, still require attention to enhance BIM efficacy. These findings underscore the complex nature of BIM implementation, guiding organizations to prioritize key areas such as robust software, strong technical support, and addressing technical challenges for improved project outcomes.

Table 9
Communalities table analysis

Communalities					
	Initial	Extraction		Initial	Extraction
a1	1.000	0.833	b1	1.000	0.831
a2	1.000	0.702	b2	1.000	0.657
a3	1.000	0.617	b3	1.000	0.647
a4	1.000	0.696	b4	1.000	0.625
a5	1.000	0.660	b5	1.000	0.660
c1	1.000	0.807	d1	1.000	0.855
c2	1.000	0.613	d2	1.000	0.689
c3	1.000	0.614	d3	1.000	0.629
c4	1.000	0.630	d4	1.000	0.647
c5	1.000	0.657	d5	1.000	0.689
e1	1.000	0.839	f1	1.000	0.799
e2	1.000	0.632	f2	1.000	0.684
e3	1.000	0.622	f3	1.000	0.652
e4	1.000	0.650	f4	1.000	0.638
e5	1.000	0.669	f5	1.000	0.665
g1	1.000	0.837	h1	1.000	0.831
g2	1.000	0.615	h2	1.000	0.660
g3	1.000	0.666	h3	1.000	0.626
g4	1.000	0.637	h4	1.000	0.665
g5	1.000	0.657	h5	1.000	0.645
Extraction method: Principal component analysis					

3.4.2 Total variance explained analysis

The Table 10 illustrates the results of the principal component analysis, which is used to identify the underlying factors that explain the variance in the data. This section provides a detailed analysis of the table, focusing on the significance of each component and its contribution to the overall variance.

Table 10
Total variance explained analysis

Total variance explained			
Component	Rotation sums of squared loadings		
	Total	% of Variance	Cumulative %
1	3.571	8.929	8.929
2	3.568	8.921	17.850
3	3.509	8.772	26.621
4	3.486	8.716	35.337
5	3.450	8.625	43.962
6	3.364	8.411	52.373
7	3.325	8.314	60.686
8	3.174	7.936	68.622
Extraction method: Principal component analysis			

The analysis of eight factors on BIM implementation in project management quality control reveals that these components collectively explain 68.622% of the total variance in the dataset, with the first component alone capturing nearly 9%. This significant portion suggests that these factors are crucial in understanding the dynamics of BIM application, particularly in areas such as technological capabilities, user expertise, data management, and inter-departmental coordination.

The high eigenvalues and percentages of variance associated with the initial components particularly underscore their importance in capturing the most substantial patterns affecting BIM adoption. This detailed variance analysis provides organizations with insights into which areas to focus on to enhance BIM practices, improve training, invest in technology, and foster collaboration, thereby informing targeted strategies for more effective project management.

3.4.3 Rotated component matrix analysis

The Table 11 shows the loadings of each variable on the identified components after rotation. The rotation (Varimax with Kaiser normalization) aims to achieve a simpler and more interpretable structure by maximizing the variance of squared loadings of a factor (component) across variables. This section provides a detailed analysis of the table, focusing on the significance of the loadings for each component and their implications for the factors affecting BIM application in project management quality control.

Table 11
Rotated component matrix analysis

Rotated component matrix[a]									
Factors	No.	1	2	3	4	5	6	7	8
E	e1	0.868							
	e5	0.754							
	e2	0.748							
	e4	0.734							
	e3	0.702							
G	g1		0.868						
	g5		0.751						
	g3		0.747						
	g4		0.729						
	g2		0.705						
F	f1			0.832					
	f2			0.731					
	f5			0.707					
	f3			0.705					
	f4			0.702					
H	h1				0.842				
	h5				0.741				
	h4				0.732				
	h2				0.716				
	h3				0.701				
B	b1					0.840			
	b2					0.739			
	b3					0.734			
	b5					0.726			
	b4					0.668			
A	a1						0.836		
	a4						0.769		
	a2						0.731		
	a3						0.659		
	a5						0.651		
D	d1							0.866	
	d5							0.725	
	d2							0.721	
	d4							0.695	

Table 11
Rotated component matrix analysis

Rotated component matrix[a]									
Factors	No.	1	2	3	4	5	6	7	8
	d3							0.640	
C	c1								0.794
	c5								0.695
	c3								0.679
	c4								0.674
	c2								0.646

Extraction method: Principal component analysis.
Rotation method: Varimax with Kaiser normalization[a].
a. Rotation converged in 7 iterations.

The PCA's rotated component matrix reveals significant correlations, highlighting key factors in BIM implementation for project management quality control. high loadings on components like data management and integration (component 1), user expertise and training (component 2), and software capabilities (component 3) underline their essential roles. other components focus on the importance of inter-departmental communication (component 4), organizational commitment (component 5), addressing technical challenges (component 6), cost management (component 7), and external collaboration (component 8). these findings underscore the need for robust data management, skilled BIM tool use, strong organizational backing, and effective external partnerships to optimize BIM's impact.

This analysis points out the complex nature of BIM implementation, guiding organizations to enhance software capabilities, training, leadership support, and collaborating to address technical and resource challenges to improve BIM effectiveness and project outcomes.

4. Discussion

This part discusses the adoption and impacts of BIM across various stages of construction projects, exploring its widespread application and the perceived benefits as evidenced by industry surveys, which extends to the challenges and strategic implementations that influence the effectiveness of BIM in improving project outcomes, emphasizing the importance of continual adaptation and training within organizational practices.

4.1 Further Discuss of Current Status

As the industry gravitates towards more sophisticated and efficient project management methods, understanding the extent of BIM's adoption and its impact on project execution becomes crucial. This part further discusses the implementation rates of BIM across the construction industry, exploring how its integration enhances project quality, efficiency, and stakeholder collaboration, which highlights the widespread benefits from BIM applications at different project stages, from design through to maintenance, while also addressing the challenges that hinder its full-scale adoption.

4.1.1 Implementation and benefits of BIM technology

Survey results indicate a significant implementation rate of BIM technology in the construction industry, with about 60% of respondents reporting full integration within their projects. This adoption demonstrates a robust recognition of BIM's utility in improving accuracy, efficiency, and collaboration across project stages. The remaining 40% of participants are in various stages of BIM integration, indicating a trend towards its universal application in the industry. BIM's role in enhancing project quality through precise 3D modelling and early detection of design flaws significantly minimizes errors and reworks, thereby boosting overall project efficiency.

The benefits of BIM extend to several critical aspects of construction management, which fosters enhanced collaboration by providing a common platform where all stakeholders have access to up-to-date project information, reducing misunderstandings and ensuring that everyone is aligned with project goals. This improved communication is particularly crucial in large-scale projects involving multiple teams. BIM's clash detection capabilities enable early identification of potential conflicts between different systems, such as electrical and plumbing, preventing costly and time-consuming corrections during the construction phase. It also contributes significantly to resource management by allowing more accurate material take-offs and scheduling, thus reducing waste and optimizing labour deployment. The technology also enhances the maintenance phase of projects by providing detailed information on building components, facilitating effective long-term facility management.

4.1.2 Advanced uses and challenges of BIM

BIM's application spans various project stages, from design to maintenance. During the design phase, approximately 74.6% (For the Factors E, the whole marks which is more than 10) of survey participants noted that BIM enables efficient and accurate architectural planning, substantially reducing the likelihood of costly design errors. In the construction phase, BIM supports the smooth progression of projects by aiding in the detection of clashes and coordinating multiple stakeholder activities, which enhances operational efficiency and project delivery. In the maintenance stage, BIM serves as a comprehensive repository of detailed, accurate building information, which significantly aids in effective maintenance planning and operation, which reduces the time and effort required to access and manage building information, thereby enhancing the overall performance and lifespan of facilities.

The implementation of BIM is also facing challenges, technical barriers, software interoperability issues and high licensing costs can hinder its widespread adoption. Resistance to change from traditional practices and the high initial investment required also pose significant obstacles, particularly for small and medium-sized enterprises. These challenges underscore the need for planning and investment in training to fully leverage BIM's potential in construction practices.

4.2 Further Discuss of Influenced Factors

This part discusses the analysis of influenced factors affecting the application of BIM in project management quality control from the survey data, focusing on the different aspects in the selected references and the result of questionnaire.

4.2.1. Training needs and technological competitiveness

Practitioners stress the urgent need for ongoing training to bridge current skill gaps, emphasizing the necessity of mastering up-to-date BIM tools for effective implementation due to immediate operational challenges that necessitate rapid upskilling. Conversely, literature emphasizes a strategic approach, advocating for continuous professional development to maintain competitiveness in the evolving technological landscape of construction, highlighting the importance of long-term planning in staying technologically updated to facilitate effective project coordination [24,29].

4.2.2 Communication challenges

Survey respondents focus on day-to-day communication challenges, emphasizing the need for effective tools to ensure all stakeholders have timely project information to mitigate misunderstandings. Literature suggests establishing robust, long-term communication frameworks that foster a collaborative environment and ensure consistent information exchange throughout project lifecycles, aiming for a sustainable and structured approach to information sharing [28,29].

4.2.3 Benefits of 3D visualization

Practitioners value the immediate benefits of 3D visualization in BIM for enhancing design accuracy and facilitating better planning and coordination, which helps in communicating complex structures during meetings. The literature, however, considers the broader strategic benefits, focusing on long-term project success and innovative design possibilities that enhance design precision, reduce errors, and facilitate more effective decision-making [25,26].

5. Conclusions

This research has provided a systematic literature review of BIM technology implementation in the Chinese construction sector. Using BIM, there is better management of works and quality assurance that is through 3D which check for lapses in designs hence fewer mistakes and consequential adjustments, which make project delivery efficient. The adoption of BIM still meets challenges, which include the lack of qualified personnel to supply the market need, capability of software in exchanging data with another program. Strategies include enhancing professional training to improve practitioner skills, promoting industry standards for data exchange, and encouraging continuous software to ensure compatibility and efficiency across different systems, which will boost the broader implementation of BIM. Another area of disparity is the divide between the here-and-now requirements of the practitioners and the discussions about the long-term views on the subject in academic literature. Such a state emphasizes the need for continued professional practice and its planning aimed at maximum potential use of BIM.

Strategies as infrastructure projects and government regulation have also been used to encourage BIM implementation and compliance with the international standards construction market worldwide, which lead to the elimination of the existing barriers and the prevalence of this technology involvement in government and educational institutions. One limitation is connected with local specificity of the given investigation, while the work is devoted to presenting Shanghai context, the findings may not be easily generalized on the other areas of China which could experience the different demands and innovations.

Subsequent researches should carry out a better geographical coverage, that is, study not only large cities, and more extended areas to get a better blueprint of how BIM has influenced China’s construction commerce. It is essential to enhance investment in training, research, and development and employment of specific policy measures to address the current difficulties and the stable penetration of the BIM technologies in the industry. Thus, this research enhances the existing knowledge base by offering an insight into the usage and significance of BIM for enhancing practicality of the concept for further research and application in the field.

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