THE FRAMEWORK OF 5D BIM ADOPTION FOR ENHANCING CONSTRUCTION PROJECT PERFORMANCE: THE CASE OF GUANGDONG PROVINCE IN CHINA

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2025

THE FRAMEWORK OF 5D BIM ADOPTION FOR ENHANCING CONSTRUCTION PROJECT PERFORMANCE: THE CASE OF GUANGDONG PROVINCE IN CHINA

by

SUN HUI

Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

October 2025

ACKNOWLEDGEMENT

I would like to express gratitude to all those who have supported and guided me throughout my doctoral studies. First and foremost, I am deeply indebted to my main supervisor, Dr. Muneera Esa, and my co-supervisors, Dr. Khoo Terh Jing and Dr. Amir Mahdiyar. Their unwavering guidance, insightful advice, and constant encouragement have been instrumental in shaping my academic journey. The meticulous scholarship and thoughtful mentorship of my supervisors have been invaluable in driving the progress of my research. Their constructive feedback and thoughtful suggestions have not only inspired me but also helped me overcome significant challenges along the way.

I am also profoundly grateful to the many individuals who assisted and advised me during my research and in the design and administration of my questionnaire. Their expertise and generous contributions were indispensable in enabling the timely completion of this thesis.

Lastly, I would like to express my deepest appreciation to my family for their unwavering support and encouragement throughout this journey. In particular, I am profoundly grateful to my mother, whose quiet sacrifices and steadfast support have been a cornerstone of my success. She left the comfort of her hometown to accompany me to a new city, selflessly enduring hardship and facing illness alone to avoid disrupting my progress. Her dedication and love have been my greatest source of motivation, and it is to her that I owe the completion of this research.

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LIST OF ABBREVIATIONS

5D BIM	Five-dimensional (5D) Building Information Model (BIM)
AVE	Average Variance Extracted
BIM	Building Information Modeling
CBIMS	China Building Information Modeling Standard Framework
CFA	Confirmatory Factor Analysis
CGDP	China Gross Domestic Product
CR	Composite Reliability
CV	Convergent Validity
DV	Discriminant Validity
GC	General Contractors
GCG1	General Contractors Grade 1
HTMT	Heterotrait-Monotrait Ratio of Correlations
IBS	Industrialized Building Systems
IFC	Industry Foundation Classes
IPMA	Importance-Performance Map Analysis
KPIs	Key Performance Indicators
LSOEs	Large State-owned Enterprises
MOHURD	Ministry of Housing and Urban-Rural Development of the People's Republic of China
NCMSPSP	National Construction Market Supervision Public Service Platform
PGC	Premium General Contractor
GPGCPG1	General Contractors Level of Premium and Grade 1
PLS-SEM	Partial Least Squares Structural Equation Modeling
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
QSIS	Questionnaire Star Information System

SLR	Systematic Literature Review
SPSS	Statistical Packages of Social Sciences
TAM	Technology Acceptance Model
TOE	Technology–organization–environment
TTF	Task Technology Fit
GDP	Gross Domestic Product
UTAU	Unified Theory of Acceptance and Use of Technology
VIF	Variance Inflation Factor

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RANGKA KERJA PENGGUNAAN BIM 5D BAGI PENINGKATAN PRESTASI PROJEK PEMBINAAN: KES DI WILAYAH GUANGDONG, CHINA

ABSTRAK

Kos, masa, dan kualiti kekal sebagai tonggak utama kejayaan projek, namun usaha untuk mencapai penambahbaikan yang mampan dalam dimensi ini menjadi semakin mencabar seiring dengan perkembangan sosio-ekonomi dan peningkatan permintaan industri. Pemodelan Maklumat Bangunan Lima Dimensi (5D BIM), yang mengintegrasikan data kos dan penjadualan ke dalam model tiga dimensi, telah muncul sebagai pendekatan berpotensi untuk meningkatkan pengurusan projek melalui perancangan bajet, penjadualan, dan visualisasi. Walau bagaimanapun, pemahaman empirikal tentang kesannya terhadap prestasi projek dalam industri pembinaan di China masih terhad. Kajian ini dipandu oleh empat objektif utama: (i) menentukan faktor-faktor yang mempengaruhi penerimaan 5D BIM dalam industri pembinaan di China, (ii) meneroka hubungan antara faktor berkaitan 5D BIM dan prestasi projek pembinaan, (iii) meneliti kesan dasar kerajaan sebagai moderator terhadap hubungan antara faktor berkaitan 5D BIM dan prestasi projek, serta (iv) membangunkan rangka kerja komprehensif yang menyokong penerimaan dan pelaksanaan 5D BIM secara berkesan. Bagi mencapai objektif tersebut, satu tinjauan literatur sistematik melibatkan 222 artikel daripada Scopus dan Web of Science telah dijalankan berasaskan prosedur PRISMA untuk mengenal pasti penunjuk yang berkaitan dengan penerimaan 5D BIM dan prestasi projek. Seterusnya, kaedah kuantitatif melalui soal selidik terhadap 234 responden telah digunakan bagi mengesahkan penunjuk ini dan menguji rangka kerja yang dicadangkan. Dapatan kajian menunjukkan bahawa lima dimensi faktor berkaitan 5D BIM—operasi, teknologi, organisasi, projek, dan persekitaran—mempunyai pengaruh signifikan dalam meningkatkan prestasi projek dari segi kos, masa, dan kualiti. Selain itu, dasar kerajaan didapati memoderasi hubungan antara faktor berkaitan projek dan faktor persekitaran dengan prestasi projek. Hasil akhir kajian ini ialah satu rangka kerja bersepadu dan disahkan secara empirikal yang bukan sahaja memperkukuh pengetahuan teori mengenai mekanisme yang menghubungkan penerimaan 5D BIM dengan hasil projek, tetapi juga memberikan panduan praktikal kepada kontraktor, penggubal dasar, dan pihak berkepentingan dalam memperkasakan strategi transformasi digital dalam sektor pembinaan.

THE FRAMEWORK OF 5D BIM ADOPTION FOR ENHANCING CONSTRUCTION PROJECT PERFORMANCE: THE CASE OF GUANGDONG PROVINCE IN CHINA

ABSTRACT

Cost, time, and quality remain the cornerstones of project success, yet achieving sustainable improvements in these dimensions is increasingly challenging as socio-economic development and industry demands intensify. Five-dimensional Building Information Modeling (5D BIM), which integrates cost and scheduling data into three-dimensional models, has emerged as a promising approach to enhance project management through budgeting, scheduling, and visualization. However, empirical understanding of its impact on project performance in the Chinese construction industry remains limited. This research is guided by four objectives: (i) to determine the factors affecting 5D BIM adoption in the Chinese construction industry, (ii) to explore the relationship between 5D BIM-related factors and construction project performance, (iii) to examine the moderating effect of government policy on the relationship between 5D BIM-related factors and project performance, and (iv) to develop a comprehensive framework fostering effective 5D BIM adoption and implementation. To achieve these objectives, a systematic literature review of 222 articles from Scopus and Web of Science was conducted following PRISMA procedures to identify relevant indicators of 5D BIM adoption and project performance. Subsequently, a quantitative survey of 234 respondents was employed to empirically validate these indicators and examine the proposed framework. The findings demonstrate that five dimensions of 5D BIM-related factors—operational, technological, organizational, project-related, and environmental—significantly

enhance project performance in terms of cost, time, and quality. Moreover, government policy was found to moderate the relationship between project-related and environmental factors and project performance. The final output of this research is a validated and integrated framework that not only advances theoretical knowledge on the mechanisms linking 5D BIM adoption to project outcomes but also provides practical guidance for contractors, policymakers, and stakeholders to strengthen digital transformation strategies in the construction sector.

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces the research context, problem statement, objectives, and questions that guide the study. It also addresses the scope of the research and highlights its significance. The adoption of 5D BIM is a topic of great importance with the potential to significantly enhance the quality of life for construction stakeholders, as well as improve economic outcomes for society and the broader construction industry. This research examines the impact of 5D BIM-related factors in China and analyzes how 5D BIM influences project performance.

1.2 Background of Research

China, the world's largest developing nation, has emerged as a central driver of global economic growth, contributing over 27% of global GDP expansion in 2021 (International Monetary Fund, 2023). The construction industry plays a fundamental role in the national economy, accounting for a significant portion of GDP and employment (Hussein et al., 2025). The construction industry is labor-intensive and contributes to employment growth, particularly in urban areas, due to the demand for residential and commercial buildings (Mitra, 2023). Yet, this progress has been accompanied by challenges. The construction sector accounts for 36% of global energy use and 39% of carbon emissions (Chen et al., 2023), with China a key contributor. Moreover, growing project scale, technological complexity, and stakeholder expectations heighten risks of delays, cost overruns, and inefficiencies (Akinosho et al., 2020a). To address these concerns, digital technologies such as Building Information Modeling (BIM) are increasingly adopted. Particularly, five-dimensional

(5D) BIM strengthens cost control, reduces overruns, and enhances investment efficiency (Hosamo et al., 2024; Strange et al., 2023).

1.2.1 The Contribution of China to Global Economic Development

China, as the world's largest developing nation, has significantly contributed to global economic growth, particularly as globalization has accelerated (Wang, 2019). China's sustained economic growth has served as a significant catalyst for global economic advancement. Between 1978 and 2018, the country transitioned from relative isolation to active participation in globalization, establishing itself as a prominent actor in the international economy (Wang, 2019). Owing to four decades of steady economic expansion and revitalization, China has emerged as a driving force behind global economic development (Wang, 2019). China is a significant importer and exporter Li (2023), and a far more significant portion of the world's economic production currently comes from emerging economies led by China and India (Som, 2014). Projections by Goldman Sachs suggest that, based on current market exchange rates, the economies of China and India will reach approximately 80% and 125% of the U.S. GDP, respectively, by 2050 (Som, 2014).

Furthermore, China's rapid economic growth has spurred a surge in global trade, with its contribution to global economic development consistently increasing. (Chen, 2023). As the world's second-largest economy, China has demonstrated robust growth indicators in recent years, further solidifying its pivotal role in global economic dynamics. According to the International Monetary Fund (IMF), China's contribution to global economic growth reached 27.1% in 2021, ranking first in the world. Zhang (2022) and Chen (2023) claim that from $231 in 1978 to $10,504 in 2019, the Gross Domestic Product (GDP) per capita has risen in the economy. The Chinese economy is substantial due to its rapid expansion rate, as Figure 1.1 illustrates. The consistent rise in GDP and employment rates is the country's remarkable economic achievements and its profound impact on global trade and commerce.

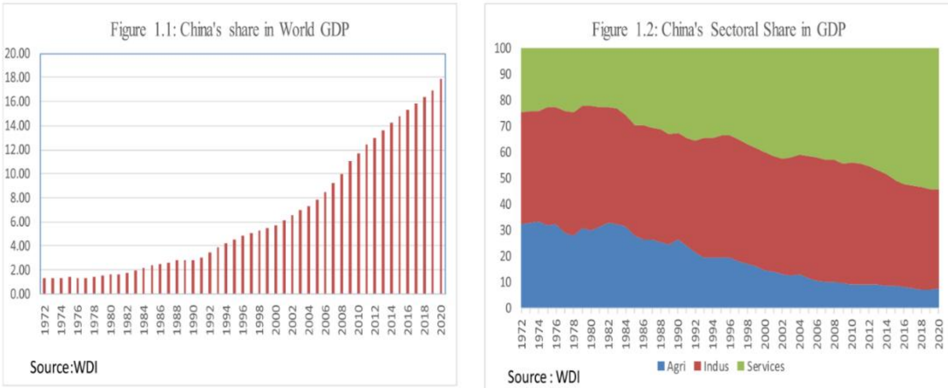

Figure 1.1 China's Economy and Economic Growth (Huan et al., 2022)

1.2.2 The Pillar Position of the Construction Industry in China

China's economy depends mostly on the construction sector, and the growth of construction companies is intimately influenced by China's economic expansion (Li et al., 2019). By the end of 2022, there were 143,621 construction enterprises with construction activities nationwide, a year-on-year increase of 11.55%; the number of employees was 51,840,200, and the labor productivity calculated based on the total output value of the construction industry was 493,526 yuan per person (Zhao et al., 2023). In 2022, the annual GDP will be 1,210,207.2 billion yuan, an increase of 3.0% over the previous year (calculated at constant prices). The construction industry as a whole realized an added value of 8338.31 billion yuan, an increase of 5.5% over the previous year (at constant prices), with a growth rate 2.5% higher than that of GDP, as shown in Figure 1.2 (Zhao et al., 2023).

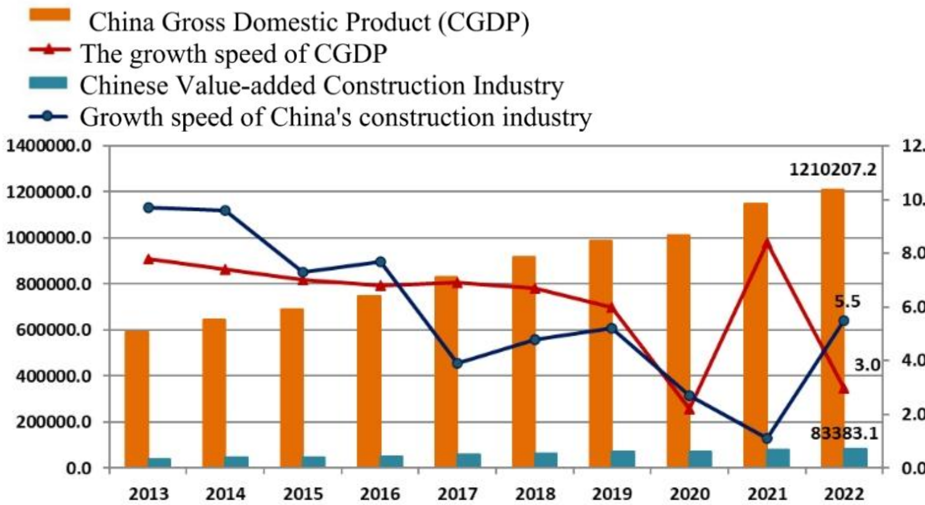

Figure 1.2 China GDP, Construction Value Added and Growth Rate from 2013 to 2022 (Zhao et al., 2023)

Rapid urbanization has significantly contributed to the growth of the construction industry in China (Deng & Zhong, 2023). This urbanization has driven substantial migration to urban areas, creating a heightened demand for housing, commercial spaces, and infrastructure development (Weith et al., 2021). Consequently, the construction sector has played a pivotal role in reshaping urban landscapes, creating modern metropolises, and driving economic development in urban centers. (Zhao et al., 2023). The construction sector's robust growth has propelled economic development and has been a substantial source of employment, absorbing a significant portion of the workforce (Alaloul et al., 2022). Additionally, the construction industry has become a major source of employment, offering diverse opportunities ranging from skilled labor to roles for engineers and architects. According to Zhao et al. (2023), China's construction industry enterprises signed a total contract amount of 715,674.69 billion yuan, the number of personnel employed in the construction industry 51,840,200 employees in 2022, as shown in Figure 1.3. This dynamic sector continues to fuel China's economic growth and contributes to its broader socio-economic development.

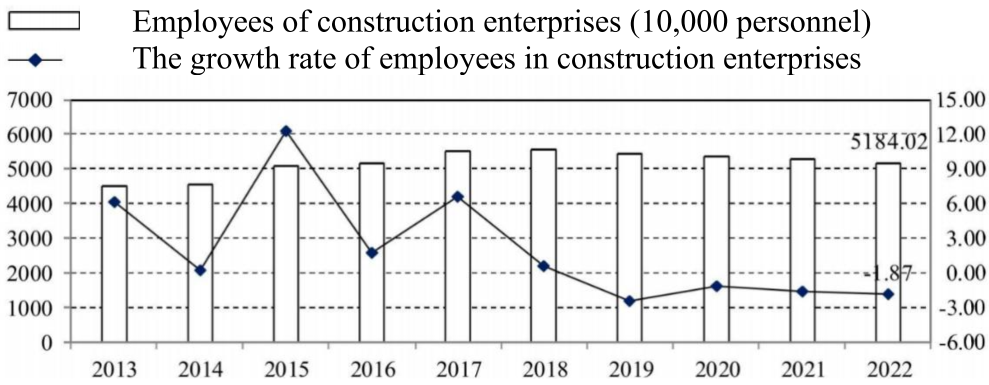

Figure 1.3 Number of Employees in the Construction Industry in 2013-2022 (Zhao et al., 2023)

1.2.3 Challenges in China's Construction Industry

As China's global economic prominence has increased, the construction industry has faced several challenges and criticisms. Rapid urbanization, increased tertiary-sector activities, and the expansion of urban building floor areas have significantly contributed to rising carbon emissions, which are projected to escalate in the coming years (Wei et al., 2024; Huo et al., 2021). This trend poses significant challenges to reducing emissions, curbing energy consumption, and mitigating global climate change (Kandasamy & Menon, 2024; Huo et al., 2021). Moreover, it would even have significant effects on long-term socioeconomic growth (Zhang & Liu, 2025; Miao et al., 2019). The construction sector is responsible for 36% of global energy consumption and 39% of greenhouse gas emissions, making it a major contributor to environmental degradation (United Nations Environment Programme, 2024; International Energy, 2019). Achieving a sustainable built environment requires critical measures, including sustainable services design, construction practices, operations, and cost management (Pagare et al., 2025; Chandramohan et al., 2022). The critical areas for attaining the requirements for a sustainable built environment, according to Bolade et al. (2020), are sustainable services design, sustainable construction, sustainable operation, and sustainable cost management.

Furthermore, the social economy's development has led to modern engineering construction being characterized by expanding scales and heightened technical complexity. These trends pose substantial challenges for project management, while productivity in the construction industry remains unstable and, in some cases, is declining (Bahamnia & Kumar, 2024; Akinosho et al., 2020b). The industry is further plagued by issues in resource planning, risk management, and logistics, often resulting in design flaws, project delays, cost overruns, and contractual disputes (Nishaant et al., 2025; Suseelan & Senthil Vadivel, 2024; Akinosho et al., 2020b). Inadequate digital proficiency and limited technology adoption exacerbate these issues. These gaps have been linked to inefficient project budgeting, poor-quality project outcomes, ill-informed decision-making, and subpar productivity, health, and safety results (Tanoli, 2025; Naji et al., 2024; Abioye et al., 2021). Addressing these systemic challenges is critical to improving the construction industry's overall performance and sustainability.

1.2.4 Digital Technologies & 5D BIM Implementation

Industries in the informational economy have progressively transitioned from being labor-intensive to becoming information-intensive (Li et al., 2019). Digital technologies are transforming the construction industry by introducing new solutions to persistent challenges, such as low productivity, profitability issues, inconsistent project performance, skill shortages, and environmental concerns (Cartlidge, 2023). These technologies are essential for achieving the objectives of intelligent construction in many countries (Dou et al., 2023). Digital technologies such as building information modeling (BIM), artificial intelligence, 3D scanning, digital twin, virtual reality, 3D printing, and cloud computing are portrayed in future trend reports and hype curves, indicating their relevance and potential adoption in the industry (Bosch-Sijtsema et al., 2021). These innovations offer significant potential to improve productivity and fundamentally revolutionize work processes in the sector (Cartlidge, 2023).

Building Information Modeling (BIM) serves as a digital representation of a facility's functional and structural characteristics, alongside related project data (Tam et al., 2022). Each dimension of BIM defines distinct capabilities, such as 4D (time), 5D (cost), 6D (facility management), and 7D (sustainability). The integration of cost data within a five-dimensional (5D) BIM framework can help mitigate construction project cost overruns while delivering substantial returns on investment for clients (Olawumi et al., 2018).

Information from construction operations may be integrated into a project using BIM, which benefits stakeholders by increasing information availability and efficiency. The reduction of service provider complaints as a result of BIM 5D implementation (Noviani et al., 2022). The novelty of BIM, project complexity, and the absence of standardized, unified efficiency measurements make it challenging and complex to statistically quantify project performance, even with the creation of methodologies to study the benefits of BIM in terms of construction project performance (Nguyen et al., 2023). Stakeholders, on the other hand, are reluctant to embrace policies unrelated to their industry (Sun, Khoo, Ha, et al., 2023). Disregarding the advantages of 5D BIM in project cost management is a significant risk to project success and a lost opportunity (Sun, Khoo, Ha, et al., 2023; Yuan et al., 2019).

1.3 Problem Statement

China's economy has achieved remarkable growth over the past three decades, with the construction sector playing a pivotal role in providing infrastructure, housing, and driving urbanization (Ouyang et al., 2022; Xing et al., 2021). However, while the sector contributes substantially to GDP, it faces persistent challenges, including low profit margins, cost overruns, delays, and quality concerns (Li & Ma, 2024; Zhao et al., 2021). Profitability has declined continuously since 2014, falling below 3% in 2022 (Zhao et al., 2023), as depicted in Figure 1.4. Such issues highlight the need for more advanced management and digital solutions to ensure project success.

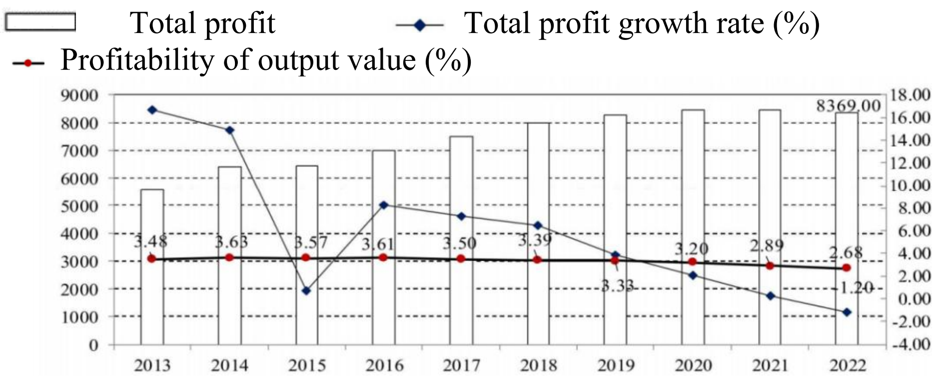

Figure 1.4 Total Profit and Production Value Profit Rate of China Construction Industry, 2013~2022 (Zhao et al., 2023)

Despite its economic importance, China's construction industry is recognized as one of the least digitalized sectors globally due to its early stage of digital transformation (Zhu et al., 2024; Zhang et al., 2023). Excessive reliance on manual processes, limited technological adoption, and resistance to change continue to undermine efficiency (Abioye et al., 2021; Davila Delgado & Oyedele, 2021). Consequently, project management suffers from poor cost efficiency, delays, and rework, while overall productivity growth stagnates (Zulu et al., 2023). Given these shortcomings, digital innovations such as Building Information Modeling (BIM) have been widely recognized as crucial tools for tackling inefficiencies, improving decision-making, and enhancing project performance (Bunse et al., 2025; Shojaei & Burgess, 2022).

BIM provides a comprehensive platform for collaboration, coordination, and information integration across the project lifecycle (Li, 2023; Koseoglu et al., 2018). BIM enhances efficiency, reduces errors, and supports project planning and control (Mahmoud El-Eila et al., 2024). Among its extensions, 5D BIM is particularly significant as it integrates cost data with 3D and 4D models, allowing dynamic cost estimation, budgeting, and financial monitoring throughout project delivery dimensional (5D) cost model—also referred to as “5D BIM”—is recommended (Hosamo et al., 2024; Vigneault et al., 2020a; Zheng et al., 2019). However, the adoption and development of BIM—and especially 5D BIM—are underperforming in China (Tai et al., 2021; Jin et al., 2015). According to industry reports, only 17.2% of Chinese firms had BIM-trained staff, with merely 9.6% satisfied with BIM usage (Tai et al., 2021). Prior studies reveal that 5D BIM adoption is constrained by limited organizational and financial capacity, shortage of skilled personnel, weak stakeholder collaboration, inadequate documentation, high training costs, client indifference, and deep-rooted cultural resistance, thereby undermining reliable implementation and scalability (B. Ghosh & Karmakar, 2025; Moses et al., 2020; Vigneault et al., 2020a; Hasan & Rasheed, 2019). In short, these studies show that a few studies have looked into the challenges of 5D BIM applications, such as Hussain et al. (2024), Luth et al. (2014) but not from a general contractor’s perspective (Mayouf et al., 2019a; Moses et al., 2020).

Although BIM provides substantial benefits across the architecture, engineering, construction, and operation (AECO) industries, its adoption remains uneven due to stakeholders' limited awareness, reluctance to change established practices, and uncertainty regarding software performance, resulting in divergent views on its effectiveness in improving cost and time performance(Sun, Khoo, Ha, et al., 2023; Chiu & Chang, 2022; Doan et al., 2021; Wong et al., 2020). By linking design, schedule, and cost, 5D BIM has the potential to improve project cost control and thereby enhance overall performance. Failure to fully utilize BIM's cost management potential not only increases risks of excessive costs, rework, and errors but also jeopardizes overall project success and the sustainability of the construction industry (Hosamo et al., 2024; Yuan et al., 2019; Bui et al., 2016). These challenges highlight the need for further analysis of BIM adoption, particularly in emerging markets like China, where its impact on project performance remains underexplored.

Government policy plays a crucial role in shaping BIM implementation. Studies reveal that legal and institutional frameworks significantly influence BIM adoption decisions (Mitera-Kiełbasa & Zima, 2024). In many countries, policy mandates have accelerated BIM integration, yet in China, government-led requirements for 5D BIM remain absent. This policy gap leads to fragmented adoption, confusion among stakeholders, and wasted resources (Rosander & Kadefors, 2023). Without coherent guidance and supportive policy instruments, enterprises face difficulties justifying the investment in training, systems, and process reengineering required for BIM integration. Moreover, the internal and external policies that oversee the operations of the construction industry are investigated by the factors related to project performance (Masoetsa et al., 2022).

Ullah et al. (2019) conducted a detailed analysis of the advantages and challenges associated with assessing BIM adoption stages in the global construction sector. Their findings emphasized the need to develop an effective BIM-based framework addressing significant barriers to improving BIM implementation in the architecture, engineering, and construction (AEC) industry. Developing a systematic framework for 5D BIM-related factors can enhance project performance more effectively (Herdyana & Suroso, 2023). However, no research has yet developed a comprehensive framework to foster 5D BIM adoption and enhance project performance in China's construction sector.

In summary, despite advancements in BIM, empirical studies on multidimensional drivers of 5D BIM adoption and their quantifiable impacts on cost, time, and quality remain limited. Global research highlights interoperability, cost, and skills challenges, while Chinese studies show low adoption and weak policy support. Existing literature lacks theoretical grounding, underscoring the need for an integrated framework to capture adoption dynamics and performance outcomes.

1.4 Research Questions

i. What are the factors affecting the fifth dimension (5D) of building information modeling (BIM) adoption in the Chinese construction industry?

ii. What is the relation between 5D BIM-related factors and construction project performances?

iii. What is the effect of government policy as the moderator on the relationship between 5D BIM-related factors and construction project performance?

iv. How can the 5D BIM-related factors framework be effectively implemented to facilitate project performance?

1.5 Research Objectives

This research aims to develop a robust and comprehensive framework that fosters the effective adoption of 5D BIM and enhances project performance within the Chinese construction industry.

i. To determine the factors affecting 5D BIM adoption in the Chinese construction industry.

ii. To explore the relationship between 5D BIM-related factors and construction project performances.

iii. To examine the effect of government policy as the moderator on the relationship between 5D BIM-related factors and construction project performance.

iv. To develop an entire framework fostering 5D BIM adoption and implementation in the project performance in the Chinese construction industry.

1.6 Research Scope

The scope of this research is limited to the Chinese construction industry. The decision to focus on this sector was based on the following considerations: (1) China is one of the world's most significant economies and serves as a hub for digital technology integration, including BIM adoption and investment (Zheng et al., 2021). The country actively encourages industries to embrace comprehensive digital transformation and promotes advanced digitalization resources such as BIM technology, strategies, and concepts among scholars and practitioners. (Zheng et al., 2021). (2) Government support: The Chinese government published the 14th Five-Year Plan, giving reformed large state-owned enterprises (LSOEs) the responsibility of guaranteeing the advancement of the digitization of the construction industry (Zheng et al., 2021). (3) Practical application limit: Despite the government's efforts to promote BIM, its practical application in the construction industry remains limited (Farrukh et al., 2022). Local government organizations and sectors often support BIM by adopting foreign data and practices, which can lead to misunderstandings among domestic practitioners and academics, impeding progress in digitalizing the construction industry (Khanzadi et al., 2020). It is essential to study the promotion of BIM in China, especially 5D BIM, which is capable of enhancing performance within the industry.

This research examines construction projects that incorporate 5D Building Information Modeling (BIM) technologies in Guangdong Province, China. The application of 5D BIM in construction projects can reduce construction duration, costs, and lifecycle expenses while enhancing working efficiency and competitiveness (Pakhale & Pal, 2020). The practical value of 5D BIM lies in its ability to ensure project completion on time and within budget, minimize rework, resolve coordination problems, and reduce paperwork. Moreover, it enhances project efficiency and effectiveness across all stages, from design to operation and maintenance (Pakhale & Pal, 2020). Geographically, this study is delimited to Guangdong Province in southern China, an economically advanced region comprising 21 prefecture-level cities as of 2015. Covering a total area of 179,716 km^2, the province comprises 55% woodland and 27.5% agricultural land, including arable, orchard, grass, and other agricultural lands (excluding forests) (Gong et al., 2022). In 2023, the total contract value signed by construction enterprises in China was 724,731,0700 yuan. Guangdong Province led the country, signing contracts worth 6,899,122,000,000 yuan. Data from the Bureau of Statistics of Guangdong Province and the National Bureau of Statistics indicate steady growth in the construction industry in Guangdong Province from 2015 to 2020. This aligns with predictions from Markets and Markets, estimating that China's BIM market size will reach 1.353 billion USD by 2025, supported by a compound annual growth rate of 10.49% in civil engineering construction output value. Preliminary estimates indicate that Guangdong Province's BIM market size grew annually from 2015 to 2020, surpassing 400 million yuan in 2020. Considering the compound annual growth rate of the province's BIM market size during this period, the industry's future development prospects appear strong. From 2021 to 2026, the BIM market in Guangdong Province is projected to grow annually, and by 2026, it is expected to surpass 1.2 billion yuan (Report of Market Prospects and Investment Strategy Planning Analysis on China Building Information Modeling Industry 2024-2029).

This research focuses on general contractors in China. According to the "China Construction Industry Enterprise Qualification Standards", construction contractors are categorized into four types: integrated contractors, general contractors, professional contractors, and labor subcontractors. General construction contractors are further classified into Premium, Grade 1, Grade 2, and Grade 3, ranked from highest to lowest. Premium general contractors must meet more stringent qualifications, including net assets exceeding 100 million yuan, employing over nine first-grade registered constructors, and having technical leaders with more than 10 years of construction experience.

The decision to focus on general contractors was based on two main reasons: (1) they generally undertake large, complex projects that often involve construction activities with significant environmental impacts, and (2) they are more likely to engage with and have knowledge of 5D BIM compared to lower-level contractors, who primarily acquire projects through subcontracting. Marzouk et al. (2018) suggest that BIM is increasingly adopted in the construction industry for project execution. This indicates that experts and general contractors need to integrate 5D BIM into their workflows (Vigneault et al., 2020a). Furthermore, general contractors should assess the maximum overdraft that might occur during project execution alongside the anticipated profit (Elghaish et al., 2021). Therefore, the contractors will understand specifically what the maximum deviations would be as a result of poor service (Elghaish et al., 2021). Therefore, general contractors in China have the potential to improve performance significantly through the application of 5D BIM.

1.7 Significance of the Study

This research results enhance the efficiency, effectiveness, and success of project performance and management processes. Project success depends directly on performance, a critical element evaluated based on factors such as safety, cost, scheduling, and quality (Moradi et al., 2022), and is evaluated in accordance with factors such as safety, cost, scheduling, and quality, all of which are critical to the successful completion of a project (Alhasan et al., 2017). The integration of 5D BIM into the construction industry is expected to improve cost performance, streamline project timelines, and enhance overall project quality (Akbar & Latief, 2024). Tender documents, human resources, BIM software, planning processes, and production processes are the success factors that influence the implementation of 5D BIM in relation to the time and cost performance of high-rise construction projects at UIN Sunan Ampel Surabaya, by Herdyana and Suroso (2023). Reducing project costs frequently extends the timeline and could undermine quality, whereas shortening the duration can incur higher expenses and quality concerns. (Olsen & Taylor, 2017; Wang et al., 2021). The implementation of BIM 5D technology is expected to accelerate and streamline the protracted construction procedures. Identifying critical factors for 5D BIM adoption is essential for achieving these objectives and addressing long-standing inefficiencies in the industry. Adriaanse et al. (2010) and Rajabi et al. (2022) underscored the significance of motivational elements in the integration of new technologies, such as BIM, within the AECO industry. The integration of developing technologies, including digital breakthroughs, can foster socio-economic development and innovation across multiple sectors (Park & Choi, 2019).

This research result moves forward the application of digital technology in the construction industry. The construction industry is increasingly focusing on digitization to enhance resource efficiency and sustainability (Musarat et al., 2023). The digitization of the construction industry presents both possibilities and challenges, with the need to address barriers to digitization and select critical success factors to promote the process of digital transformation (Cartlidge, 2023). Successful digital transformation depends on careful investigation and analysis of the possible usage, benefits, and risks of new technological trends, including consideration of people, culture, strategy, and processes (Ghosh et al., 2022). Building Information Modelling (BIM) is identified as one of the leading digital technologies with the potential to influence and speed up the transition to a circular economy in construction (Eze et al., 2024). 5D BIM fosters better communication and coordination among project stakeholders, ensuring that everyone has access to the same up-to-date information (Akinradewo et al., 2023). By providing a detailed and accurate representation of project costs and schedules, 5D BIM helps mitigate the risk of time and cost overruns (Inzerillo et al., 2024). The implementation of 5D Building Information Modeling (BIM) is indeed poised to significantly promote the application of digital technology in the construction industry.

1.8 Thesis Organization

This thesis has six chapters and it is organized as follows:

Chapter 1: This chapter delineates the implementation background of 5D BIM, emphasizing the economic significance of the construction sector and the issues it faces in shifting industrial environments. It then highlights gaps identified in previous 5D BIM research, which are used to formulate the research questions. The research objectives are derived from these questions. Finally, the chapter concludes with the scope and significance of the research.

Chapter 2: This chapter reviews literature on 5D BIM factors, project performance, and policy roles. It analyzes operational, technological, organizational, project-related, and environmental influences on cost, time, and quality performance, while also addressing the moderating function of 5D BIM policy.

Chapter 3: This chapter outlines the research methodology. It details the research design, data collection methods, respondent profiles, pilot study process, and approaches to ensuring data reliability and validity. The analytical techniques, including the PLS-SEM method, are also discussed.

Chapter 4: This chapter presents the research findings and includes a concise discussion of the results. The analysis focuses on data collected through distributed questionnaires using a quantitative research approach. Techniques such as descriptive and PLS-SEM analysis are employed to interpret the data.

Chapter 5: This chapter focuses on interpreting the results of the data analysis. It discusses the impacts of 5D BIM-related factors on project performance, particularly in the context of the moderating roles played by government policy. The findings are critically analyzed to identify their implications for construction management practices.

Chapter 6: The final chapter synthesizes the study's contributions, beginning with a concise summary of key findings and related discussions. It highlights theoretical and practical implications, identifies research limitations, and proposes future research directions, thereby consolidating the study's significance within the broader academic and professional domain.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter focuses on reviewing relevant literature. It begins by explaining the theoretical foundation of 5D BIM. Next, it examines factors influencing 5D BIM implementation in the construction industry. It also explores project performance indicators and the effects of 5D BIM-related factors on project performance. Additionally, the roles of government policy are also discussed in this chapter. Finally, the chapter concludes with the development of a conceptual framework and research hypotheses.

2.2 Operational Definition

The concepts used in the research have been defined and are shown in the list below.

BIM: BIM can be defined as a digital representation of a facility's physical and functional characteristics, serving as a shared knowledge resource (Azhar et al., 2012; Sacks et al., 2018). A digital depiction of a building's structural and operational features and a common knowledge base for data about a building that serves as a dependable foundation for choices.

5D BIM: 5D Building Information Modeling (BIM) integrates the 3D model of a building with both the construction schedule (4D) and cost information (5D). This integration allows for more efficient project management by enabling automatic generation of quantities, cost estimation, and improved visualization of construction details (Khamees et al., 2020; Stanley & Thurnell, 2014a) Connecting the 3D model to cost data. It handles the 5D as a connection between costs and the designers' Project

Information Model (PIM), facilitating quantity extraction, lifetime costs, scenario analysis, and real-time modeling and cost planning.

5D BIM-related Factors: The factors related to 5D BIM encompass technological advancements, economic optimization, environmental considerations, and social challenges. The adoption and implementation of 5D BIM are influenced by a range of factors, including technological capabilities, economic viability, environmental sustainability, and social acceptance and expertise (Hosamo et al., 2024; Saupi & Ismail, 2024).

Operational Factors of 5D BIM Implementation: Operational factors in the implementation of 5D Building Information Modeling (BIM) refer to the expert's competencies, experiences, and attitudes of individuals responsible for utilizing 5D BIM technologies (Sun et al., 2024). These include specialized training and technical proficiency in operating 5D BIM tools for precise modeling and analysis, comprehensive understanding of project scope and objectives to align BIM functions with deliverables. The capability and willingness of personnel to adapt to new technologies and workflows are critical for the effective implementation of 5D BIM (Saupi & Ismail, 2024).

Technological Factors of 5D BIM Implementation: Technological factors of 5D BIM implementation encompass the capabilities and infrastructure required for its effective operation. Robust digital platforms facilitate the sharing and exchange of project information among stakeholders (Hussain, Moehler, & Walsh, 2024). High-quality systems are necessary for the efficient use of BIM tools (Umaapathy & Sundarrajan, 2023).

Organizational Factors of 5D BIM Implementation: Provides direction and structure for 5D BIM implementation, ensuring adherence to quality standards and effective decision-making (Hussain, Moehler, Walsh, et al., 2024). The existing organizational culture is highlighted as a key factor influencing the embedding of information management capability for 5D BIM implementation (Ali & Miah, 2018). Organizational factors of 5D BIM implementation pertain to internal factors that affect an organization's capacity to adopt and optimize 5D BIM utilization.

Project-related factors of 5D BIM Implementation: Project-related factors of 5D BIM implementation encompass specific characteristics of construction projects that impact its adoption and effectiveness. These include the availability of comprehensive 3D modeling and design, integration of 4D scheduling for construction activities, challenges in verifying BIM documentation, data integrity and accuracy, predictability of project outcomes, project complexity, and scale (Sun et al., 2024).

Environmental factors of 5D BIM Implementation: Competitive pressures in the construction sector push companies to adopt advanced technologies like 5D BIM to minimize errors, reduce costs, and optimize project timelines (Sattineni & Macdonald, 2014). Moreover, the global shift toward sustainability and ESG principles drives BIM adoption, with sustainable practices and resource efficiency as key determinants (Jing & Alias, 2024).

Project Performance: Project performance is a multifaceted concept that encompasses various quantitative and qualitative metrics, capability factors, and strategic considerations (Masum et al., 2023; Unterhitzenberger & Bryde, 2019). Project performance refers to the record of outcomes produced or services delivered during a specified job function or activity within a defined time period (Wibowo et al., 2015). Project performance is primarily measured by three components of project management: progress, quality, and cost.

Project Cost Performance: Project Cost Performance refers to the ability of a project to effectively manage and control its costs in order to achieve its financial objectives (Devi & Ananthanarayanan, 2017; Tichacek, 2006). Project cost performance encompasses accurate cost estimation, systematic cost control mechanisms, precise budgeting practices, detailed quantity takeoff processes, and effective management of claims (Sun, Khoo, Ha, et al., 2023).

Project Time Performance: Project time performance refers to the effectiveness with which a project adheres to its planned schedule, ensuring that all activities and milestones are completed within the allocated time frame. It is a critical success criterion in project management, particularly in the construction industry, where timely completion is often linked to overall project success and client satisfaction (Joko Wahyu Adi et al., 2016; Rachmawati et al., 2024). It involves decision-making enhancement, schedule variance analysis, and coordination optimization to reduce project durations.

Project Quality Performance: Project quality performance refers to the extent to which a project meets the standards and requirements for which it was initiated, ensuring that the final deliverables conform to predefined specifications and stakeholder expectations. This concept encompasses various dimensions and processes within project management, including quality planning, quality assurance, and quality control (Simion-Melinte & Jiroveanu, 2011).

Government policy: Refers to regulatory frameworks and standards that support and mandate the use of BIM in construction projects (Hussain, Moehler, Walsh, et al., 2024). It generally involves mandates and regulations aimed at enhancing the efficiency, collaboration, and quality of construction projects through digital processes.

Adoption of common standards across the industry to ensure compatibility and efficiency in BIM processes (Ghazaryan, 2019).

2.3 Evolution of BIM Dimensions towards 5D

The evolution of Building Information Modeling (BIM) reflects a progressive expansion from basic two-dimensional representations to multidimensional platforms that integrate diverse project information. Initially confined to 2D and 3D design visualization, BIM gradually incorporated temporal aspects (4D) to facilitate scheduling and construction sequencing. The subsequent integration of cost-related data (5D) marked a significant milestone, as it enabled project stakeholders to link design and time dimensions with financial considerations, thereby enhancing decision-making, cost control, and project predictability. This evolutionary trajectory towards 5D BIM not only illustrates the technological maturation of BIM but also underscores its growing role as a comprehensive decision-support system that aligns with the increasing complexity and performance demands of modern construction projects.

2.3.1 Building Information Modeling (BIM)

The idea of BIM was born in the 1970s, and the concept of BIM is defined in detail. The National Institute of Building Sciences (NIBS) defines the building life cycle as "from the earliest concept existence to demolition," and BIM is defined as "the digital representation of the physical and functional characteristics of the facility." BIM is a shared knowledge resource that is used as a basis for decisions throughout the building life cycle (Meng et al., 2020). This definition has been widely accepted by scholars. BIM can be viewed from both a limited and a broad perspective (Gray et al., 2013), as shown in Figure 2.1. In its limited definition from Eastman et al. (2018), BIM (also known as "small BIM" or "tool") refers to the digital building model itself as a central hub or repository for information management.

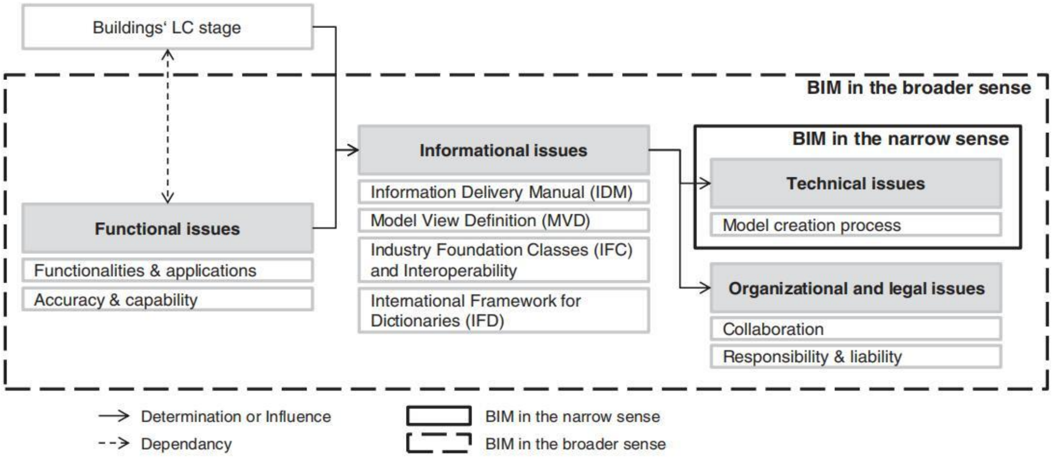

Figure 2.1 Relations between building life cycle and BIM (Volk et al., 2014)

BIM has become more popular over the last several decades in the construction industry, which has recognized its many benefits and resource-saving possibilities throughout the design, planning, and building of new projects (Volk et al., 2014). BIM is a digitalized technology that may be described as a technique to create, organize, manage, trade, and share building-related information in an open and reusable manner (Lin, 2015). At present, the research on BIM is more extensive and mainly divided into the following aspects:

ⅰ. Reparation of Industry Foundation Classes (IFC) standards. The standard is currently a more mature international BIM data standard developed by an industry alliance initiated by Autodesk. It is a standard, open data expression and storage method. Much software can import and export engineering data in accordance with the IFC standard. The IFC standard core focuses on two aspects: the description of engineering information and engineering information acquisition (Li et al., 2025).

This standard is designed to solve the problem of data and information sharing among software companies. Therefore, IFC has attracted much attention since its launch.