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Advances in Construction and Project Management Volume I

Construction and Project Management

Edited by
Srinath Perera, Albert P. C. Chan, Dilanthi Amaratunga, Makarand Hastak, Patrizia Lombardi, Sepani Senaratne, Xiaohua Jin and Anil Sawhney

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Cover image courtesy of Srinath Perera

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About the Editors

Srinath Perera

Professor Srinath Perera is chair professor of built environment and construction management and the founding Director of Centre for Smart Modern Construction (c4SMC) at Western Sydney University. He joined WSU in June 2016 after serving as professor of construction economics at Northumbria University, Newcastle, in the UK. He is a Board member and the chair of the future leaders committee of the International Council for Research and Innovation in Building and Construction (CIB, www.cibworld.org).

He is a fellow of the Royal Society of New South Wales (FRSN) and also a fellow of the Australian Institute of Building (AIB). He is a chartered surveyor and a member of the Royal Institution of Chartered Surveyors (RICS), the Australian Institute of Quantity Surveyors (AIQS) and Australian Institute of Project Management (AIPM). He has over 30 years' experience in academia and industry and has worked as a consultant quantity surveyor and project manager in the construction industry.

Professor Perera is a pioneer in the field of construction informatics integrating AI technologies to construction and project management. He co-authored a research monograph, "Advances in Construction ICT and e-Business" (2017) and two internationally recognized textbooks, namely *Cost Studies of Buildings* (2015) and *Contractual Procedures in the Construction Industry* (2017) published by Routledge. He is also the author of "Managing Information Technology Projects: Building a Body of Knowledge in IT Project Management" He has authored over 250 peer reviewed publications and his current research leads work in the areas of blockchain and IoT applications in construction, BIM, Digital Twin, offsite construction, construction business models and construction performance leading to Industry 4.0.

He recently published the *Digitalisation of Construction* report, indicating the status and future directions of digitalization of the NSW construction industry.

Albert P. C. Chan

Professor Albert P. C. Chan is currently PolyU's Dean of Students, associate director of Research Institute for Sustainable Urban Development, and chair professor of Construction Engineering and Management. He earned his MSc degree in construction management and economics from the University of Aston in Birmingham, and a PhD degree in project management from the University of South Australia. Before joining the Department of Building and Real Estate of PolyU in 1996, Professor Chan taught at the University of South Australia as a senior lecturer and deputy head of the School of Building and Planning. He was appointed by PolyU as associate head (teaching) of the Department of Building and Real Estate from 2005 to 2011, associate dean from 2011 to 2013, interim dean of the Faculty of Construction and Environment from 2013 to 2014, and head of the Department of Building and Real Estate from 2015 to 2021. He has been an Adjunct Professor in a number of Mainland and overseas universities.

A chartered construction manager, engineer, project manager and surveyor by profession, Professor Chan is devoted to a myriad of research subjects as varied as project management and project success, construction procurement and relational contracting, public–private partnerships, and construction health and safety, as manifested by his prolific research output of over 1,000 refereed journal papers, international refereed conference papers, consultancy reports, and other articles. Besides being an expert member of the Engineering Panel of the Research Grants Council, HKSAR, since 2015, Professor Chan has also served as an expert member in the Built Environment Panel of FORMAS, Swedish Research Grants Council, and the Faculty of Architectural and the Built

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Dilanthi Amaratunga

Professor Dilanthi Amaratunga holds the chair in Disaster Risk Management at the University of Huddersfield, UK, where she leads the Global Disaster Resilience Centre. She is a leading international expert in disaster resilience, with an extensive academic career that has a strong commitment to encouraging colleagues and students to fulfil their full potential. Her research interests include disaster risk reduction in the built environment; understanding disaster risk, preparedness for response; early warning systems; disaster resilience from the perspective of the social/political, economic, and physical sciences; and compound hazards and systemic risks. She has managed the successful completion of a large number of international research projects (over GBP 20 million), generating significant research outputs and outcomes, with the engagement of many significant research collaborations around the world in partnership with key academic and other stakeholders. To date, she has produced over 500 publications, refereed papers, and reports, and has made over 100 keynote speeches in around 40 countries.

Her outstanding contributions, publications, and services to her field of expertise have been recognised with numerous international awards. Between 2016 and 2019, she was winner of the prestigious 2019 Newton Prize, which recognises the best research and innovation projects which create an impact socially and economically, between Indonesia and the United Kingdom. In 2018, she received the "His Excellency the President of Sri Lanka Award" from the President of Sri Lanka, for here contribution to Disaster Resilience in Sri Lanka. In 2018, she won the UALL International Award, which recognises innovative engagement that creates change in an international and transnational context. She is a fellow of the RICS; fellow of the Royal Geographical Society, UK; fellow of the Higher Education Academy, UK; and fellow/chartered manager of the Chartered Management Institute, UK.

Makarand Hastak

Dr. Makarand Hastak is professor and Dernlan Family Head of Construction Engineering and Management as well as professor of civil engineering at Purdue University. Prof. Hastak is recognized around the world as an expert in construction engineering and management, with specific expertise in the profitability of construction companies, disaster risk reduction, infrastructure management, project control, and risk management. He is a licensed professional engineer (PE), a construction risk insurance specialist (CRIS), and a certified cost professional (CCP). Prof. Hastak has worked on numerous projects sponsored by prestigious funding agencies. As a fellow of the American Council on Education (cohort of 2013-14), his work at Cornell University focused on hybrid RCM budgets, engaged institutions, and public–private partnerships in academia.

He is the current president of the International Council for Research and Innovation in Building and Construction (CIB) (https://cibworld.org/) and serves as the academic advisor to the CII Downstream and Chemicals Committee (DCC) as well as the Department of Building and Real Estate, Hong Kong Polytechnic University. Prof. Hastak has authored/co-authored over 200 publications and reports as well as co-authored and edited three widely used books. He served as (Editor-in-Chief of the ASCE *Journal of Management in Engineering* (2009–2016). Prof. Hastak is a founding member and the past chair of the GLF-CEM, the Global Leadership Forum for Construction Engineering and Management programs.

Dr. Hastak received his BE (civil) from Nagpur University, India, MSCE from the University of Cincinnati, and PhD (civil) from Purdue University, USA. In addition, he is a trained university planner through SCUP and has received training at Cornell University in executive leadership, financial management, and advanced strategic human resource management. He has worked at Georgia Tech, NYU, University of Cincinnati, and currently at Purdue University.

Patrizia Lombardi

Professor Patrizia Lombardi, full professor of Projects Appraisal and Planning Evaluation at Politecnico di Torino, she is currently vice-rector for Sustainable Campus Development and Community Inclusion, after having been deputy rector and Urban and Regional (DIST) Department director. Since 2015, she has been coordinating the University Green Team, dedicated to the implementation of Agenda2030, in the context of the university's third mission. She is also president of the Network of Universities for Sustainable Development (RUS), of which she has been a promoter since 2013 and advisor of a number of Industries, NGOs, European Think Thanks, Joint Research Center of the European Commission and the Italian Ministry of Sustainable Infrastructure and Mobility. At international level, she is an established figure in the field of sustainable development evaluation for over 25 years and has coordinated or served as core partner several pan-European projects. Her research concerns issues of sustainable development assessment of the built environment with reference to decision support tools, including interactive Multicriteria Spatial Decision Support Systems. She is the author of more than 240 publications (h-index 32 Google Scholar with more than 4700 citations) and member of the Editorial boards of various international scientific journals. She has received several scientific and career awards.

Sepani Senaratne

Associate professor Sepani Senaratne is currently the director of Academic Program for UG Construction Management at Western Sydney University in Australia. Sepani has more than 20 years of academic experience in the quantity surveying (QS), construction management (CM) and built environment (BE) disciplines, attached to reputable universities in Sri Lanka, the UK and Australia. Her first degree is in BSc (Honours) first-class in QS from Sri Lanka and her PhD is in CM from the University of Salford, UK. Her key research expertise is in knowledge management and project management applications in construction projects and her research interests expand to include sustainable construction, smart modern construction and cost management areas. She has over 150 publications, including several peer-reviewed journal articles, conference papers, books and reports. Sepani's research has benefited various BE industry sectors and professions such as quantity surveyors, project managers, and contractors in solving project management problems. In 2022, as co-coordinator, Sepani launched a task group in CIB (The International Council for Research and Innovation in Building and Construction) on 'TG 124 on Net Zero Carbon' to create a global discussion and research. The sustainability research and activities that she is currently conducting contribute to United Nations Sustainable Development Goals. She has received several best paper awards at international research conferences, an Emerald Award of Excellence for Highly Commended Paper in 2009 and an Outstanding Research Performances Award by the University of Moratuwa consecutively five years. She is actively serving the academic community as a paper reviewer, postgraduate thesis examiner and member of conference committees.

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Anil Sawhney

Dr. Sawhney is a construction and infrastructure sector expert, an educator, a researcher, and a ConstructionTech enthusiast. In his role at the RICS, he is involved in producing the construction and infrastructure sector's body of knowledge, standards, guidance, practice statements, education, and training. Anil is the current chair of the International Cost Management Standards (ICMS) Standard Setting Committee and the co-chair of the AECO Working Group of the Digital Twin Consortium. He is also an adjunct faculty at Columbia University, visiting professor at Liverpool John Moores University in the UK, and an adjunct faculty at the University of Southern California. Anil has gathered a rich mix of academic, research, industry, and consulting experience in the USA, India, Canada, the UK, and Australia. In 2020, he co-authored a book entitled *Construction 4.0—Innovation Platform for the Built Environment*. He is currently the co-editor of the *Construction Innovation Journal*. Dr. Sawhney serves on the international editorial board of the *ICE Infrastructure Asset Management journal and the Journal of Information Technology in Construction*.

Preface to "Advances in Construction and Project Management—Volume I"

Construction and project management are two critical areas that play significant roles in society's progress and development. Construction projects play crucial roles in shaping the built environment, with an impact ranging from towering skyscrapers to intricate transportation systems. Effective project management is equally vital in this process, ensuring projects are completed on time, within budget, and to the required quality standards.

The field of construction and project management is constantly evolving, with new technologies, processes, and best practices emerging regularly. Keeping up with these advancements is essential for professionals in these fields, allowing them to ensure that they are delivering the best outcomes for their clients and stakeholders.

This book, entitled *Advances in Construction and Project Management*, compiles a collection of chapters from experts in these fields, covering the latest developments and trends. This publication covers a wide range of topics, including sustainable construction, digital technologies, project risk management, and stakeholder engagement, among others.

Written by leading academics and industry professionals from around the world, the individual chapters provide global perspectives on the subject matter. The authors draw on their experience and research to provide practical insights and solutions to the challenges facing construction and project management professionals today.

This book constitutes an essential resource for anyone involved in the construction or project management industries, including architects, engineers, contractors, project managers, and consultants. It is also an excellent reference for students studying in the disciplines of built environment, architecture, engineering, and construction, providing them with the latest information on the subject matter.

We hope to inspire readers to embrace new technologies, processes, and best practices and continue to advance the fields of construction and project management. We would like to express our gratitude to all the authors who contributed to this book and to the readers for their interest in this important topic. We also wish to acknowledge the Centre for Smart Modern Construction (c4SMC) and their industry partners for continued support and collaborations. I would also like to thank the centre researchers, Dr Samudaya Nanayakkara, Thilini Weerasuriya and Prasad Perera, for helping in the compilation of this topics issue.

Srinath Perera, Albert P. C. Chan, Dilanthi Amaratunga, Makarand Hastak, Patrizia Lombardi, Sepani Senaratne, Xiaohua Jin, and Anil Sawhney
Editors

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Article

The Conditional Configuration Path for Private Enterprises Participating in PPP: A Fuzzy-Set Qualitative Comparative Analysis

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Abstract: Public–private partnership (PPP) projects have been widely applied in infrastructure construction. Leveraging private capital is the key to promoting the high-quality development of PPP projects. This study examines the combined effect of seven factors determining private enterprises that participate in PPP and collects materials from 102 PPP sewage treatment projects to examine the causal configuration path of private enterprises participating in PPP (PEP3P) from an overall perspective by using necessary condition analysis (NCA) and fuzzy-set qualitative comparative analysis (fsQCA). The findings support the fact that any single antecedent condition is not a necessary condition for PEP3P and is instead the combined effect of different factors that commonly form the diversified causal configuration paths of PEP3P. There is an obvious asymmetry between the configuration paths of the high participation and low participation of private enterprises. The enterprise technology level (ETL) and doing business (DB) are important internal driving forces and give external traction for PEP3P, while the enterprise credit level (ECL) and project investment scale (PIS) are important factors that restrict private enterprises from participating in PPP. This research fills a theoretical gap for PEP3P and can be applied to developing strategies for attracting private enterprises to participate in PPP.

Keywords: private enterprises; public–private partnerships (PPP); configuration path; fuzzy-set qualitative comparative analysis (fsQCA)

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1. Introduction

Over the past few years, with rapid economic expansion and the ongoing effects of the COVID-19 pandemic, the limited fiscal revenue provided by local government is far from enough to meet the huge funding needs for infrastructure construction and public services [1]. Public-private partnership (PPP) has increased in popularity as an alternative method of procurement to alleviate financial pressures and improve the quality and efficiency of public projects and services [2,3]. PPP is characterized as a type of collaboration between the government and social capital in China. State-owned enterprises constitute a substantial portion of the second "P" of PPP because of their typical Chinese features [4]. Private enterprises' competitors, the state-owned enterprises, and centralized enterprises have the natural advantages of robust financial strength, low expectations of profits, and closer relationships with the government due to their backgrounds, advantages that are not available to private enterprises, which must also fulfill certain economic responsibilities for the government while pursuing profits and economic goals [5].

On the other hand, the apparent difference between state-owned and private enterprises participating in PPP projects has resulted in major "crowding-out consequences" to private enterprises and even the possibility of a state-owned monopoly [6]. Problems such as disguised financing, public-sector government cooperation, higher and lower levels of government cooperation, government manipulation, and actual management rights have arisen one after the other during the course of cooperation between local governments and state-owned enterprises [6]. This runs counter to the PPP model's goal of leveraging private finance, utilizing private enterprise production and management technology to reduce project risks and optimize overall profits [2,3]. Naturally, the commonplace emphasis on PPP programmatic development, stability, and permanency across studies allows us to define, for this study, the fact that mobilizing private investment is critical to the sustained and stable development of infrastructure through PPPs [7,8]. However, private enterprises have always retained their low participation and small share. To effectively utilize the capital and technology of private enterprises, reviewing internal and external factors on how to restrict private enterprise involvement in PPP projects and identifying participation paths for private enterprises in PPP projects are critical.

PPP projects usually have a long payback period, high risk, and relatively low return rate [9]. In recent studies on private enterprises' participation in PPP projects, researchers started with the influencing factors restricting the participation of private enterprises, based on the policy text, to discover the reasons behind their low participation [7,10]. Some scholars have used case-study methodologies to summarize the market-led, government-led, and enterprise-led factors that influence private company participation in PPP projects [11–13]. Others employed empirical research methods to analyze the net effect of various restrictions on private enterprise participation from various perspectives [2,14,15]. Most previous studies have focused on how to evaluate the effect of various factors on private enterprises participating in PPP(PEP3P), whereas the factors that limit private firms' participation in PPP projects are not mutually independent but rather have complicated causal relationships. Despite the relevance and high visibility of this situation in China, this topic has received little research attention regarding the participation paths for private enterprises. Given this finding, the purpose of this article is to answer the following questions:

1. Is there a single necessary condition for private enterprise participation in PPP?
2. What are the configuration paths for private enterprises to make them participate in PPP projects in China?
3. What are the differences in configuration paths between high and low participation in PPP for private companies?

Given the current state of the PPP model in China and the difficulties encountered by private enterprises when participating in PPP projects, this study takes 102 PPP projects regarding sewage treatment as the research object and aims to identify the configuration paths that motivate private enterprises to participate in PPP projects by using the necessary condition analysis(NCA) and fuzzy-set qualitative comparative analysis(fsQCA) methods. The contributions of this study are therefore geared toward identifying the factors that influence PEP3P from three perspectives: these include participant characteristics, doing business(DB), and project characteristics; employing set theory to explain the complex causal relationships among multiple factors and unveiling the condition configuration paths that drive private enterprises to participate in PPP projects, making up for the shortcomings of traditional measurement methods that rely on univariate net effect analysis; and utilizing fsQCA to analyze causal asymmetry for the configuration paths of PEP3P and explore separately the configuration paths that lead to high and low participation, which helps government departments to make better decisions and solve problems more effectively.

The remainder of the paper is structured as follows: a detailed literature review is given in Section 2, which helps to identify the factors influencing PEP3P, followed by a summary of the research design. In Section 3, the methodologies and data used in this study are explained. Section 4 shows the results of this study and the research findings. Section 5 puts forward our recommendations to encourage private enterprises to participate in the PPP, based on the findings. The paper ends with concluding remarks, a summary of the study's limitations, and suggestions for future research in Section 6.

2. Literature Review and Research Propositions

2.1. Literature Review

2.1.1. Participants' Characteristics

Most studies about participants in the PPP field currently focus on participant management [16,17], risk allocation [17–20], the distribution of control rights [21,22], and governance mechanisms [23,24], which ignores the micro factors of a single subject. The objective characteristics of government and enterprises play a crucial impact on private enterprise participation in PPP investment.

At the government level, the PPP method offers a means for the administration to hide fiscal deficits and circumvent expenditure restrictions, providing a fiscal protection mechanism for the government [25]. An inverted U-shaped relationship exists between the weakness of local free financial resources and private sector participation in PPP projects [26]. Furthermore, PPP transactions need aggressive management by a strong, competent government [27,28]. The reasons for past PPP failure focus on limited public sector capacity, lack of political will, and perceived legitimacy and trust issues between the public and private sectors [8,29]. The capacity of government institutions is an important indicator of the effectiveness of government PPP governance, and government departments must have a comprehensive and clear PPP concept that can guide more private enterprises to obtain investment opportunities [7,30].

At the enterprise level, PPP is most apparent in the differences in finance, profitability, and technical innovation capability. Discrimination against diverse ownership led to difficult and expensive financing for private enterprises, drastically reducing profit space and indirectly raising the limit of PEP3P [31]. The private enterprises' technology innovation capacity plays an important role in their participation in PPP projects. Private enterprises with a high level of technological innovation are more likely to participate in PPP projects [32]. Conversely, private enterprises with a low level of technological innovation are less likely to participate.

2.1.2. Doing Business

Economic theory studies translate "doing business" (DB) into the possible advantages or costs to participants, which is an important and comprehensive aspect that directly influences government decision-making and enterprise investment. A favorable DB efficiently decreases information asymmetry, reduces the cost of government–enterprise collaboration, and reduces risks in investment activities [26]. A poor DB increases private enterprise participation costs and forces them to abandon PPP projects in search of alternative investment opportunities. A complete legal framework [33–35], regional economic development level [17,19], available financial markets [17,19,36] and the degree of information transparency [37,38], corruption [11,14,29], foreign exchange and inflation risks [35,39,40], and other single environmental factors have been shown by many scholars to have an impact on private enterprises' participation in PPP projects.

However, analyzing the impact of the macroenvironment on participants from the point of view of a single aspect might easily obscure the nature of the impact of the macroenvironment on participants. A few scholars have been drawn to the DB as a thorough indication of the macroenvironment [26,31,41]. A favorable DB contributes to the elimination of rent-seeking and the promotion of enterprise innovation and development. A good DB plays a positive regulating role in the relationship between the local government's financial resources and enterprises attracted by PPP projects, which is conducive to reducing the resistance of the private financial resources gap to PPP projects [41]. The government represents the interests of the public and must create good DB to guide investors in exerting a great deal of effort in a partnership [31].

2.1.3. Project Characteristics

In addition to the influence of participant characteristics and DB on private enterprise investment decisions, project characteristics are also necessary factors for enterprises to consider regarding investment. While research on project characteristics factors focuses on the project franchise period, project type, project scale, and project risk [5,17,33,34,37,39,40], how to design appropriate PPP projects to promote private enterprise participation needs to be studied further.

As rational economic subjects, private enterprises consider avoiding risks and delivering predictable returns to be the crucial project selection criteria [31]. However, PPP project characteristics, such as long return cycles, high financing costs, and unpredictable returns, increase the enterprises' concerns [17]. Private enterprises will invest in a project only if the profit they can gain from this project is equal to or greater than the income they can obtain from other, similar, projects [42]. Project risks, for example, run throughout the project's whole life cycle, and reasonable risk allocation is the key for the government and private enterprises to "play to their respective strengths" and achieve the collaboration aim of "$1 + 1 > 2$". The government usually shares the risk with enterprises, but excessive risk-taking increases the government's financial burden, whereas an insufficient risk responsibility reduces the confidence of the investors participating in the project [31,43]. Reasonable projects' risk allocation (PRA) not only minimizes the government's risks but also increases investors' confidence, thereby reducing costs and improving social welfare. Furthermore, with limited capital, private enterprises prefer small-scale and low-cost projects, such as sewage treatment, ecological environmental protection, and culture [14,17].

Few if any of these studies have examined whether different constellations of factors create conditional configuration paths to attract private enterprises to participate in PPP projects [44]. This study thus attempts to build on the cross-project findings and influencing factors of PEP3P from other extant studies by addressing the following research question: What combinations of factors lead to PEP3P? To address this research question, we begin by outlining the importance of PEP3P. Next, we identify the influencing factors affecting PEP3P. Then, we outline our analytical approach and case selection strategy using NCA and fsQCA. Finally, we discuss the results of our fsQCA and the implications of our findings for future research on PPP areas.

2.2. Research Propositions

The majority of previous studies indicate that private enterprise participation in PPP is affected by many factors. In this context, the paper argues that examining configurations of factors is more important for understanding private enterprise participation in PPP than evaluating individual causal conditions. The configurational perspective implies complicated causal patterns and higher-level interactions among the constructs. Configuration theory emphasizes conjunction causality [45], meaning that outcomes of interest (e.g., private enterprise participation in PPP) rarely result from a single cause but rather from sequential causal conditions that create insufficient configurations that result in the outcome. Thus, a causal condition causes an outcome that is not in isolation but is in combination with another one or more other conditions. In this respect, this article puts forth the following hypotheses:

Proposition 1 (P1). *A single condition is not a necessary condition for private enterprise involvement in PPP; it is rather a variety of conditions interacting to influence private enterprise participation in PPP.*

Proposition 2 (P2). *There is no single best configuration path of antecedent conditions that occurs to explain private enterprise involvement in PPP, but multiple, equally effective configurations of causal factors do exist.*

The configuration theory also proposes the occurrence of causal asymmetries. Causal asymmetry means that an outcome may occur even when a causal condition does not exist, depending on how it combines with other causal conditions; a configuration that explains the presence of an outcome cannot be interpreted as the mirror image of a configuration that explains its absence [45–47]. For example, alternative configurations of private enterprise participation in PPP may involve high government revenue in one configuration and low government revenue in another configuration. A causal condition can be associated with a positive or negative outcome, based on how it is combined with other causal conditions. In addition, even if all the antecedent conditions are the same, the non-set of the conditional configuration of high participation is not the conditional configuration of the low participation of private enterprises. Thus, explanations for the presence of an outcome do not imply that reversed explanations inevitably account for its absence [47]. Therefore, this article puts forth two additional propositions:

Proposition 3 (P3). *Single causal conditions (i.e., government fiscal revenue, government institute capacity, enterprise credit level, enterprise technology level, and so on) may be present or absent within configurations for PEP3P, depending on how they combine with other causal conditions*.

Proposition 4 (P4). *Configuration paths of the high participation in the PPP of private enterprise are not perfect reverses of the configuration paths of the low participation in PPP of private enterprise*.

3. Methodology and Data

3.1. Research Design

There is a matching link between the characteristics of participants, the DB, and the characteristics of a project. First, government characteristics concentrate on government fiscal revenue (GFR) and government institutional capacity (GIC) [5,19,30,35]. Areas with low GFR tend to use the PPP model to provide public goods or services, and PPP projects are typically tiny, which might easily cause private enterprises to be concerned about their income stability [26]. A favorable DB might help to mitigate the resistance effect of limited financial resources on PPP projects [48]. The preparation and implementation of PPP projects are represented by the capacity of government institutions [8,29]. The government may efficiently integrate market resources, launch high-quality PPP projects, and leverage private capital through standardized and orderly PPP operations, which have a positive feedback impact on the DB.

Second, enterprise characteristics encompass a range of behavioral activities, such as enterprise operational costs, innovation capability, revenue capability, and financing capability [31,32]. According to the principal–agent theory, the two parties achieve the same aim through information search, negotiation, contract design, and other activities, all of which require the consumption of scarce economic resources; therefore, market allocation is ineffective [49]. Reducing ineffective agency activity is the key to increasing private enterprises' participation. A good DB provides a sound market mechanism and property rights protection; perfect information for enterprise operation lowers the cost of the enterprise search for the local market and interpersonal behavior information ensures contract fulfillment and increases private enterprise participation enthusiasm [41]. In the same DB, enterprises with a high credit level and high innovation ability can fully utilize their advantages in terms of resource integration, leverage the benefits of market size and investment, compensate for a lack of project characteristics, and have a stronger willingness to participate in PPP projects. As a result, PEP3P is a process in which the features of the government and enterprises, DB, and project characteristics, as well as other elements, simultaneously constrain, complement and substitute, match, and interact.

The study is led by concurrent method theory and creates a three-dimensional research framework consisting of seven conditional variables and one outcome variable, based on references and stakeholder perspectives. Due to the condition number constraints of the fsQCA technique, we only evaluate the seven criteria that have been widely addressed in other literature and are acknowledged by experts, without considering additional factors, such as government corruption, the project cycle, project incentive system, and so on. Secondary factors for the features of the participating subjects are determined to be government financial revenue (GFR), government institute capacity (GIC), enterprise credit level (ECL), and enterprise technology level (ETL) [5,30]. The area of DB is a comprehensive index of external factors and conditions, such as the government affairs environment, market environment, legal environment, and cultural environment, which are engaged in the market entities' economic activities. The DB plays a moderating role in the relationship between government financial resources and PPP project investment and is regarded as an important indicator influencing private enterprise participation [26,41]. Secondary indicators of project characteristics are determined to be project investment scale (PIS) and project risk allocation (PRA), when combined with the division of project features [11,17]. As a result, this paper selects the above seven conditional variables from the four aspects of government characteristics, enterprise characteristics, doing business, and project characteristics, to construct a configuration analysis model using the fsQCA method to drive private enterprises to participate in PPP projects and reveal the complex causal relationship between different conditions. Figure 1 depicts the theoretical model framework.

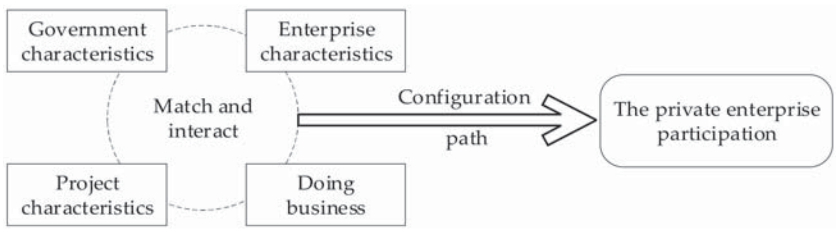

Figure 1. Theoretical model framework.

3.2. NCA and fsQCA

Once the theoretical model framework was established, we explored the necessity of specific conditions for results and which combinations of conditions lead to PEP3P. Inferring such systematic patterns among several factors is infeasible with traditional deductive correlation-based approaches [50,51]. However, the combination of NCA and QCA is the preferred method for addressing this type of research question [52,53]. NCA focuses on a single condition that is necessary but is not always sufficient, whereas QCA focuses on combinations of conditions (configurations) that are sufficient but are not always necessary [54]. Although QCA focuses on sufficient configurations, it may also evaluate a single necessary condition, but there is a limitation in terms of quantitative analysis [55]. The combination of these two approaches will explain the necessary conditions and causality adequately [55].

The first step toward identifying the conditions is whether it is necessary to condition PEP3P with NCA. The necessary condition analysis (NCA) method clarifies the necessary but not sufficient conditions of various organizational determinants for predictable outcomes [54]. Necessary conditions are those that must be present but alone are not sufficient to produce the outcome of interest, while sufficient conditions (or combinations thereof) are sufficient but not necessary (because of multiple causal pathways) to produce the outcome of interest [54,56,57]. Compared to traditional data analysis, which is the additive model, NCA is able to express the necessary causality as a multiplicative phenomenon [54]. Thus, before the intended outcome may be realized, these necessary conditions must be removed [54].

Then, we determined which combinations of factors result in PEP3P. For this type of research question, QCA is the preferred strategy [57,58]. QCA is a hybrid method that incorporates the benefits of both qualitative (case-based research) and quantitative analysis (variable-oriented research). QCA, on the other hand, is based on the investigation of sufficient and necessary conditions to create an outcome and uses small-to medium-level case studies to explain various concurrent causalities [59]. This technique aids in the research of equifinality, or the existence of several combinations of variables that result in the same outcome [45]. FsQCA is one of the main QCA technologies and was selected for this study. This approach combines the inferential power from "large n" data sets with in-depth case knowledge [60] and involves the scoring of causal and outcome conditions for each case, based on the extent of its membership in a set of cases sharing a particular characteristic [56]. A range of continuous values from 0 to 1 is used to score both the causal conditions and outcome measures. Cases with a score of 0 are considered to be "fully out" of a set of cases with a given characteristic, while cases with a score of 1 are considered to be "fully in" the set [61].

3.3. Data

3.3.1. Sample and Data Collection

According to the National PPP Comprehensive Information Platform management database project's 2021 semi-annual report, the database contained 4138 municipal engineering projects, accounting for 40.9 percent of the total. We chose the sewage treatment industry as a research object to avoid industry disparities and maintain timeliness. Between 2018 and 2019, 355 municipal engineering sewerage treatment projects entered the execution stage. Based on three criteria, we chose 102 sewage treatment projects at the implementation stage as examples because of the diversity of cases, representativeness of instances, and comprehensiveness and rigor of data. We utilized the "National PPP Comprehensive Information Platform Project Management Database" to gather project-specific information, including the project name, project location (province, city, county), project investment amount, value for money score sheet, shareholder name, shareholder capital contribution, and shareholder equity ratio. The GFR and DB scores for the project's location were obtained from provincial statistical yearbooks, as well as data released by the Guangdong-Hong Kong-Macao Greater Bay Area Research Institute and the 21st Century Economic Research Institute. Through docking with the enterprise basic information and annual report on the Tianyancha website, we acquired enterprise-related data, including the enterprise nature, enterprise punishment data, enterprise punishment history, and enterprise patent information.

3.3.2. Measures

Any fuzzy set can be seen as a continuous variable that has been purposefully calibrated to indicate the degree of membership of a well-defined set [61]. Therefore, calibration is regarded as the process of assigning case membership values. Direct calibration was used to determine the fuzzy set (or clear set) of outcome variables and numerous antecedent conditions, based on applicable theories and substantive knowledge [46,61]. Table 1 shows the descriptive statistical analysis and calibration score values for the outcome variables and various antecedent conditions, demonstrating that there are no abnormal values.

Outcome variable: The project shareholders' information for 2018–2019 was obtained from the National PPP Comprehensive Information Platform management database. We measured the involvement of private enterprises in terms of the nature of the enterprise and the percentage of private enterprises' equity. Company law's eight equity lines were used to determine a fuzzy set of private enterprise participation. The absolute controlling interest is 67 percent, which translates to 100 percent authority, while the temporary meeting equity is 10 percent. To avoid a contradiction between the fuzzy membership threshold and the original data, a small modification was made [61]. The full non-membership threshold value was 10.00, the crossover point was 50.01, and the full membership threshold value was 66.99.

Antecedent conditions of participating subjects: GFR and GIC are characteristic of government qualities, while ECL and ETL are characteristic of enterprises. GFR data focused on the city and county levels to eliminate disparities caused by administrative unit inconsistencies. GIC was determined by the project's value-for-money expert score, which was averaged after excluding the highest and lowest scores from a single project. If multiple projects were in the same city or county, the GIC score was averaged once again. We chose the sum of the administrative fines and historical administrative penalties to measure DB. Corporate administrative punishment represents the government's method of evaluating untrustworthy firms' behavior, and indirectly reflects their credit, funding, and profitability [62]. Company innovation capability was expressed by the number of authorized and effective patents [63] because the level of enterprise patents has a long-term promoting effect on a company's innovation level [64]. Three calibration points for GFR, GIC, and ETL were expressed by quartiles of the descriptive statistics of the case samples (25%, 50%, and 75%, as follows). For ECL, we adopted a dichotomy: the value is 0 if the firm had an administrative penalty or a historical administrative penalty; otherwise, the value is 1.

Table 1. Calibration and descriptive statistics of the outcome and the antecedent conditions.

Condition		Descriptive Statistics				Membership Threshold Values		
		Mean Value	Standard Deviation	Minimum Value	Max Value	Full Nonmembership	Crossover Point	Full Membership
Outcome	PEP3P [1]	43.77	42.02	0.00	100.00	10.01	50.01	66.99
	GFR [2]	563,950.79	945,888.87	18,309.00	4,078,417.00	80,944.00	148,825.00	484,306.50
	GIC [3]	85.49	5.79	66.67	33.33	82.47	85.75	88.30
	ECL [4]	0.57	0.50	0.00	1.00	0.00	—	1.00
Antecedent	ETL [5]	66.61	102.40	0.00	691.00	2.25	21.50	83.75
	DB [6]	0.30	0.08	0.23	0.37	0.25	0.28	0.30
	PIS [7]	55,258.32	62,167.32	1784.89	365,222.11	15,316.13	33,724.12	67,336.61
	PRA [8]	81.34	6.33	61.20	32.80	77.82	82.01	85.98

[1] TPEP3P = private enterprises participation in PPP; [2] GFR = government financial revenue; [3] GIC = government institute capacity; [4] ECL = enterprise credit level; [5] ETL = enterprise technology level; [6] DB = doing business; [7] PIS = project investment scale; [8] PRA = project risk allocation. The same applies below.

Conditions antecedent to the DB: Improving the DB was crucial in fostering enterprise transformations and upgrading, and ongoing improvement will promote high-quality development [48,65]. There are currently two approaches for measuring the DB. The first way is to create a DB indicator based on the existing mature report and its research objectives, while the second method is to directly measure the DB in the mature report. This method is known as the "marketization index" of DB [66]. The overall score from the DB study for 2020 for the 296 cities in China above ground level, published in a report from the Greater Bay Area Guangdong-Hong Kong-Macao and the 21st Century Economic Research Institute, was used to calculate DB scores. Three calibration points for DB were expressed by quartiles of the descriptive statistics of the case samples.

Antecedent conditions of project characteristics: The amount of money invested in a project influences its size, which is a crucial issue for participating companies to consider [11,14]. Many variables, including political risks, market potential risks, and reasonable risk allocation, limit private company participation in PPP projects. Enterprises more actively participate in PPP as a result of the more complete identification of project risks and a reasonable allocation of risks between the government and social capital [31]. The risk allocation scores were calculated by averaging the expert scores in the evaluation of the value for money of each project, after removing the highest and lowest scores. Three calibration points for PIS and PRA were expressed by the quartiles of the descriptive statistics of the case samples.

4. Results Analysis and Discussion

4.1. Results

4.1.1. Results from NCA

Before we reached our "analytic moment", we needed to conduct a necessary conditions analysis for mature PPP market performance [61]. First, we used NCA to find the necessary antecedent condition. The effect size (ES) is a measurement of how much a necessary condition limited the outcomes. The larger the value of the effect size, the greater the restriction and the impact of a necessary condition on the outcome.

The ES has the following expression:

$$d = C/S, \quad (1)$$

where C is the ceiling area, S is the range, and d is the effect size. The required condition effect size ranges from 0 to 1, with "$0 < d < 0.1$" denoting a "low effect", "$0.1 < d < 0.3$" denoting a "medium effect", and "$0.3 < d < 0.5$" denoting a "high effect" [54]. The effect size was measured and expressed using both piecewise ceiling envelopment (CE) and continuous ceiling regression (CR). The effect sizes of each antecedent condition are reported in Table 2, and the relevant data were the calibration data. For the NCA approach to work, two elements must be met at the same time. First, the effect size should be no less than 0.1($d > 0.1$); second, the Monte Carlo simulation permutation test should demonstrate that the effective amount is statistically significant ($p < 0.05$) [54]. As a result, the effect size of each antecedent condition was 0, and the significance of the effect size was minor. Thus, each antecedent condition is not necessary for private enterprises to participate in PPP projects, and there will be no bottleneck for private enterprises.

Table 2. Results of the NCA method for determining necessary conditions.

Antecedent Conditions	Method	Accuracy	Ceiling Zone	Ranges	d [a]	p [b]
GFR	CR	100%	0	0.98	0.000	1.000
	CE	100%	0	0.98	0.000	1.000
GIC	CR	100%	0	0.98	0.000	1.000
	CE	100%	0	0.98	0.000	1.000
ECL	CR	100%	0	0.98	0.000	1.000
	CE	100%	0	0.98	0.000	1.000
ETL	CR	100%	0	0.95	0.000	1.000
	CE	100%	0	0.95	0.000	1.000
DB	CR	100%	0	0.97	0.000	1.000
	CE	100%	0	0.97	0.000	1.000
PIS	CR	100%	0	0.97	0.000	1.000
	CE	100%	0	0.97	0.000	1.000
PRA	CR	100%	0	0.98	0.000	1.000
	CE	100%	0	0.98	0.000	1.000

[a] The membership value of a fuzzy set after calibration. [b] The permutation test in NCA analysis (permutation test, the number of redraws = 10,000).

Following this analysis, the fsQCA method was utilized to test the necessity of the antecedent conditions; antecedent conditions with a consistency level of more than 0.9 are considered necessary conditions, based on the discrimination criteria from the previous study. Table 3 shows the result of the necessary analysis of antecedent conditions performed with fsQCA3.0. All antecedents and the negation of the antecedent conditions have a p-value of less than 0.9, and the test results are consistent with the NCA. These conditions are not necessary to entice private enterprises to participate in PPP projects. This finding gives credibility to Proposition 1, which anticipates that no single condition is a necessary condition for private enterprise participation in PPP.

4.1.2. Results from the fsQCA

When employing fsQCA for conditional configuration analysis, the configuration consistency level is typically greater than 0.80 [48]. The sample size determines the frequency threshold. The frequency threshold for small samples is 1. The frequency threshold is bigger than 1 for large samples. According to the prior literature's sample circumstances and discrimination criteria, the consistency was set at 0.85, and the frequency threshold was set at 1. Based on the attribution relationship between the simplified and intermediate solutions, we determined the core condition and edge condition of a single intermediate solution. The antecedent condition of both the simplified and intermediate solutions is the core condition, and only the antecedent condition of the intermediate solution is the edge condition. In counterfactual analysis, where there were insufficient evidence and theories to determine the precise direction of the antecedent conditions influencing results, it was assumed that the existence or absence of a single antecedent condition can drive private enterprises to participate in PPP projects. According to the fsQCA, Table 4 shows four paths for private enterprises to participate in PPP projects, namely, M1, M2, M3, and M4, indicating that private enterprises can participate in PPPs in a variety of different ways. This conclusion supports Proposition 2, which states that there is no single best configuration that predicts private company involvement in PPP but, rather, that different and equally effective configurations exist.

Table 3. The necessity test of a single condition in the QCA method.

Antecedent Conditions	High Participation of Private Enterprises		Low Participation of Private Enterprises	
	Consistency	**Coverage**	**Consistency**	**Coverage**
GFR	0.503	0.467	0.597	0.586
~GFR	0.554	0.565	0.456	0.493
GIC	0.558	0.547	0.472	0.489
~GIC	0.478	0.462	0.562	0.574
ECL	0.491	0.420	0.642	0.580
~ECL	0.509	0.574	0.358	0.426
ETL	0.651	0.636	0.382	0.395
~ETL	0.381	0.368	0.648	0.663
DB	0.418	0.435	0.556	0.611
~DB	0.626	0.572	0.485	0.469
PIS	0.465	0.452	0.572	0.587
~PIS	0.575	0.559	0.466	0.480
PRI	0.568	0.562	0.455	0.476
~PRI	0.470	0.449	0.581	0.587

The tilde represents the negation of the characteristic.

Table 4. Configuration analysis of PEP3P.

Antecedent Conditions	High Participation of the Private Enterprises				Low Participation of the Private Enterprises			
	M1	**M2**	**M3**	**M4**	**FM1a**	**FM1b**	**FM2**	**FM3**
GFR	⊗	⊗	⊗	•	⊗	⊗		•
GIC	⊗	⊗	•	⊗	⊗	⊗	⊗	⊗
ECL	⊗	⊗	⊗	⊗	•	•	•	•
ETL	•	•	•	•	⊗	⊗	⊗	
DB	⊗	•	•	•	⊗		•	•
PIS	⊗	⊗	•	•	•	•	•	•
PRA	•	⊗	•	•		⊗	⊗	⊗
Consistency	0.861	0.891	0.918	0.930	0.953	0.935	0.912	0.892
Raw coverage	0.041	0.034	0.045	0.035	0.116	0.080	0.085	0.099
Unique coverage	0.024	0.018	0.031	0.023	0.046	0.005	0.001	0.028
Overall consistency	0.914				0.931			
Overall coverage	0.116				0.207			

Black circles (•) indicate the presence of a condition, and circles with crossing-out (⊗) indicate its absence. Large circles indicate core conditions, and small circles refer to peripheral conditions. Blank spaces indicate a "don't care" situation in which the causal condition may be either present or absent.

Table 4 shows that the overall solution and single solution consistency levels are greater than 0.80, the overall solution consistency is 0.91, and the overall coverage is 0.116, indicating that these four configuration paths explain 11.6 percent of the reasons for PEP3P. Configuration M1 shows that the existence of ETL is a core condition, but the presence of

PRA is a peripheral condition. The configuration's consistency is 0.864, its unique coverage is 0.024, and its raw coverage is 0.041. As a result, a high degree of technology is a crucial guarantee for private enterprises to participate in PPP projects. The core conditions in the M2 configuration are the ETL and DB. This configuration's consistency is 0.891, has a unique coverage rate of 0.018, and a raw coverage rate of 0.034. As a result, improving technical innovation skills is an important condition for encouraging private enterprises to become important players in PPP projects in areas with better DB. Configuring M3 and M2 involves the same core existence conditions, and GIC, PIS, and PRA are important auxiliary variables. There is a consistency of 0.918, a unique coverage rate of 0.045, and a rate of raw coverage of 0.031. This demonstrates that enterprises with higher levels of technical innovation prefer to invest in locations with superior DB to attain the dual goals of government financial support and project seeking. The existence of GFR, ETL, DB, PIS, and PRA are all core conditions in configuration M4, which has a consistency of 0.930, unique coverage of 0.023, and raw coverage of 0.035. Thus, enterprises with high levels of technological capacity choose to participate in high-quality PPP projects in locations with superior business conditions, to fulfill the goal of local financial support. GRF, on the other hand, is absent in the configuration paths of M1, M2, and M3, which support Proposition 3, which predicts that single causal conditions may be present or absent in PEP3P configurations, depending on how they combine with other causal conditions.

4.1.3. Robustness Test

The robustness of the results is evaluated by varying the level of consistency. The results are considered robust if changing the consistency level results in a clear subset relationship between the setups. Table 5 reveals the results of the robustness tests. The consistency level was enhanced from 0.85 to 0.87, and the entire solution's consistency level was somewhat improved from 0.914 to 0.929. Although the configuration M1 no longer exists, it is still a subset of the original configuration. The M2 configuration has undergone a slight tweak. The GIC has switched from a lack of core conditions to a lack of edge conditions, but the underlying mechanism is the same; namely, that enterprises choose to participate in PPP projects in regions with stronger DB. The antecedent forms of other configurations are the same. As a result, after increasing the consistency criteria, the study results have not altered significantly; thus, the research findings are robust.

4.2. Discussion

4.2.1. The Configuration Paths for Private Enterprises to Participate in PPP

The PPP model that motivates private enterprises to participate in PPPs is further classified into three types, based on the core and peripheral conditions of the four conditional configurations: "enterprise technology-led" and driven (M1), the "DB-led" pulling type (M2 and M3), and "project characteristics-led" push type (M4). The three driving modes indicate the diverse and complex motivations that drive private enterprises to participate in this type of investment.

The "enterprise technology-led" driven configuration demonstrates that higher levels of technical innovation can be leveraged to compensate for a lack of corporate credit, achieving the goal of generating predictable investment returns by focusing on high-quality projects. Companies with stronger technological innovation skills have a more comprehensive organizational structure, a larger production scale, more efficient management capabilities, and more willingness to engage in PPP activities [32]. The sewage treatment PPP industry is constantly improving sewage treatment technology. Currently, the newly constructed sewage treatment plants in cities and towns have achieved a Class A pollution standard, and the previous Class B standard needs to be upgraded. As the sewage treatment industry improves its technical innovation capabilities, enterprises must ensure technological advancements through R&D and knowledge transformation, which helps to regulate the agents' trust relationship and improve project performance [67]. For example, Beijing Bishuiyuan Technology Co., Ltd. is ranked fourth on the list of cumulative capital participation in PPP projects, and independently researches and develops more than 50 core sewage treatment technologies to obtain a competitive advantage in the corporate world. Guangxi Boschke Environmental Technology Co., Ltd. has a skilled R&D team and a scientific research platform that can provide advanced technical assistance to PPP project participants.

Table 5. Robustness tests for adjusting the consistency level.

Antecedent Conditions	High Participation of Private Enterprises			Low Participation of Private Enterprises			
	M2′	M3	M4	FM1a	FM1b	FM2	FM3
GFR	⊗	⊗	•	⊗	⊗		•
GIC	⊗	•	⊗	⊗	⊗	⊗	⊗
ECL	⊗	⊗	⊗	•	•	•	•
ETL	•	•	•	⊗	⊗	⊗	
DB	•	•	•	⊗		•	•
PIS	⊗	•	•	•	•	•	•
PRA	⊗	•	•		⊗	⊗	⊗
Consistency	0.891	0.918	0.930	0.953	0.935	0.912	0.892
Raw coverage	0.034	0.045	0.035	0.116	0.080	0.085	0.099
Unique coverage	0.024	0.033	0.023	0.046	0.005	0.001	0.028
Overall consistency	0.929			0.931			
Overall coverage	0.092			0.207			

Black circles (•) indicate the presence of a condition, and circles with crossing-out (⊗) indicate its absence. Large circles indicate core conditions, and small circles refer to peripheral conditions. Blank spaces indicate a "don't care" situation in which the causal condition may be either present or absent.

Based on the results of the "DB-led" pull configuration, it is evident that creating a sound DB is essential to entice private firms to participate in PPP projects. There are two alternative paths for private firms to participate through this form of participation, with the core roles of ETL and DB playing a key part in both tracks. This reveals that enterprises with a higher potential for technical innovation are more inclined to participate in PPP projects launched in places with a more favorable DB. An uncertain business climate may lead to increasing non-productive and tax expenditures among enterprises, raising the cost of productive resources and diminishing private enterprise enthusiasm [48]. Private firm engagement in PPP projects is hampered to some extent by financing difficulties and high finance costs. Great DB can relieve corporate financial limitations, enhance technology diffusion and transfer, and eventually improve the innovation capabilities of private enterprises and stimulate corporate investment [26]. In superior DB, private enterprises tend to have fewer restrictions. Property rights protection, policy support, and more transparency increase the willingness and opportunities for private enterprises to participate [68]. As a result, private enterprises with higher levels of technological innovation choose to participate in PPP projects in regions with a stronger DB to reduce risk uncertainty.

According to the configuration results of the "project feature-led" pushing type, the internal character factors of the project and the level of GFR also play key roles, based on the two core conditions of ETL and DB. This model combines the dual advantages of "technology-led enterprise" and "DB-led" types. Private enterprises are willing to invest in larger-scale PPP projects under the pull of a reasonable PRA and the support of the GFR, but more companies prefer to invest in projects with small initial investment scales [69]. Only when the external environment becomes better will private enterprises choose projects with a relatively significant investment scale. Because private firms have fewer financial resources and negotiation advantages than state-owned enterprises, when private enterprises select larger projects, they are more inclined to choose projects with reasonable risk allocation [70]. When local governments have insufficient financial resources, the private sector will be worried about the government's ability to perform contract work [26]. Higher GFR guarantees encourage private enterprises to trust the government's ability to fulfill contracts, generating a pulling effect on private firms' participation in PPP projects. A better DB improves the funding platform for private enterprise participation, reduces transaction costs, and decreases uncertainty regarding potential dangers. Reasonable PRA and the government's financial income guarantee enable private enterprises to participate in large-scale PPP projects.

4.2.2. The Differences in Configuration Paths between High and Low Participation in PPP by Private Enterprise

Finally, the paper tries to analyze the configuration paths for the low participation of private enterprises in PPP projects. In other words, state-owned enterprises constitute a high proportion of project equity and identify the asymmetry of causality. This fuzzy-set analysis demonstrates that four configuration routes can result in the low participation of private enterprises in PPP projects, based on the assumption that the existence or nonexistence of each antecedent condition would induce the poor participation of private enterprises. The consistency of both the single solution and the overall solution is greater than 0.85, which explains 20.7 percent of the private enterprises' low participation. The findings show that the combination of antecedent conditions that drive high participation in PPP projects by private firms and limit the low participation of private enterprises has an obvious asymmetry. That is, the negative combination of conditions that drive the high participation of private firms is not the combination of conditions that limit the low participation of private firms. This finding points to asymmetric effects, as posited by Proposition 4. The four configuration options for the low participation of private firms all reveal that the existence of ECL and PIS are the core conditions for the low involvement of private enterprises. This demonstrates private firms' disadvantages in terms of enterprise credit and investment, which must be compensated for when they fully exploit their technological advantages. FM2 indicates that GFR is the core condition for state-owned firms to participate in PPP projects, and the core condition for private enterprises to participate in PPP projects, demonstrating that GFR is critical for all participants.

When viewed from the perspective of the individual conditions (horizontal) of the overall configuration, there is a significant difference in the core conditions regarding the high participation of private firms and the low participation of private enterprises. Figure 2 compares the core conditions of the high and low participation of private firms in typical PPP project cases. Figure 2a indicates that the ETL and DB exist as core conditions in many configurations of high participation by private enterprises. Figure 2b indicates that in different configurations of the low participation of private firms, ECL and PIS appear as core conditions. The study shows that the ETL and DB play an important role in driving PEP3P, whereas the ECL and PIS seriously restrict private enterprise participation. This corresponds to the actual situation. Private enterprises, as opposed to state-owned enterprises, have a greater innovative capability and more sensitive market insight, to increase their competitiveness, along with lower expenses. Meanwhile, they require a favorable DB to compensate for their shortcomings in financing and negotiating with the government. Because of their greater corporate credit level, state-owned firms are more likely to obtain credit funds, have more negotiating power with the government, and have more experience operating public utilities. They have a higher risk tolerance than private firms and are more likely to invest in large-scale PPP initiatives.

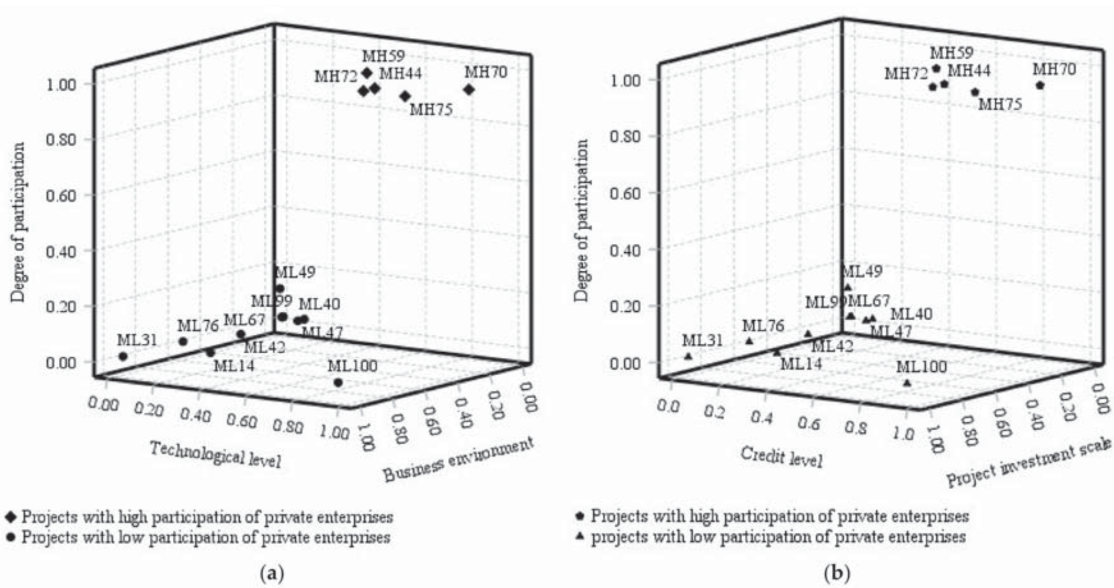

Figure 2. Comparison of the core conditions of projects with high or low participation of private enterprises. (**a**) Comparing the technological level and business environment of projects with high or low participation of private enterprises; (**b**) Comparing the credit level and project investment scale of projects with high or low participation of private enterprises.

5. Recommendations

Managerial and policy implications, as well as several recommendations, can be drawn from the aforementioned findings. First, governments and top management need to improve local DB, which will attract private enterprises to participate in PPP. They need to strengthen the legal, policy, and market environment to support private firm growth while protecting their property rights and interests in conformity with the law. The government needs to make certain that private enterprises have equal access to resources and factors in line with the law, that they engage in an open, fair, and just manner, and that they are equally protected by the law.

Second, the government needs to improve the institute's capacity for PPP management and to build standardized communication channels between the government and the private sector to reduce the information asymmetry between the two, which is conducive to opportunity. The government should encourage high-quality private-sector development, assist companies in basic research and scientific and technological innovation, and participate in the research and development of vital core technologies and major national scientific and technological initiatives.

Third, credit constraints restrict private enterprises from participating in PPP. Improving project cooperation performance capacity and reducing unnecessary administrative penalties will help increase the right to speak in the project bidding, construction, implementation, and assessment process, reduce the risk of negotiation and renegotiation, and lay down a good credit foundation for future PPP participation.

Finally, enterprises choose those PPP projects begun in regions with superior "doing business," based on their objective conditions and market developments, rather than investing blindly, to avoid the problem of investment failure or low investment efficiency. Besides this, private enterprises constantly increase the ability of technical innovation to fulfill each project's new criteria. The PPP sewage treatment project establishes a production technology threshold objectively. Only when it reaches and exceeds the technical threshold set by the project's initiator can private enterprises choose to invest in the project and realize the expected benefits. Small and medium enterprises with scientific research weaknesses might improve their power by partnering with external scientific research organizations, such as universities and research institutes.

6. Conclusions

This paper explores the configuration paths of PEP3P from the viewpoints of participator characteristics, DB, and project characteristics, and integrates the motivation of PEP3P into the same framework. First, we identified the extent to which traditional factors play a role in PEP3P. Then, we collected the relevant data from 102 PPP sewage treatment projects that entered the implementation stage in 2018–2019. Next, we explored the configuration paths of PEP3P by combining NCA and fsQCA. Finally, we compared the differences between these pathways' antecedent conditions and configurations. Relevant research conclusions do not deny the interpretation results of existing theories on private enterprise participation in PPP, but rather show the core conditions and complex interaction mechanisms affecting private enterprise's involvement in PPP projects from a configuration perspective, providing a new clue for leveraging private capital and enriching private enterprise PPP investment theory. The following conclusions are drawn from the study.

First, no single antecedent condition is a necessary condition for PEP3P, and the combined effect of different factors commonly form diversified causal configuration paths of PEP3P. The configuration results of PEP3P show that there are four equivalent configurations paths and three participation modes: the "enterprise technology leading" driven-type, "DB leading" pull-type, and "project character leading" push-type. ETL is the core motivator for PEP3P under the three types of participation. The good DB helps investment optimization under the "DB leading" pull-type method and encourages private enterprise involvement. With the double advantage of high technological innovation ability and good DB, a reasonable PRA helps private enterprises to participate in investment on a much larger scale of PPP projects. It also confirms the importance of FFR for the participation of private enterprises to form an effective pull and provides a more abundant theoretical basis for PEP3P.

Second, PTL and DB, respectively, are the most important internal driving forces and external pulling power for PEP3P by comparing the antecedent configurations of the three modes, which broadens the theoretical perspective of private enterprises in terms of participating in PPP projects in China. The findings indicate that the rationality of PRA effectively encourages private enterprises to participate in PPP projects with larger investment scales, revealing the relationship between internal project characteristics and PEP3P. There is an obvious asymmetry between the configuration paths of the high participation and low participation of private enterprises. ETL and DB are important internal driving forces and give external traction for PEP3P, while the ECL and PIS are important factors that restrict private enterprises from participating in PPP.

The results of this study cannot be generalized and are constrained by some limitations. First, only typical sewage treatment projects that are PPP projects have been selected as research objects, and the configuration effects of PEP3P in other industries will be examined more in the future. Second, at present, the participants in this theoretical framework are primarily the government and enterprises, but PPP projects involve a wide range of subjects. We will also investigate the incentive path for private enterprise participation in PPP by considering members of the public, suppliers, financial institutions, and other stakeholders. Third, while the antecedent conditions of enterprise characteristics primarily involve ECL and ETL, the connotations of enterprise characteristics are quite rich. A consideration of enterprise credit level and technical skill alone may overlook the broader explanation of other dimensions of enterprise characteristics for PEP3P. Further research that involves more enterprise characters may provide a more scientific understanding of private enterprises involved in PPP.

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Public–Private Partnerships for Higher Education Institutions in the United States

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Abstract: Public–private Partnerships have become a common delivery method for diverse types of projects ranging from transportation and energy infrastructure to social infrastructure. Previous research has mainly focused on PPPs for infrastructure and other non-social projects. Although PPP projects for higher education institutions share some common attributes with their traditional counterparts, they also have unique aspects such as institutional culture as well as structure of ownership and management. Hence, the objectives of this research were to (1) conduct a systematic collection and analysis of PPP projects in higher education institutions in the United States; and (2) conduct a gap analysis to provide recommendations for future projects and lessons learned from past ones. A gap analysis of the published data on higher education PPPs was undertaken, identifying 45 educational PPP projects in the United States. The main areas of study were type of project (e.g., housing, commercial, mixed use, etc.), size, and investment made. Additionally, a questionnaire survey was disseminated to experts in the field to collect data on these projects and report on them. The results showed an increasing trend in project size between 1994 and 2018 with the majority being for housing developments while a smaller percentage was for commercial and utility projects. A geographical representation shows a large number of projects clustered in the Southern and Northeastern regions of the United States. Additionally, a questionnaire survey was used to identify samples of these projects and present them as a case study. The number of PPPs is expected to rise due to funding cuts and state appropriation cuts. Finally, the proposed recommendations can also be extrapolated for other social or infrastructure projects.

Keywords: public–private partnership; higher education; social infrastructure; United States

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1. Introduction

In recent years, public institutions have suffered from a decline in available funds. In 2020, Rutgers University lost $60 million from canceled surgical proceedings at their center and $50 million in refunds to students for unused university facilities [1]. The University System of Georgia's 26 colleges and universities faced a $350 million loss from canceled events and summer revenue. Several organizations have reported that higher education needs approximately $46 billion [2]. Although several state appropriations and Congressional Acts have been passed to support the universities, they may not amount to the total fund needed. For example, Congress has passed the Higher Education Emergency Relief Fund awarding $14 billion to postsecondary education [3]. This has motivated higher education institutions in the United States to seek private investment for the delivery of their projects. Therefore, these institutions have increasingly turned to PPPs for the delivery and operation of facilities such as housing and parking lot projects. University PPP projects have increased in value from a total of $100 million in 2003 to $3.1 billion for housing projects alone [4].

Public–private partnerships (PPPs) have become an attractive form of project delivery for many public entities due to their potential benefits including faster project completion, reduced delays in projects, and reduced change order costs. Generally, the private sector is contracted to undertake some of the financial burden and to deliver the services due to their experience in these projects [5]. PPPs have been used for the delivery of projects in diverse sectors such as infrastructure (roads, bridges, railways), environmental (waste, water, wastewater), and social projects (housing, libraries, healthcare, recreation) [4]. In a PPP, the private sector plays a larger role in the procurement and delivery of a project as compared to the traditional approach, which is of benefit to the university [6]. Public universities are then able to transfer risk and delegate their project to a private entity, thereby freeing the university and its resources to focus on education [7].

Previous literature shows that PPPs have mainly penetrated non-social infrastructure projects in the United States in transportation and environmental projects [8]. For social infrastructure projects, there has been a proclivity for the studies to focus on some aspects such as lifecycle performance [9]; PPP contracting for primary and secondary education [10]; affordable housing projects [11]; social infrastructure for universities [3]; asset recycling [12]; and low-income housing [13].

Although there has been extensive research on PPP use in the United States, their focus has mainly been on infrastructure projects. However, research on PPPs for higher education institutions in the United States remains limited. In that regard, this paper makes a novel contribution to literature by focusing on PPPs for higher education institutions in the United States and reports on these projects. A gap analysis was conducted to identify current trends as well as recommendations for future projects. Therefore, the objectives of this paper were as follows:

a. conduct a systematic collection and analysis of PPP projects in higher education institutions in the United States;
b. conduct a gap analysis to provide recommendations for future projects and lessons learned from past ones.

Firstly, a systematic identification and collection of U.S.-based higher education PPP projects was conducted. Secondly, a questionnaire survey was administered to high-level experts working in these institutions (and involved in these projects) to provide an in-depth analysis on a sample of the projects. These two methods were used to combine tacit and explicit knowledge and show a comprehensive presentation of the use of PPP in U.S.-based higher education institutions.

The following section presents the background on PPPs for higher education institutions, governance mechanisms, legislation in different states, contractual frameworks between the public and private parties, and, finally, the advantages and challenges observed.

2. Background

2.1. Public–Private Partnerships in Higher Education Institutions

PPPs have typically been used for the delivery of traditional infrastructure projects such as transportation and water sanitation projects. The successful delivery and operation of these projects has spurred the spread into many other project types. This has caused a shift towards delivering social infrastructure projects such as housing, healthcare, and court houses using PPPs. According to Casady et al. [8], social infrastructure projects have amounted to 25% of total PPP projects in the United States as of 2018. The main drivers for this wave have been the public sector's high debt levels as well as their inability to finance some projects due to the unavailability of funds. State government appropriations for higher education institutions have declined by 21% between 2009 and 2013, which have amounted to $14 billion [14]. The decreased state contribution coupled with increased operating costs and increased enrolment numbers have fostered the need for an alternative delivery mechanism. Many public entities have sought this alternative procurement method because of their struggle with obtaining financing for their projects [15]. Examples of higher education institutions that have entered into PPPs are the University of Maryland, University of Arizona, University of West Florida, and the University of California.

PPPs as a model usually service one of three areas of an institution (or a combination of these areas):

a. front-office, which includes student affairs and enrolment;
b. back-office, which includes supporting operations such as finance;
c. facilities, which are the physical assets such as halls, cafeterias, and dorms.

Previous research has mainly focused on the first two types, where the private entity delivers a service for the public institution. For example, Warasthe [16] presented a framework of partnership between Namibia University of Science and Technology (NUST) and The Chartered Institute of Logistics and Transport, which is a private organization that offers training and certification. This enabled NUST to offer new training opportunities, penetrate a new market, and utilize an established and experienced organization [16].

This paper focuses on the third type, which is PPP use for the delivery of higher education facilities in U.S. institutions. These facilities can be classified into mission-serving or revenue-generating [17]. Mission-serving facilities are built for a specific purpose such as the neurosciences project for the University of California in San Francisco, while revenue-generating facilities include housing complexes (Texas A&M College Station) or parking garages (Ohio State University). Multiple reasons exist behind an institution's choice for this delivery method, including:

a. lack of required financing (due to budget cuts);
b. inexperience of an institution in this development type or with the targeted population that the development is being built for;
c. experience of the private sector;
d. risk mitigation (transfer to the private sector);
e. fast delivery for a development [18,19].

For example, the University of California (UC) in Davis entered into a partnership for a $280 million development (the West Village) with a direct investment of only $17 million [20]. Another example is the University System of Georgia's PPP agreement, which was off the balance sheet, which meant that it would not affect the university's credit rating. Similarly, the University of California-Davis campus residence hall project was incentivized by off-balance sheet financing and the University of California-Irvine's Vista Del Norte housing project aimed to not impact its debt capacity [21]. Although private capital may come at an increased cost compared to public financing (and debt), it can also include lower costs in terms of maintenance as well as risks (when the private party is responsible for them). These are among the important drivers behind PPP use for these projects.

2.2. PPP Governance in Higher Education Institution Projects

The two main factors that dictate how public universities handle PPP projects are the structure of the university and governance. The United States does not have a centralized PPP unit responsible for overseeing all projects. Hence, governance mechanisms vary widely across different states as well as within each state [5]. Some states have a centralized division that controls all public–private partnerships in the state's educational institutions, whereas in other states each university is considered autonomous in its decision-making. For example, the state of Georgia controls 26 higher education institutions and has established financing programs to build housing projects in these institutions [22]. These programs offer financing options to the institution and are governed by the 'Board of Regents' (BOR). This 'Board of Regents' oversees the administration of public education in a state and can even authorize or decline the use of a PPP in a university. Examples of states that have a BOR are Georgia, Iowa, Arizona, Kansas, South Dakota, California, and Texas. On the opposite end of the spectrum are states that have a decentralized structure, such as Virginia, where each institution is responsible for its own public–private partnership endeavors.

Other countries such as Egypt, Japan, and the United Kingdom have a central PPP unit, which enables a consistent governance mechanism. This unit aids in pre-project screening, provides technical and project-delivery support, and provides advisory services [23,24]. Casady and Geddes [23] proposed creating PPP units to lower the transaction cost in these contracts by centralizing all needed expertise into one agency. O'Shea et al. [24] proposed the consolidation of PPP procurement in one agency to benefit from the experience. Although it would be difficult to create a centralized PPP unit for the United States, several units could be created based on geographical location. These units would be responsible for policy formulation, project analysis, quality control, and providing assistance to public entities. Casady et al. [25] suggested the creation of a central/national PPP unit as well as sectoral agencies and other enabling agencies for the success of PPPs.

2.3. PPP Legislation

Similarly, PPP-enabling legislation is also inconsistent across the different states. This PPP-enabling legislation is important as it addresses whether agreements can include revenue sharing, non-compete clauses, and other details [26]. They can either limit or encourage private sector participation depending on the specific provisions in the legislation. According to Martin [27], 37 states have some type of legislation for PPPs. However, the provisions in these legislations are not consistent throughout the states. For example, Geddes and Reeves [2] reported that Indiana and South Carolina were the only states that did not allow unsolicited bids whereas California and Arkansas were the only states that protected the confidentiality of the private entity's proposal. Several states (Arkansas, Indiana, New Jersey, Oklahoma, and Texas) have generic PPP social infrastructure enabling legislation while other states (California, Florida, Georgia, and Virginia) have specific legislation, both of which apply to public universities [3].

However, not all states have PPP-enabling legislation; therefore, some states are ahead of the curve in their PPP adoption. For example, Georgia passed PPP-enabling legislation in 2015, which allows any department, agency, authority, or Board of Regents of the University System of Georgia to enter into contract with a private entity to lease, develop, finance, construct, operate, and maintain projects. Although many states have PPP-enabling legislations, these legislations are not consistent in all states and are sometimes limited to certain project types such as transportation infrastructure. According to Martin [28], 37 states had passed PPP-enabling legislation and only eight of them included social infrastructure projects as of 2018. Hence, there is no standard for all PPPs in the United States.

2.4. PPP Contractual Frameworks

Under any PPP contractual framework, there are generally two main methods for the concessionaire to recuperate its investment. The first method is through user fees, where the concessionaire receives payment for services from developments such as residence halls or dining courts. The second method is through public sector subsidies, where the public institution pays the concessionaire a pre-established amount. An example of this is an availability payment or payment for performance where the public institution pays the concessionaire regardless of demand. Two definitions exist for 'availability': pure and constructive. Pure availability refers to the presence of a functioning and available facility for use while constructive adds metrics that must be met such as quality, safety, and performance [29]. For example, pure availability of a residence hall would refer to usable halls while constructive availability refers to clean, safe, and well-lit, in addition to other criteria. Generally, some contracts retain that the contract is terminated upon payoff of bonds or when a minimum rate of return is achieved by the concessionaire.

In some instances, the university chooses an arrangement whereby it opts to provide some monetary contribution in addition to private financing if the private financing comes at a higher cost. Another form of agreement is when the public institution leases its land to a for-profit company that funds the project. For example, the developer can lease the land for a period of 50 years during which it will construct the property, operate it, and recuperate the money invested [30]. Some private entities opt for partial or full financing of the development using equity. For example, in Ohio State University's Parking Project, one of the private entities involved was an Australian state-owned pension manager that provided an equity investment. Although this method expedites the development, it forces the public institution to surrender some control over the financial and managerial aspects [31].

2.5. Advantages of Public–Private Partnerships for Higher Education Institutions

Public–private partnerships have many advantages over the traditional delivery method, including [14,32]:

a. perceived lower cost to the public institution;
b. possibility for unaffected credit rating and investments off the balance sheet;
c. single contract (with one private party), which makes it easier to track, manage, and divide responsibilities and risks;
d. better method for entry into a new market (such as housing or energy) without any previous experience;
e. quicker execution and utilization of the private entity's experience;
f. an efficient method to meet the growing university needs.

These needs can be observed as on-campus student housing and parking lots to accommodate the increased student enrolment every year as well as accommodate the vehicles. Martin [28] reports that around 300 housing projects valued over $9 billion were completed for public and private universities.

2.6. Challenges That Face PPPs for Higher Education Institutions

Several challenges arise with the increased adoption of PPPs in the higher education sector, including [33,34]:

a. potential for void contracts;
b. university ceding high levels of control of the development;
c. complexity of deals;
d. multi-parties involved and possibility of disagreement;
e. limitation on future developments so as not to affect the current project (for example, a new housing project that would compete with the current one and possibly reduce its revenue);
f. lack of a consistent legal framework.

The differences in PPP enabling legislation among states have also been observed and reported by previous studies. PPP projects are procured at the local and state levels and are subject to different legal frameworks from one state to another. The lack of a centralized legal framework or PPP unit in the United States leads to differences in PPP adoption among the states as well as in procurement among the signed projects.

3. Research Methods

3.1. Systematic Literature Review

In this study, a systematic literature review (SLR) was used to collect comprehensive data on the use of public–private partnerships for higher education institution projects in the United States. The SLR was used to identify projects and reduce bias in the selection and inclusion of studies due to its systematic nature [35]. There are three steps involved in SLR: plan the literature review, conduct the review, and finally, report on the findings [36]. In the planning step, the objectives and protocols for systematic literature review are developed. The objective in this paper is to identify cases where a PPP was used in U.S. higher education institutions. The research questions identified were as follows:

R.Q.1 What are the trends of PPP use for higher education institutions in the United States?

R.Q.2 What are the benefits and challenges observed in these types of projects?
R.Q.3 What are the recommendations for future projects and lessons learned from past ones?

The planning step of SLR starts by identifying the search process to be followed. The order of search conducted was as follows:

a. Journal articles were identified using pre-identified sources from Scopus such as ASCE library and Science Direct. Google Scholar was also used for cross-referencing and multiple refinements of the search were also conducted to search for the projects. The keywords used in this paper were "Higher Education Institutions" and "public–private partnership", "social infrastructure", "Public–Private Partnerships for Higher Education Institutions", and "Higher Education Projects in the United States". Over 600 articles on PPPs were identified, which were narrowed down to 90 relevant articles for review and further analysis as only studies in English that were published from 2010 onwards were selected to proceed to the next review stage. The articles were then evaluated by reading the abstract of each article for inclusion/exclusion. Exclusion was mainly for articles that discussed projects outside the United States or those that did not discuss projects for higher education institutions.
b. Online PPP databases were searched, such as the World Bank database, Infra PPP database, and P3 Bulletin.
c. Websites of well-known private parties in the PPP area were searched including Plenary Group, American Campus Communities, JLL, and Corvias. Some of these companies had separate sections for education projects. This was used as a secondary search to identify projects.
d. Magazines and newspaper articles were also targeted to identify projects. An example is Forbes.com, where PPPs such as those for Wayne State University and the University System of Georgia were identified [37].
e. Finally, university websites were searched to cross-reference projects found in magazines and newspaper articles and to gather more information on the identified projects. For example, after identifying Wayne State University's PPP project in the previous step, a search was conducted on the university website to gather more details.
f. This resulted in the identification of 60 PPP projects conducted for U.S. higher education institutions from 1994 to 2018 (date of project signing). There were several projects before 1994, but this study limited the years studied to only after 1994 due to data unavailability. These projects were found among 54 universities. This study investigated contract structures, stakeholders, types and sizes of facilities, and budgets and durations of the projects that have been objectively sorted through SLR.

3.2. Literature Review of Previous PPP Surveys

While the previous subsection focuses on reviewing the literature on PPPs for higher education institutions, this subsection focuses on reviewing previous studies that focused on understanding PPP projects through questionnaire surveys. In general, research on PPPs for higher education institutions has been scarce and mainly reported on a specific project in a newspaper article or website. Thus, this subsection will focus on discussing previous surveys that analyze PPP projects in general, including the surveys conducted for higher education institutions. Table 1 summarizes previous studies that utilized questionnaire surveys for understanding and analyzing PPP projects. The table shows that the response rates in similar surveys can be as low as 17% and 12.5% as highlighted in the studies by Xu et al. [38] and Ika et al. [39]. Additionally, Luthra et al. [40] reviewed previous studies that utilized surveys for understanding PPP projects and showed that a response rate of 20% is acceptable in similar surveys. Finally, Table 1 shows that the total number of responses in similar surveys can be as low as 8 [41], 10 [42], or 13 [43] respondents in their studies because of the scarcity in the number of experts in these areas.

Table 1. Summary of previous surveys that utilized questionnaire surveys for understanding and analyzing different PPP projects.

Study	Scope	Number of Responses
[44]	Understanding the nature of PPP projects in China to propose the appropriate risk allocation across the different sectors.	The survey was sent to 203 experts and 47 experts completed the survey and sent it back (23% response rate)
[38]	Developing a risk assessment model for transportation PPP projects in China.	A total of 98 responses were collected out of the 580 invitations that were sent to experts in the area (17% response rate).
[45]	Understand the main barriers for renewable energy PPP projects in China.	A total of 73 responses were collected out of the 105 invitations that were sent to experts in the area (70% response rate).
[39]	Understand and identify the success factor for the World Bank PPP projects across the globe	A total of 178 responses were collected out of the 1421 invitations that were sent to the World Bank experts (12.5% response rate).
[46]	Analyze and study the nature of renewable energy PPP projects in the North African region	The analysis was conducted based on the responses of 18 experts.
[47]	Analyze and identify the main barriers for PPP projects in Egypt.	The analysis was conducted based on the responses of 23 experts.
[48,49]	Analyze and identify the main barriers for PPP projects in Egypt.	The analysis was conducted based on the responses of 25 experts.
[41]	Understand the impact of the construction period on the success of transportation PPP projects in India.	A total of 8 responses were collected out of the 30 invitations that were sent to the experts (27% response rate).
[50]	Understand the nature of PPP projects in the MENA region.	The analysis was conducted based on the responses of 50 experts from Egypt, 19 from Jordan, and 20 from Tunisia.
[51]	Analyze the factors affecting renewable energy projects in Pakistan	The analysis was conducted based on the responses of 273 employees who were involved in renewable energy projects.
[52]	Analyze the key success factors for renewable energy projects in Pakistan	A total of 272 responses were collected out of the 450 invitations that were sent to experts in the area (60% response rate).
[53]	Understand the main barriers for renewable energy PPP projects in China.	A total of 216 responses were collected out of the 369 invitations that were sent to experts in the area (59% response rate).
[54]	Understand the main barriers for PPP projects in Iran.	A total of 48 responses were collected out of the 51 invitations that were sent to experts in the area (94% response rate).
[55]	Understand the nature of transportation PPP projects in Ethiopia.	A total of 52 responses were collected out of the 85 invitations that were sent to experts in the area (61% response rate).
[42]	Analyze the nature of housing PPP projects in Tanzania.	The analysis was conducted based on the responses of 10 experts.
[56]	Understand the barriers and key success factors for PPP projects in Egypt.	A total of 55 responses were collected out of the 80 invitations that were sent to experts in the area (69% response rate).
[57]	Understand the nature of water-specific PPP projects in Egypt to propose the appropriate risk allocation	The analysis was conducted based on the responses of 53 experts.
[58]	Understand the nature of renewable energy PPP projects in the Dominican Republic.	The analysis was conducted based on the responses of 25 experts.
[43]	Understand the nature of PPP projects in the educational sector in Egypt.	The analysis was conducted based on the responses of 13 experts.
[59]	Understand the nature of PPP projects in the renewable energy sector in Kenya.	A total of 263 responses were collected out of the 769 invitations that were sent to experts in the area (34% response rate).
[60]	Understand the main factors affecting PPP projects in developing countries (Egypt, India, China, and Pakistan).	The analysis was conducted based on the responses of 42 experts.

Table 1. *Cont.*

Study	Scope	Number of Responses
[61]	Understand the main factors affecting renewable energy PPP projects in China, India, and Russia.	The analysis was conducted based on the responses of 57 experts in total.
[62]	Understand the main factors affecting renewable energy PPP projects in Pakistan.	A total of 516 responses were collected out of the 750 invitations that were sent to experts in the area (69% response rate).
[63]	Understand the main factors affecting renewable energy PPP projects in Pakistan.	A total of 376 responses were collected out of the 408 invitations that were sent to experts in the area (92% response rate).

3.3. Questionnaire Surveys

A questionnaire survey was then conducted to collect insights from a sample of the higher education PPP projects in the United States. Purposeful sampling was used to identify experts who are involved in PPPs at each university. It is a widely used technique to identify individuals experienced in a certain area to report on information-rich cases [64]. Experts involved in the projects were identified from various sources, including journal and newspaper articles and university websites. All experts were all involved in the decision-making phases of their respective project. Forty-five questionnaires were distributed with three reminders sent out and the survey was kept open for a period of three months. A total of 10 responses were received from experts working at the identified universities with a response rate of 22.2%. The number of responses and response rate obtained is similar to previous studies in the literature as shown in Table 1. This observed response rate and number of responses is mainly due to the scarcity in the number of experts in the area. Hence, the acceptable response rate can reach 15% and the acceptable number of responses can be as low as 8 responses as observed in the study by Gupta et al. [41]. According to previous literature on qualitative research, the number of samples is small in case-oriented analysis where no statistical inference is made based on the sample size [65,66]. This is enriched through purposive sampling to choose the correct experts to report on data-rich cases [67,68]. Hence, the sample size depends on the researchers, the survey respondent's expertise, and the data obtained from the survey. The respondents had an average of 20 years of experience in facilities management and operations, specifically at higher education institutions. Their specific positions are listed below:

- President and CEO of a university property foundation with over 25 years of experience serving higher education institutions.
- Vice president for finance and administration with over 25 years serving in this position
- Vice President for student life with over 20 years of experience in university housing and operations
- Associate Vice President Facilities Management and Campus Services with over 30 years of experience in facilities management and operations
- Associate Vice President for Capital Budgeting & Facilities Operations with over 30 years of experience
- Associate Vice President of Facilities Management with over 20 years of experience
- Associate Vice President for Business and Auxiliary Operations and Chief Housing Officer with over 25 years of experience
- Chancellor with over 20 years of experience in university operations and capital planning.
- Associate Vice Chancellor with over 15 years of experience in facilities management

The survey was divided into two sections: multiple-choice questions focusing on the status of their projects and open-ended questions targeting the reasons behind choosing PPP as a delivery method, problems the institutions faced, and suggestions for future projects. The survey consisted of four sections. Section one focused on collecting information about the project such as the name of the project, type of delivery method (Build–Operate–Transfer, Build–Own–Operate, etc.), purpose of the project (student housing, parking facility, or mixed-use facility), duration of concession, contractual cost of the project, any changes in the project cost, project type (new construction, demolition + new construction, rehabilitation of existing structure, remodeling of existing structure, operation of existing facility), project start year, project completion year, current stage of the project (in design phase, in operation phase, etc.), state of the project with respect to schedule, and finally the state of the project with respect to cost.

Section two focuses on collecting information about the background of the projects such as the reason for adopting PPP, percentage of financial support provided by the university, and the financing structure. Section three focuses on evaluating the projects with respect to the challenges the project faced and whether PPP was a better approach as compared to the traditional procurement approach. Finally, section four focuses on collecting the experts' feedback about PPPs and future recommendations. The experts were asked whether they would adopt PPP in future projects and what recommendations they have for future higher education PPP projects. The next section of the paper describes the analysis conducted on the literature review followed by a discussion of the results. Similarly, the section afterwards describes the analysis and discussion of the questionnaire survey conducted to showcase a sample of these projects.

4. Systematic Literature Review

4.1. Analysis of the Systematic Literature Review

Forty-five higher education PPP projects were shortlisted in this study using a systematic literature review. The remaining 15 projects (out of 60) were eliminated due to insufficient data on them. These projects were first analyzed in terms of geographical locations and mapped out in order to visualize the number of projects and project types as well as location trends.

Figure 1 shows a graphical representation of the shortlisted projects. These projects were plotted on the map of the United States in order to visualize the trends of PPP use in terms of:

a. geographical characteristics;
b. type of project. The total number of projects collected was 60.

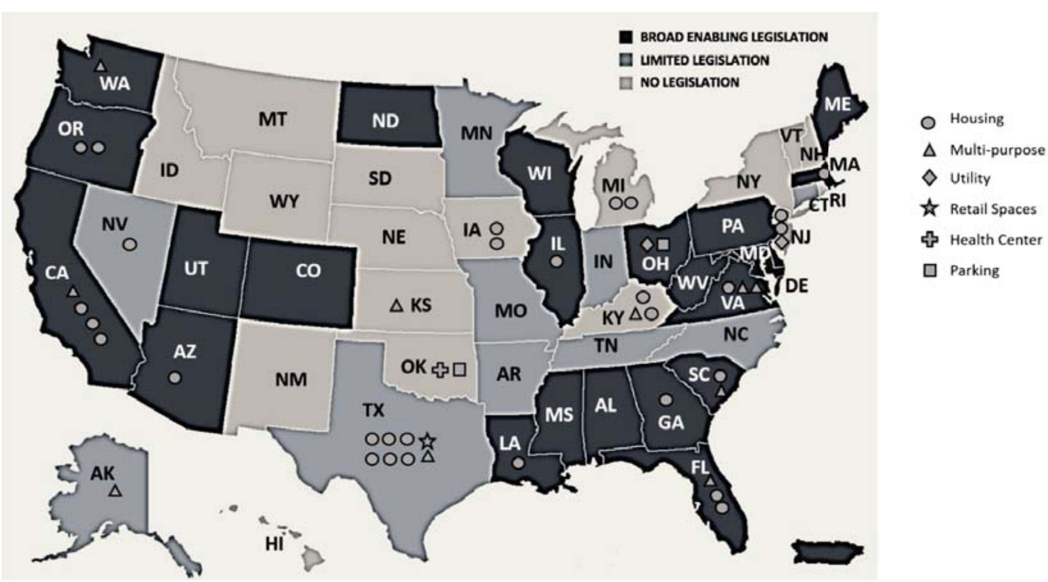

Figure 1. Map of the types of PPP Projects.

Out of these projects, 15 projects were eliminated due to insufficient data on either the cost or contract sign date. Figure 1 shows the resulting 45 projects plotted on the map of the United States. These 45 projects were all for public colleges and universities. It can be observed that the largest number of projects was found around the Southern and Northeastern regions of the United States. The projects were also plotted based on their type, which include:

a. housing;
b. mixed-use (a combination of housing/commercial/retail use);
c. utility;
d. commercial/retail space;
e. health center;
f. parking.

Figure 1 shows the distribution of project types and shows the following numbers: 28 housing projects, eleven multipurpose projects, two parking projects, two utility projects, one retail, and one health center. It can be observed that the most common type of project is the construction and operation of facilities, especially of housing complexes. Other facilities include parking lots and commercial and office spaces. The main reason behind this is that these facilities are revenue-generating, which in turn helps the concessionaire recover the money spent during the construction phase quicker. This way, in many instances, the public institution does not have to provide any money to the concessionaire (or sometimes only small amounts are provided). Generally, available financing options include tax-exempt bonds and subsidies from the institutions themselves, whereas the concessionaire can bring in their own private investments or that by other lenders.

There is no available source on PPP legislation specifically for higher education projects; however, the Federal Highway Administration (FHWA) has provided a classification, mainly for transportation projects. In some instances, it is explicitly stated that the legislation also includes other project types such as housing or education. FHWA's legislation is classified into three levels: broad, limited, or no legislation [69]. Broad legislation indicates that there is no limitation on the use of PPP with respect to project type or sponsoring agency, while limited legislation restricts PPP use to certain project types or sponsoring agencies.

Some states that have PPP-enabling legislation include Texas, California, Pennsylvania, and Florida. It can be observed that these states were found to have more higher education-related PPP projects than their counterparts. Although some of this (limited) legislation was for transportation-based projects, nevertheless, it helped pave the way for different types of PPPs. This classification helps in comparing between states with legislation (broad or limited) and those without. A cluster of projects can be noticed in California, Pennsylvania, Texas, and New Jersey, all of which have broad/limited legislation. The states that do not have any PPP projects are generally those that do not have PPP-enabling legislation. Although some states like Oklahoma and Kansas have PPPs even though there was no legislation found. Some legislation specifies that educational/housing facilities are authorized to be implemented as PPPs including that of Arkansas, Connecticut, Florida, and Maryland. Previous studies have highlighted that states with available legislation tend to attract private sector's attention more, thereby increasing the number of PPPs in these states [3,27,70,71]. This is in line with the findings of this research, as shown in Figure 1.

Table 2 shows the list of 45 PPP projects that were shortlisted along with the universities associated with them, cost, and year of signing. Some of the observations on these projects include that the majority of the projects were housing developments with the exception of seven projects, which were energy systems, parking lots, and research centers. Table 3 shows a breakdown of the 45 projects by state, type of project, as well as total investment. The largest project (in terms of cost) is Wayne State University's $1.4 billion housing project. The next is Ohio State University's $1.165 billion energy systems project, followed by the University of California's $1.138-billion-dollar multipurpose project for its Merced Campus. The remaining projects are all between $5.8 and $718 million. The largest total

PPP investment is by the University of California at $1.8 billion. Some universities have multiple PPP projects, which are usually multiple phases of the same development. For example, the University of Texas at Dallas has two projects: Northside, a mixed-use housing project signed in 2015 followed by Northside 2, which was signed in 2017. Another example is Prairie View A&M's four phases for its housing project that started in 1996, which ended with the last one in 2011.

Table 2. List of Identified Higher Education PPPs.

Institution	Project Name	Description	Cost	Year
City University of New York	The Towers at CCNY	Development of a student housing project.	$43 M	2006
Eastern Kentucky University	Housing Project	Construction of two residence halls.	$75 M	2016
Florida International University	Bayview Housing	Develop, finance, build, own, and operate a student housing complex.	$57.60 M	2014
George Mason University	Long & Kimmy Nguyen Engineering Building	Construction of 180,000 square feet building containing classrooms, research areas, and private lease space.	$61 M	2007
Kansas University	Central District Development Project	Construction of multiple facilities including: new science building, parking garage, utility plant, a 500 and a 700-bed housing and dining hall.	$350 M	2016
Louisiana State University (LSU)	Nicholson Gateway	Development of a housing project	$575 M	2016
Montclair State University	The Heights	Construction of a housing complex composed of 2000 beds.	$211 M	2010
Montclair State University	-	Design, construction, upgrade, and maintenance and operation of the university's energy plant for a duration of 30 years.	$90 M	2011
Northeast Texas Community College	Residential Housing East	Construction of a new residence hall with 112 beds and a wellness center that includes a weight room and multipurpose room.	$5.8 M	2016
Northern Illinois University	-	Development of student housing including 120-bed residential units and commercial spaces.	$20 M	2006
Ohio State University	CampusParc	50-year concession to operate, manage and rehabilitate a car park.	$483 M	2012
Ohio State University	-	Finance, improve, operate, and maintain energy systems (electric, gas, steam, heating and cooling).	$1.165 B	2017
Portland State University	University Pointe at College Station	Construction of a 16-storey housing hall under an 85-year lease.	$90 M	2012
Prairie View A&M	University Village	Construction of a housing complex composed of 2000 beds in three phases. Three additional phases were also added (2000, 2003, 2011) to construct new housing complexes as well as remodel existing ones.	$62 M	1996
Southern Oregon University Ashland	-	Construction of a 700-bed housing complex.	$40 M	2011
Tarleton State University	Heritage Hall	Construction of a housing complex with 514 beds for a 32-year ground lease.	$25 M	2014
Texas A&M College Station	Park West student housing	Construction of a student housing complex consisting of about 3400 beds.	$360 M	2015
Texas Woman's University	Residential Village Project	Development of a student housing project that includes residential amenities such as lounge spaces, study areas, and community places.	$75.5 M	2018
University of Alaska Fairbank	Wood Center Dining Facility	Expansion to the existing Wood Center Building.	$28 M	2012
University of Arizona	-	Construction of two housing complexes that include commercial space. It includes new construction and renovations for a dormitory ($157 million), parking garage, recreation center and office building.	$300 M	2017

Table 2. *Cont.*

Institution	Project Name	Description	Cost	Year
University of California	MT Zion Medical Offices Building	Demolition and building of new operating rooms and upgrade of existing facility.	$16 M	2009
University of California at Merced	2020 Project	Development of 1680 beds in student housing, 1570 parking spaces, a 600 seat dining hall, a lab and buildings with offices and classrooms, a conference arena, a transit bus hub, a pool as well as athletic and recreational facilities	$1.138 B	2016
University of California	UCSF Neurosciences building	Development a new facility.	$357.6 M	2016
University of California	UC Davis West Village	Housing complex built to house about 4500 people, which is the largest planned “zero net energy” development in the U.S. This will be done through the use of solar power systems.	$280 M	2010
University of Houston-Victoria	-	Construction of a housing complex composed of 380 beds.	$20 M	2015
University of Iowa	Aspire at West Campus apartments—Phase 1	Phase 1 includes designing, building, financing, owning, and operating a student housing complex for a 40-year ground lease.	$31 M	2012
University of Iowa	Aspire at West Campus apartments—Phase 2	Phase 2 of the construction and involves the construction of 252 housing units for a 41-year lease	$34.5 M	2015
University of Kentucky	-	Upgrade and expansion of 9000 housing beds which is divided into five phases	$600 M	2011
University of Kentucky	-	Dining services.	$245 M	2014
University of Mary Washington	Eagle Village Mixed-use development	Development of housing, hotel, offices and commercial spaces.	$115 M	2008
University of Massachusetts Amherst campus	-	Student housing facility	$120 M	2017
University of Michigan at Flint	-	Renovate and transform a hotel into student housing.	$175 M	2008
University of Nevada at Reno	-	Construction of a housing complex composed of 132 units for a 42-year concession period.	$22 M	2013
University of Oklahoma	-	Improve, design, build, operate, and maintain utility systems for a 50-year concession period.	$718 M	2010
University of Oklahoma	Health Sciences Center	-	$128	2006
University of South Carolina	650 Lincoln	Design, build, finance, operate, and maintain an academic building and two housing residences for a 40-year lease.	$120 M	2014
University of South Carolina	Campus Village	Demolition and construction of a student housing facility.	$460 M	2017
University of South Florida	The Village	Development of a student housing project	$134	2015
University of Texas at Dallas	Northside	Design, build, finance and operation of multiple facilities including a mixed-use housing and a retail space.	$52 M	2015
University of Texas at Dallas	Northside 2	61-year ground lease with the university as part of the public–private partnership agreement to develop Northside 2.	$67	2017
University of Washington	South Lake Union Medical Research Complex	Biomedical research facility. Renovate an existing structure and construct a new structure for laboratory and conference space as well as administrative building.	$363 M	2001
University of West Florida	University Park Development	Consists of: a field house, leisure building, healthcare center, housing, student union, parking garage and bell tower.	>$500 M	2013
University System of Georgia	-	Develop ~3500 beds and manage ~6000 beds of on-campus housing for nine USG institutions for a duration of 65 years.	$517 M	2014

Table 2. *Cont.*

Institution	Project Name	Description	Cost	Year
Virginia Commonwealth University	Gladding Residence Center Project	Develop a 360,000 square feet residence hall.	$96 M	2016
Wayne State University	-	Develop, finance and operate the school's student housing. Originally set for $308 M but increased to $1.4 B.	$1.4 B	2016

Table 3. Breakdown of the 45 projects.

	Housing	Multi-Purpose	Utility	Retail	Health Centers	Parking	Total No.	Total Investment (Millions)
Alaska		1					1	$28
Arizona		1					1	$300
California	3	1					4	$1791
Florida	2	1					3	$742
Georgia	1						1	$517
Illinois	1						1	$20
Iowa	2						2	$65.5
Kansas		1					1	$350
Kentucky	2	1					3	$920
Louisiana	1						1	$576
Massachusetts	1						1	$120
Michigan	2						2	$1575
Nevada	1						1	$22
New Jersey	2		1				3	$301
New York	1							$43
Ohio			1			1	2	$1648
Oklahoma					1	1	2	$846
Oregon	2						2	$130
South Carolina	1	1					2	$580
Texas	6	1		1			8	$667
Virginia	1	2					3	$272
Washington		1					1	$363
Total							45	

According to a study by Geddes and Wagner [26], the state with the most enabling provisions was Texas, with Virginia coming in second. This is consistent with the findings in Table 2, which show Texas as the state with the highest number of higher education PPP projects. Additionally, the first modern PPP was passed in Virginia [26]. Several other researchers reported similar findings on PPP projects in the United States. Istrate and Puentes [72] found California, Texas, and Virginia to be among the states with the highest number of PPPs and the Midwestern states with the lowest PPP adoption. Gilroy [71] reported that Texas, Virginia, Florida, and Georgia had the best PPP legislation models. Albalate et al. [70] investigated PPP-enabling legislation in the United States and reported the same states to have a favorable climate for private investment. According to Geddes and Wagner [26,73], the presence of PPP-enabling legislation in a state serves the following purposes:

a. provides a framework for public and private contracting;
b. provides a basis for contractual terms, thus reducing transaction acts and negotiation time;
c. indicates the state's commitment to private sector participation in projects in general;
d. attracts the private sector due to legislation availability.

According to previous research, investment in higher education is not proportional to investment in infrastructure. Geddes and Reeves [2] reported that although California and Florida have similar state-level laws, PPP investment in infrastructure has been higher in Florida. On the contrary, investment in higher education PPPs has been significantly higher in California (over $1.5 billion) than Florida (under $700 million). This can be attributed to California's legislation that limits social infrastructure PPP use for auxiliary (revenue-generating) projects only whereas Florida does not have this limitation [3].

Figure 2 shows a scatter diagram of the size and type of the identified PPP projects from 1994 to 2018. Regarding trends on project sizes, this study observed that the project costs ranged from $15 million to approximately $1.4 billion. Most of the smaller projects were housing developments while the higher costs were for other types such as utility (a design, build, operation, and maintenance project for the University of Oklahoma for $718 million in 2010), multi-purpose university park ($550 million project for the University of West Florida in 2013), and parking facilities ($483 million project for Ohio State University in 2012 as shown in Figure 2).

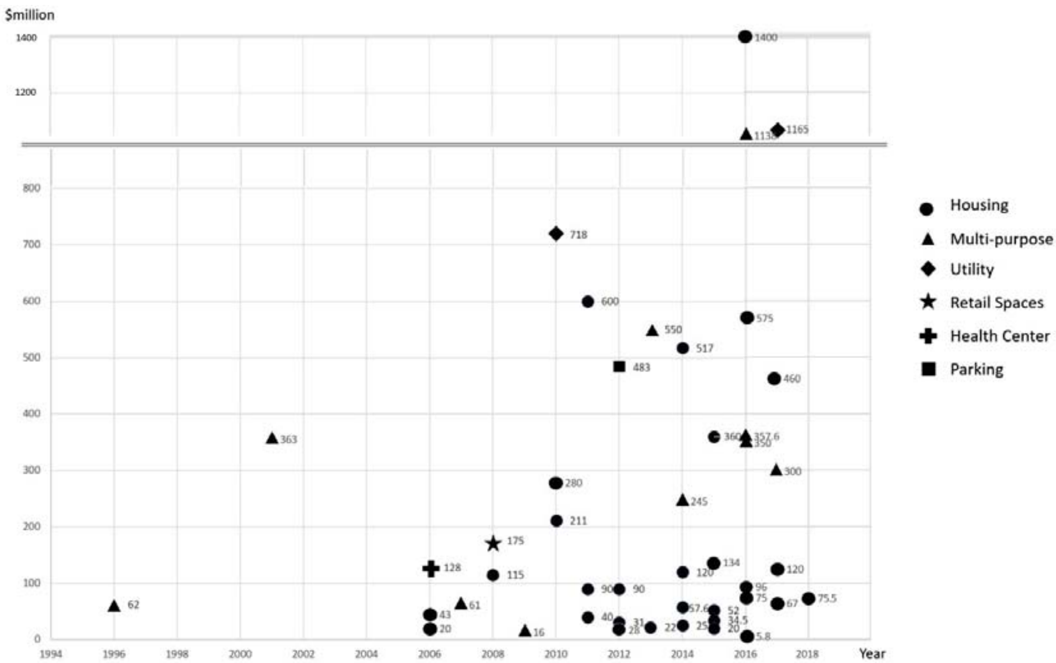

Figure 2. PPP Projects in higher education institutions by year and size.

An increase in the size and number of PPP projects over the years can be observed from Figure 2. Prior to 2010, the financial crisis caused an unstable economic climate in the U.S., which affected lending institutions and deterred PPP use. The increase in PPP use post 2010 can be attributed to many factors such as universities

a. relying on the private sector for their experience,
b. shifting to a delivery method that reduces their risk and investment,
c. lack of financial resources,
d. value-for-money attained,
e. decline in state financial support [18,19].

Private universities are also expanding their developments using private financing methods such as Drexel University, which contracted a private entity for a $3.5 billion mixed-use facilities project.

Some of these PPP projects were for unique developments such as the UC Davis West Village Development, which is considered the largest net-zero development in the U.S. of its kind [74]. Another unique project was the first PPP parking project in the U.S. by Ohio State University. Additionally, the University System of Georgia also showed a unique development by entering into a PPP for a group of nine campuses at once. It is important to note that Georgia's legislation restricts university PPPs to housing and related service [3].

4.2. Discussion of the SLR

This section presents a discussion of the research findings based on the literature review conducted and reports on the findings of the 45 identified projects. To do so, this section is divided into three topics: reasons for PPP adoption; benefits realized; and challenges faced by the higher education institutions.

4.2.1. Reasons behind PPP Adoption

This study investigated financial structures, planned budgets, schedules of the identified 45 projects, and reasons behind PPP adoption. Many public universities have recently adopted PPPs because they have suffered from a decline in the available financing or because of a need for expansion or housing. For example, the California State University (CSU) system was in need of an expansion because of its projected threefold growth in student enrolment by 2025. CSU decided to enter into partnership with a private entity to develop, operate, and maintain a 32-acre plot of land based on a ground lease mechanism [75]. The University of California at Merced is another university that sought to double its enrolment and needed to expand the classrooms, residences, retail, parking, and other facilities. It is projected to be one of the largest PPPs with a cost of $1.4 billion for a combination of housing, dining facilities, and parking projects with almost 2 million square feet of new facilities. This project was named the "North American Social Infrastructure Deal of the Year" [76]. One of the reasons that UC Merced sought a PPP was to minimize maintenance risk from the new facilities [75]. It was also the first university expansion project in the U.S. to use the availability payment mode, which meant that the concessionaire receives a payment regardless of demand.

PPPs were chosen by some institutions for projects they do not have any experience in or those where the private party has sufficient previous experience in. Sometimes, the institutions preferred to focus on academics and delegate new construction or operations to a private party. The rise of PPPs in other sectors in the U.S. has also spurred their adoption in the social infrastructure sector, specifically higher education institutions.

4.2.2. Benefits Realized by the Universities

Based on the literature review conducted, several benefits were identified from the use of PPPs in projects for higher education institutions. These include:

a. faster delivery and slightly higher quality. In some cases private financing was not the university's main goal, hence the project was able to be delivered quicker than was possible using university debt;
b. effective and efficient delivery;
c. unaffected capacity debt;
d. better streamlined processes and more decisions made by third-parties and not university staff;
e. less expensive than debt financing by the university;
f. consolidated selection and contracting period;
g. delivered a project (housing) that the university did not want to deliver/construct itself;
h. public institution not concerning themselves with the operation and maintenance of a development, since it is the developer's responsibility;
i. entering into a new market sector with reduced risks to the university.

For example, the University of Oklahoma entered into a 50-year concession to design, build, operate, and maintain utility systems. One reported benefit of this project is the "monetization of non-core assets" [4]. Another example was the Virginia Commonwealth University's PPP project (the Long and Kimmy Nguyen Engineering Building), which was the first ever to be procured under Virginia's "Public Private Educational Facility and Infrastructure Act of 2002". This act authorized public entities to enter into a PPP for the development of a project [76]. Figure 1 shows that there are three PPPs in Virginia, one housing project and two multi-purpose projects. Additionally, the types of services enlisted depend on the legislation available in a state. For example, Georgia only allows the design-build-finance-operate-maintain combination whereas Virginia allows a combination of any of the aforementioned components [3].

4.2.3. Challenges Faced by the Universities

Public opinion on non-higher education PPP projects also had an effect on these projects. For example, the increased rates for Chicago's parking project and cancellation of the parking meter systems in Pittsburg and Los Angeles were a challenge to Ohio State University's parking project. Therefore, justifying the use of PPP could be a challenge in some instances [2]. One reported risk was of the private entity deferring maintenance of the facilities. In order to prevent this, the University of California Merced used "preventive maintenance life cycle costing" in its Merced 2020 project [28].

It can be observed from this research that the trend of distribution of PPPs is not consistent among the states as well as within a state. This could be attributed to the wide spectrum of PPP legislation available and the inconsistent adoption of PPPs among the different sectors (e.g., education, transportation, energy, etc.). Out of the 45 projects, 22 projects were delivered in states with broad enabling legislation, followed by 12 projects in states with limited legislation, and 10 projects in states with no legislation. Establishing a uniform PPP procurement process and enabling legislation would lead to a smooth procurement and delivery of these assets.

5. Questionnaire Survey

5.1. Analysis of the Questionnaire Survey

The results of the questionnaire survey were analyzed to collect insights provided by the experts on their projects to provide a sample of the higher education PPP projects. Table 4 is divided into seven sections, which are facility type, duration, project status, reason for choosing PPP, mode of recouping investment by private entity, project financing, and future use. Additionally, the results of the questionnaire survey are summarized in Figure 3.

Table 4. Results of the questionnaire survey.

Name of the University	PPP Type	Project Purpose	Contractual Cost of Project	Project Start Year	Project Completion Year	Status with Respect to Schedule	Status with Respect to Cost	Method of Recouping Investment by Private Entity	% of Financing by the University	Financing by Private Entity
Tarleton State University	Build-Lease-Transfer	Student Housing	$101 M–$200 M	2014	2015	Behind Schedule (third phase was behind schedule; first two were fine)	Below budget	Rent fees	81–100%	Bonds
Northern Illinois University	Build-Lease-Transfer	Student Housing	$401 M–$ 600 M	2010	2012	Unaware of exact status	Unaware of exact status	Fees paid over the concession period.	0–20%	Commercial financing
Southern Connecticut State University	Others (City to build and assume all operating cost and the University will use the school as a lab for education and communication disorders)	Others	$50 M–$100 M	2018	2019	On schedule	Below budget	State funded public school construction funds	0–20%	State of Connecticut Public School Construction Bond Funds
UC Davis	Build-Own-Operate	Student Housing	$401 M–$ 600 M	2019	2022	Behind Schedule (due to feasibility and budget constraints)	Over budget	Rents	0–20%	Bond financing
Texas Woman's University	Design-Build-Finance-Operate	Mixed-use facility (e.g., a mixture of housing and retail spaces)	$50 M–$100 M	2018	2019	Ahead of schedule (The housing is ahead of schedule but the separate dining hall may fall being schedule	Over budget	Through rent for 40 years and also through an annual payment from dining.	0–20%	Tax exempt bonding
Wayne State University	Design-Construct-Manage-Finance	Student Housing	$201 M–$400 M	2017	2020	On schedule	On budget	Bond holders repaid through revenue stream from rents.	0–20%	Private placement bonds
University of South Florida	Build-Own-Operate	Mixed-use facility (e.g., a mixture of housing and retail spaces)	$101 M–$200 M	2017	2018	On schedule	On budget	Rent fees for a duration of 45 years after completion	Other	70 percent, 30 percent equity

Table 4. *Cont.*

Name of the University	PPP Type	Project Purpose	Contractual Cost of Project	Project Start Year	Project Completion Year	Status with Respect to Schedule	Status with Respect to Cost	Method of Recouping Investment by Private Entity	% of Financing by the University	Financing by Private Entity
Louisiana State University	Design-Build-Finance-Operate	Mixed-use facility (e.g., a mixture of housing and retail spaces)	\$401 M–\$ 600 M	2016	2021	Ahead of schedule	Below budget	Development fee and operational fee	0–20%	Bonds
University of Kansas	Design-Build-Operate-Transfer	Others (Science education; research, parking, central plant and housing)	\$201 M–\$400 M	2015	2018	Ahead of schedule	Over budget (Additional costs related to research equipment installation were not included.)	Project development fees; on-going fees for operations	81–100%	LLC established and bonds rated based on university assets; bond sale managed to outside investor group with experience in University backed research facilities
University of Iowa	Others	Student Housing	\$50 M–\$100 M	2012	2014	Ahead of schedule	Below budget	Through apartment leasing to graduate student for duration of the ground lease from the University to developer (30 years)	Other (University provided the land via a ground lease to developer at zero cost, but no additional University funds were used. Developer takes 100% of risk)	55% developers own equity and 45% financed

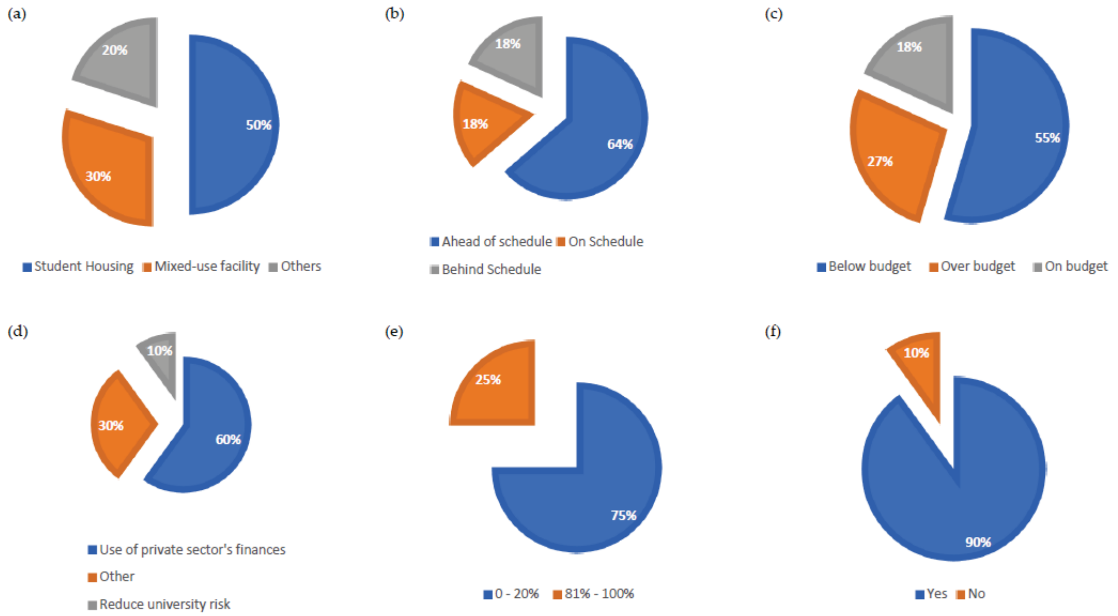

Figure 3. Statistical summary of some of the results of the questionnaire survey: (**a**) project purpose, (**b**) project status according to schedule, (**c**) project status according to cost, (**d**) reasons for adopting PPPs, (**e**) % of financing provided by university, (**f**) whether the expert will adopt PPP in the future.

5.1.1. Facility Type

The majority of the responses (50%) indicated housing as the purpose of the facility followed by mixed-use for housing and retail (30%). These two types are common revenue-generating mechanisms, showing their popularity as PPPs since it is easier for the private party to recoup their investment. Some of them were greenfield projects whereas others involved demolition followed by reconstruction. Other universities opted for PPPs for their unique projects. For example, Kansas University contracted with one developer for their 55-acre site to develop a science facility, student union, parking structure, and utility and transportation infrastructure. Hence, they benefited from having a single contract for their entire project instead of multiple contracts, which also led to an expected reduction in overall cost between $25 and $100 million as well as a shorter timeline [77].

5.1.2. Duration

All concessions had a duration between 25 and 50 years. Generally, some state legislation has a limit on the maximum concession duration. For example, Florida legislation for social infrastructure allows for a maximum concession period of 40 years while Georgia allows up to 65 years [3]. Four of the projects included the design while the rest included construction and operation only. Some universities opted for a full PPP (design, build, finance, and operate) to transfer everything to the private party and free its resources to focus on academics. This is dependent on the state legislations available, if any.

5.1.3. Project Status

Only two projects were reported to be behind schedule while those remaining were either on or ahead of schedule. Some experts reported that having the private party responsible for many phases granted it a level of autonomy which quickened the schedule. The private party is also incentivized to stay on-schedule in order to start operating the facility and generate revenues (in instances where revenue is recouped by the private or even shared among the private and public partners). Similarly, a study by the UK National Audit Office found that a higher percentage of PPP projects were completed on budget compared to traditional projects [72].

With respect to cost, three projects were reported to be over budget, which were at the University of California at Davis, the University of Kansas, and Texas Woman's University. The last project reported the reason to be Hurricane Harvey in Texas that affected the construction market. Previous research reported some PPPs being over budget, especially for their first PPP experience due to increased costs of preparing the contractual documents.

5.1.4. Reasons for Choosing PPP

The main reason chosen by the majority of the respondents was the ability to use the private sector's financing. Other reasons provided include seeking a collaboration that would benefit the university and students, leveraging the private's financing and construction process without the typical state bureaucracy of a traditional construction project, as well as leveraging the private entity's experience. Additionally, reducing university risk by transferring some of it to the private entity was an important incentive for the universities. For example, California legislation emphasizes the reason behind PPP use is risk transfer and quicker project delivery [3].

5.1.5. Mode of Recouping Investment by Private Entity

The majority of the responses indicated housing rent fees to be the only source of income for recouping the investment. Other sources include annual payments (e.g., from dining facilities), public financing, and development and operation fees.

5.1.6. Project Financing

Bonds were indicated as the most common source for the majority of the projects. Six experts indicated that the universities provided 0%–20%, two indicated 81%–100%, and one indicated that the land was provided by the university via a ground lease but no other monetary contribution was provided. This is also dependent on specific state legislation. For example, PPP-enabling legislation in Florida limits social infrastructure projects to land owned/controlled by the public university or state government while California prefers the opposite [3].

5.1.7. Future Use

Nine participants out of ten indicated that they would use PPP for future projects. Some reported that this would mainly depend on the current debt capacity and on the type of project itself. PPP would be favored for independent projects such as housing and athletics projects. One expert indicated that although they used PPP for their housing project, it was a unique setting and they will not repeat it specifically because it would be cheaper for them to execute the project themselves using bonds at a cost lower than that of the private entity.

5.2. Discussion of the Questionnaire Surveys

This section delineates the challenges faced by the universities as well as future opportunities for PPP projects at higher education institutions based on the data obtained from the ten cases.

Based on the results of the questionnaire survey, the experts reported several challenges related to PPP use at their universities. In some projects, there were construction quality concerns, which affected the construction process. Another issue reported in some instances was the lack of partner sharing of the risk. Although one of the main attractive points of a PPP is the risk sharing between the public and private entities, there were some cases where the university eventually put in more money. Under some arrangements, short of the university closing, the private partner had very little risk from changes in student enrollment or rising costs of maintenance/repairs/operations. These changes stem from the long-term commitment of a PPP project [78]. A way to overcome this would be including a role for partner involvement in operations and sharing of financial risk. Additionally, a change procedure can be included in the contract, which delineates how to deal with changes during the construction period [78].

Since the university is no longer the sole owner of the project (e.g., the private entity owned 30% equity in one project), this led to cultural changes with the presence of a private entity. Therefore, some compromises that were allowed when the housing project was fully university-owned did not fit the PPP business model. State legislations (for social infrastructure) vary in this matter where Florida requires ownership transfer to the state/university at the end of the contractual duration while California requires the ownership by the private partner [3]. Some universities reported challenges in securing bond financing. In some instances, negotiating the deal took a longer time than expected. According to Geddes and Reeves [2], some of the challenges facing a PPP include contract negotiations, complex contracts, and difficulty in managing partners throughout the project phases.

Some projects saw a quick movement of the phases, which made it difficult for the university to follow up with the private partner due to the university's limited resources. Some experts reported that any design elements were determined by contractors; therefore, the role of the design architect was diminished and the ability to adapt design to evolving research project needs was also limited.

Risk of private entity deferring maintenance of the facilities was also suggested by some experts. In some cases where the concessionaire was responsible for the maintenance over long periods of time, they received a fixed (or pre-set) fee for it. Since it is in the concessionaire's best interest to defer maintenance until after the lease is over (to reduce their expenditure), the institution should place requirements on the state of the facility during operation and at time of agreement termination. This would cause the private party to conduct maintenance early-on when it is cheaper to perform. Although this clause is generally included in many PPP contracts, it is important to highlight it due to its severity.

In the case of a design–build–finance–operate–maintain, the private party is held accountable for the asset throughout the entire lifecycle, which is an incentive to produce a high-quality product from the start to avoid high maintenance costs later on [79]. For example, in the University of South Florida's "Residential Village Project", the private entity is required to provide "life cycle repair and replacement schedules", which are verified every five years by an independent assessment [28]. The challenges reported by universities are applicable to other projects as well. For example, the UN Habitat reports that the challenges facing PPPs for urban development projects are differing goals of the public and private sectors and resistance to private sector involvement [80]. These observed challenges will aid in the formulation of PPP frameworks for future projects.

6. Lessons Learned and Recommendations for Future Projects

Although PPPs have presented many benefits to higher education institutions, there have also been some challenges that need to be tackled. This section discusses lessons learned as well as recommendations for higher education institutions based on the literature review and cases reviewed. Recommendations for future projects include using a development advisor and conducting a 'study of need' prior to seeking a vendor. According to O'Shea et al. [24], Irish guidelines require four ex-ante Value for Money assessments to be conducted during the procurement process of social infrastructure PPPs. This multi-step process can also be implemented in U.S. higher education projects to ensure the suitability of use of a PPP over the traditional method. Ex-post reviews of PPP procurement are also encouraged to extract key lessons [24]. For housing projects, a post occupancy evaluation can be conducted and a comparison be made to traditionally procured projects. This study should not only include the cost of construction, but also operation and maintenance. Several studies have highlighted the importance of the operations phase and the uncertainty that occurs within it [78,81]. For example, when UC Merced conducted a study, they found that construction costs were higher (for the PPP method than the traditional method) but lifecycle, maintenance, and financing costs were lower, which led to their choice of PPP [82].

In order to retain control of housing projects during the operation phase, some universities opt for selecting the directors of the housing complexes [74]. Additionally, government supervision during the concession and especially in the operation phase is necessary to curb the private party's opportunism [83,84]. For the concessionaire, as a strategy to secure themselves, some have agreements with the institutions to guarantee a minimum rate of occupancy for housing projects or a minimum usage for parking projects. For example, UC Irvine committed to a three-year occupancy guarantee with the concessionaire for its housing project Vista Del Norte [17].

It is also important to delineate a method in the contract for future refinancing gains and cost-savings. For example, UC Merced sought a 50/50 split with the private party on future refinancing gains as well as any potential cost-savings that the private party may later introduce in the future. On the other hand, the private party must also secure its position by including a non-compete clause in the contract if necessary. This would protect it should the university think of building another competing facility during the concession period. Moreover, a stakeholder management plan must be created in the beginning to manage the multiple parties involved. This can be adapted from a currently available framework such as that proposed by Jayasuriya et al. [85] for stakeholder analysis, management, engagement, and monitoring.

Although PPP can be used to deliver any project type, it would be more beneficial to independent projects that would not hinder a university's operations. The most common independent projects are housing, parking, and commercial. These would provide mutual benefit to both parties; the university would benefit from the completion of the project without having to be involved in the daily activities and the private entity would benefit from the profits earned throughout the project operations. Additionally, since these projects are revenue-generating, they are attractive to the private sector [17].

It is also important for an institution to involve all stakeholders early-on in order to get their support. For example, UC Davis involved the community by holding 30 public meetings throughout the planning stage. Another strategy taken by Ohio State University (OSU) for its parking project was a contract provision to protect itself in case the concessionaire defaults by instilling that it keeps the upfront payment made to it by the concessionaire. OSU also limited the rate increases of housing rent to those similar to previous years' increases so that the concessionaire would not enforce tremendous increases. Another example is UC Irvine, which limited the private entity's rent to a range bounded by 100% of similar UC housing and 90% of similar private housing at most [17].

Finally, the success of some PPP projects has spurred private universities to use private financing initiatives. For example, Drexel University has entered into partnership with a private party for a $3.5 billion community construction consisting of educational, medical, and business institutions to support the university's innovative mission [75]. This highlights the increasing trend of the use of private capital and expertise in delivering projects for higher education institutions. PPPs for higher education institutions have been generally regarded as lucrative projects by the private sector due to the growing enrolment of students at universities, which has had a positive effect on projects such as housing and mixed-use facilities.

7. Conclusions

Public–private partnerships have become a popular delivery method for traditional infrastructure as well as social infrastructure projects in the United States. These social infrastructure projects have mainly been developments for higher education institutions. As such, a steady increase has been observed of private entities developing projects that inevitably support the mission of universities and colleges. The findings of this research suggest that PPPs have become an attractive project delivery method for higher education institutions in the United States. Based on the data collection and the questionnaire survey that was disseminated, PPP was used by many institutions to reduce their risk, use private financing, deliver various project types, and transfer the maintenance and operating risks as well as full/partial expenses to the private party. It is especially beneficial to deliver revenue-generating projects and those the university is inexperienced in. Studying these PPPs raised several issues in relation to PPP units and legislation. Although a relationship was observed between the number of university PPPs and the availability of social infrastructure PPP legislation, this needs to be further studied in a state-by-state manner. The presence of consistent frameworks, PPP legislation, and PPP units would enable the delivery and success of more university projects. Hence, PPP units can be established in each state to support the spread of PPP projects in various sectors. Future research should focus on PPP legislations and public policy that can support non-infrastructure projects. This study contributes to the body of knowledge by identifying the current state on PPPs for higher education institutions in the United States and providing a gap analysis that reports on the lessons learned as well as recommendations for future projects based on the identified case studies. Potential challenges and benefits behind PPP use were also discussed based on the identified case studies.

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Discerning Recurrent Factors in Construction Disputes through Judicial Case Studies—An Indian Perspective

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Abstract: Construction disputes have become a recurrent phenomenon in the industry, due to which progress is halted. From a bird's eye perspective, the most frequent cause of a dispute might be payment issues. However, when observed keenly, it has an inter-relationship with almost every other cause, such as contractual changes, delays in project completion, compromising on the quality of construction, etc. Therefore, analyzing the factors which cause a dispute is important. It is also essential to understand the interrelationship of the factors. In this study, judicial construction disputes, along with judgements in different domains, were collected. The most frequent causes of disputes are identified among these cases. Sixty-five cases were considered for the analysis, which constitutes the writ petition, response and final judgment. These items were collected to gain the perspective of the petitioners and respondents over the cause of the dispute and the final judgment to analyze the factors responsible for decision-making. Factor analysis is done to find out the influencing factors, interrelationships and similarities of the disputes respectively. Among the 8 major factors identified, a strong, positive correlation was found between Poor Performance related issues and Payment related issues. By performing Principal Component Analysis (PCA), causes were classified into 3 domains based on their variables.

Keywords: construction disputes; contractual changes; delays; factor analysis; judicial cases

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1. Introduction

The construction industry faces many problems, which can be either technical or managerial. Technical difficulties have often been addressed and even been solved with adaptations according to the time and industry situation [1]. When it comes to managerial constraints, their presence does affect progress but often has been given a blind eye [2–4]. To confine it to being just a human behavioural issue and no active measures to deal with it has to be considered a major hurdle [5–7].

Contractors, especially in India, have to deal with the noncompliance of local people as well as the governments. It is a well-known fact that the payment delays caused by the governments citing issues related to poor performance and time delays in handing over play a major role in hindering the morale of the contractor [8]. Not only is the record of the contractor getting spoiled, but also sustainability is ambiguous as to what is the time of completion of the project [9].

Construction of any kind has to follow certain rules and regulations to ensure safety, quality and uniform development [10,11]. Noncompliance with those rules leads to disasters. This holds true for all the aspects and phases of the construction process, starting from tendering and execution to completion. The care taken during the initial stages to make sure each intrinsic factor is in tandem with the other is of paramount importance [12]. The way a contract is drafted and the necessary steps to be taken while execution to follow the contractual rules is vital [13,14]. Despite knowing its prominence, not many in the industry make a constant effort to follow all the rules. One of the main reasons for this is that no construction project is similar with different stakeholders, different costs etc., and therefore, apart from a few, common rules are minimal [7,15].

Although it is up for an entirely separate discussion, the perception of dispute settlement only in a court of law seems to bring no change in the resolution process. It is heavily burdened, requires abundant monetary fueling and takes a significant amount of time [16–18]. A strong foundational study based on the types of construction disputes, the causes that lead to a dispute and the possible combination of causes may be fruitful in making people aware of this and counter accordingly in a quick and efficient manner [19–21].

2. Dispute Arousal

Conflicts are useful in bringing out the best output in any organization [22]. Constructive criticism does lead to retrospection and has a better impact on the work progress. However, conflicts should be curtailed to the point that they give positive returns. Conflict management, therefore, has paramount importance in controlling conflicts and terminating them before they manifest into disputes [23–27]. Contract drafts which in a way clearly recognize the managerial process and dispute resolutions process in case of arousal, shall minimize the impact of the disputes on a project [28–30].

Based on the literature, disputes can be categorized into 6 distinctive scenarios with respect to the contractual structures.

1. Contracts are sometimes misinterpreted in a way that confuses understanding the details of the contract. These are most often seen in situations where the contractor and owner are not knowledgeable of the contractual norms [31–33].
2. Commitments made in contracts are sometimes evaded in a strategical method, which might benefit only a particular party [34–36].
3. Inefficiency in collaborating with respect to a single party's working process. The contractual provision is not given importance due to the rigidity of the working process [10,37,38].
4. Insufficient information is provided by parties by imposing restrictions in the working process [39–41].
5. Contract drafting is made in such a way that aids in taking undue advantage of a situation by a particular party. This is the case of deliberate sabotaging [42–44]
6. Aspects are not mentioned in the contract and most often are a result of a conflict of interest [45,46].

While the first three are aspects that fall under the category of "mentioned in the contract", the latter comes under "not mentioned in the contract".

It is known that until the dispute is resolved, it is difficult to prevent the conflict from manifesting into another dispute. Therefore, it becomes necessary to understand the combinations of disputes which usually occur in the construction industry [47,48]. While the constraints are repetitive in nature and often observed in combinations, it is important to cluster them with their commonalities such that it offers an understanding with respect to the possible future occurrences of disputes [48,49]. The above-mentioned aspects, such as managerial constraints, non payments, poor performance, contractual changes, etc., are often interrelated with each other. Commonalities among those causes are to be identified to group (cluster) them.

3. Research Framework and Methodology

3.1. Framework of the Study

A framework is developed using research on the various causes of disputes in the construction sector as well as the idea of uncertainty. This conceptual framework tries to identify trends in the fundamental causes of construction disputes [50–52]. This framework has been used to examine the research's data, which consists of 65 numbers of construction litigant cases heard by the various State High Courts as well as a few cases by the Supreme court of India. Data collection based on keyword identification, such as construction quality, contractual changes, nonpayment of funds etc., was done. From the obtained results, citations of previous cases given in those cases were traced back and incorporated as well. Lawyers (advocates) were approached with this base data, and further data was collected.

3.2. Case Study Analysis

The framework offers a way to understand how disagreements are caused, in addition to offering a causal analysis of disputes. The parties involved in these disputes were from the public sector and private sector, as well as governments under their jurisdiction. Table 1 shows the cases, their disputed causes, the point of argument and the verdict.

Table 1. Litigation cases studied.

Case No.	Point of Argument	Causes Categorized	Judgment
Multiple Causes			
WP No. 17337 of 2022	Seeking demolition of unsafe construction.	Performance, payment, contractual, demolition of building	The authorities are made responsible for approvals. Demolition is justified as it holds a threat to the safety of residents. The payments need to be returned.
WP No. 17952 of 2022	Compensation for poor construction quality	Performance, compensation, payment, demolition of building	The contractor is held responsible for repair works or new construction according to the will of the petitioner.
WP No. 17707 of 2022	Illegal construction causing problem,	Land acquisition, contractual, illegal, demolition of building,	The authorities are made responsible for maintaining legality of the construction work causing no inconvenience to the petitioner are accordingly demolish any illegal construction.
WP No. 178 of 2020	Construction affecting the soil fertility, compensation demanded	Land acquisition, contractual, illegal, demolition of building,	Since the construction is temporary and no evidence shows the damaged quality of land, the petition is dismissed.
Co. PET 759 of 2014	Compensation for poor construction quality	Performance, compensation, payment, demolition of building	Contractor is held responsible for repair works or a new construction according to the will of the petitioner. This was based on the corruption charges being true.
WP (MD) No. 13460 of 2014	Usage of workers violating contractual norms	Payment, contractual, illegal, demolition of building	Laborers have to be used only for construction purposes and should be paid more if they are employed for any other works.
WP No. 4042 of 2004	Compensation for poor construction quality	Performance, compensation, payment, demolition of building	Compensation is not justified as the fault in construction is not identified during an early stage which is the primary job of the petitioner. Hence, contractor cannot be held responsible for compensation.
Triple Causes			
WP No. 18223 of 2022	No clearance of bills for the works executed	Performance, payment, contractual	Based on the evidence, payment for the works carried out has to be made with adequate compensation for the delays.
WP No. 18245 of 2022	Demolition of deviation structure	Performance, contractual, demolition of building	Local authorities are held responsible for the approval of deviation structure. Ordered to demolish and compensate the affected party.
WP No. 16460 of 2022	Construction by deviation of sanctioned plan	Compensation, Land acquisition, demolition of building	Changes in the plan are in accordance with the revised by-laws. However, inconvenience to the petitioner has to be compensated by the authorities

Table 1. *Cont.*

Multiple Causes			
Case No.	**Point of Argument**	**Causes Categorized**	**Judgment**
Triple Causes			
WP No. 17962 of 2022	Contractual discrepancies	Performance, payment, contractual	Fault in the contract is a false claim. Norms are satisfied and therefore payments are to be made.
WP 328 of 2002	Denial of payment citing poor performance	Performance, payment, contractual	Contractual clauses being ambiguous cannot be attributed to poor performance on part of the contractor. Therefore, payment has to be made as per the contract.
WP No. 16626 of 2022	Non release of bill amounts worth 1500000	Performance, compensation, payment	Unjustified delays in payments citing lack of funds are unacceptable. Payments with 12% interest have to be made.
WP No. 17975 of 2022	No clearance of bills for the works executed	Performance, payment, contractual	Based on the facts of the evidence, payment for the works carried out has to be made with adequate compensation for the delays.
WP No. 17722 of 2022	Compensation for poor construction quality	Performance, compensation, Payment	Since the authority has taken up the responsibility of poor construction, compensation in the form of rents are to be paid.
WP No. 15067 of 2022	The compensation amount for land acquisition is insufficient	Compensation, Land acquisition, contractual	The compensation process aided deficit payment as middlemen were involved. The payments need to be completed and only then can construction take place.
WP No. 18751 of 2022	Deduction from the amount of refund.	Performance, compensation, contractual	Although poor quality construction is observed, the compensation demanded is way too high. Hence, deduction is allowed.
WP No. 15195 of 2022	Compensation for contractual breach.	Compensation, contractual, illegal	Contractual norms not followed in construction. Therefore compensation needs to be paid.
WP No. 17697 of 2022	Reconstruction due to poor quality	Performance, payment, demolition of building.	The claim that construction was done by using poor quality materials doesn't have evidence as such compensation is not liable.
AP 24 of 2020	Compensation for poor construction quality	Performance, compensation, payment	Material shortage is identified during technical examination. Balance work is not satisfactory, therefore compensation has to be paid.
WP No 161 of 2020	Flats delivered after long postponement	Performance, payment, demolition of building.	Compensations are to be paid as the delay is not justified with an interest of 15% p.a
AP 130 of 2017	Construction is poor with prolonged delays	Performance, compensation, payment	Government authorities couldn't justify the delays as a result; compensation needs to be paid.
CA No. 4921 of 2016	Demolition of illegal construction.	Compensation, contractual, illegal	Illegal construction is to be demolished. Irrespective of the lapse in time, compensation cannot be claimed as it is a violated construction. Hence demolition is justified.
CS (COMM) 914 of 2016	Land acquired used for other purpose than contractually stated	Compensation, Land acquisition, contractual	Although the acquired land is given by consent, it is being used for the construction of a flyover rather than a bypass road. This is unacceptable and has to be stopped.

Table 1. *Cont.*

Multiple Causes			
Case No.	**Point of Argument**	**Causes Categorized**	**Judgment**
Triple Causes			
WP. No. 12809 of 2015	Arbitral award being challenged.	Performance, payment, contractual	Arbitral award being challenged which states that payment has to be made is upheld. Along with which interest also has to be paid for the escalated amount.
WA. No. 88 of 2012	Seeking exemption from compensating amount that is insured.	Performance, insurance, demolition of the building	Due to the lack of evidence that argues opposing the insured amount, the case has been dismissed and amount needs to be paid accordingly.
Arbitration petition No. 6 of 2009	Arbitral award being challenged	Performance, payment, contractual	Adding to the faulty construction, which was not the fault of the contractor, bills were not cleared. Therefore the arbitral award is wrong and has to be changed.
RP No. 1147 of 2007	Contractual clause violation	Performance, compensation, contractual	The contractual clause states that the construction shouldn't be done on the first floor. Hence breach of contract is observed and hence needs to be demolished.
OMP 152 of 1984	Un satisfactory arbitral award	Performance, payment, contractual	Arbitral award was challenged but evidence wasn't present to support the claim. Hence the award is valid and need no objections for the same.
Dual Causes			
WP No. 18232 of 2022	Supply of low quality materials	Performance, payment	Materials supplied with respect to the payments made in accordance with the contract. The contractor is found not guilty.
WP No. 18224 of 2022	Contractual clause violation	Contractual, performance	Since the contract specifies avoidance of certain materials in construction, breach of contract is identified. Reconstruction ordered.
WP No. 18234 of 2022	Non payment of bills citing poor performance	Performance, payment	Compensations are to be paid as the delay is not justified with an interest of 12% p.a
WP No. 16663 of 2022	Usage of materials not mentioned in the contract	Performance, contractual	Work needs to be done with quality materials. Repair work needs to be carried out and compensation to be paid accordingly.
WP No. 16824 of 2022	Payment denial due to poor quality construction	Performance, payment	No evidence with respect to poor performance was found. Therefore, payments have to be done as per the arbitrational award.
WP No. 17957 of 2022	No clearance of bills for the works executed	Performance, compensation	Based on the evidence, payment for the works carried out has to be made with adequate compensation for the delays.
WP No. 15062 of 2022	Quality of construction termed faulty.	Performance, contractual	Contractual clauses being ambiguous cannot be attributed to poor performance on part of the contractor.
WP No. 15065 of 2022	Illegal construction causing problem, seeking approval for demolition	Contractual, illegal	The authorities are made responsible for maintaining the legality of the construction work causing no inconvenience to the petitioner and accordingly demolishing any illegal construction.

Table 1. *Cont.*

Multiple Causes			
Case No.	**Point of Argument**	**Causes Categorized**	**Judgment**
Dual Causes			
WP No. 15203 of 2022	Illegal construction causing problems, seeking approval for demolition	Illegal, demolition of building	The authorities are made responsible for maintaining legality of the construction work causing no inconvenience to the petitioner are accordingly demolish any illegal construction.
WP No. 15203 of 2022	Road widening issue.	Land acquisition, contractual	In view of public interest, land acquired is justified as the petitioner also agreed before.
WP No. 15219 of 2022	Legality of construction	Contractual, illegal	As long as the construction is according to norms, which in this case is, the legality cannot be questioned.
WP No. 17713 of 2022	No clearance of bills for the works executed	Performance, payment	Based on the facts of the evidence, payment for the works carried out has to be made with adequate compensation for the delays.
WP No. 15068 of 2022	Contractual breach	Land acquisition, contractual	Land acquired more than that specified in the contract. Excess land needs to be handed over.
WP No. 17706 of 2022	Contractual breach with respect to poor construction quality	Performance, contractual	Work quality is un satisfactory and not according to contractual norms. Work has to be redone.
CA. 304–306 of 2004	Contract norms being challenged	Contractual, demolitions of building	Fault in the contract is a false claim. Norms have to be satisfied irrespective of anything for awarding the contract.
WP. No. 748 of 2017	Payment denial due to poor quality construction	Performance, payment	No evidence to prove that the quality of work was unsatisfactory. Therefore, payment has to be made.
C.A No. 9128 of 2003	Dispute about material quality used in construction.	Performance, contractual	Work needs to be done with quality materials and arbitration wasn't performed at the right time.
OMP 208/2006	Compensation amount for land acquisition is insufficient	Land acquisition, compensation	Compensation process aided deficit payment as middlemen were involved. The payments need to be completed and only then construction can take place.
WP No. 35782 of 2016	Petition for need of arbitration	Performance, contractual	Arbitrational requirement is cancelled as there is no evidence for poor quality of work as per petitioner.
WP No. 35879 of 2017	Poor performance claim being challenged	Performance, payment	No evidence with respect to poor performance was found. Therefore, payments have to be done as per the arbitrational award.
OMP 75 of 2006	Reconstruction / compensation due to poor quality	Performance, compensation	The claim that construction was done by using poor quality materials doesn't have evidence as such compensation is not liable.
WP No. 12773 of 2013	Rejection of contract unjustified	Performance, contractual	Expertise is required to execute such work which is not with the petitioner (contractor). Hence the contract not being awarded to the petitioner is justified.

Table 1. *Cont.*

Multiple Causes			
Case No.	**Point of Argument**	**Causes Categorized**	**Judgment**
Dual Causes			
CS (OS) 503 of 2009	Local authority obstruction for construction	Contractual, illegal	Work being executed following norms and according to the contractual clauses, need not be halted. Authorities shall not interfere in the process as the construction is not illegal.
CA No. 99 of 2017	The legality of the construction being challenged	Illegal, demolition of building	Approvals took during the time of construction 40 years ago as per laws and regulations. Citing the same for the present scenario is unfair. Hence construction is legal.
AP No. 9 of 2019	Unjustified reasoning over shifting of construction	Land acquisition, contractual	Place shifted from disputed area as it falls under forest land. Therefore it is shifted and hence the petition is approved.
WP No 16715 of 2021	Flats delivered after long postponement	Performance, payment	Compensations are to be paid as the delay is not justified with an interest of 12% p.a
AP 12 of 2020	Construction is poor with prolonged delays	Performance, payment	Irresponsible delays adding to increase in prices which are unjustified. Citing increase in prices, low quality materials were used. Compensation has to be paid.
AP 12 of 2019	Contractual breach with respect to poor construction quality	Performance, contractual	Even after repeated complaints, performance is not improved. Therefore, arbitrational award is revised in favour of buyer.
WP No. 17714 of 2022	Contractual breach with respect to poor construction quality	Performance, contractual	Work quality is un satisfactory and not according to contractual norms. Work has to be redone.
Singular Cause			
WP No. 18470 of 2022	Contractual clause violation	Contractual	Since the contract specifies avoidance of certain materials in construction, breach of contract is identified. Reconstruction ordered.
WP No. 17361 of 2022	Award of the contract is restricted	Contractual	For awarding the contract, various parameters have to be considered. Failure to meet them will cause losing the contract. Hence no fault was found.
WP No. 18090 of 2021	Demand for a refund due to changes in plot allotment.	Contractual	Irrespective of the previous confirmations, due to the changes in plot allotment, refund has to be given. Contractual clauses are not to be amended at a later stage.
WP No. 526 of 2020	Payment issues due to delays. Compensation expected	Payment	The buyer is not responsible for the delay. Therefore, construction according to previous rates needs to be compensated accordingly.
WA 1498 of 1990	Award of contract being restricted	Contractual	For awarding the contract various parameters have to be considered. Failure to meet them will cause loosing the contract. Hence no fault found.
WP No. 17711 of 2022	Payment issues due to delays. Compensation expected	Payment	The buyer is not responsible for the delay. Therefore, construction according to previous rates needs to be compensated accordingly.
WP No. 17721 of 2022	Compensation for poor construction quality	Performance	No evidence found with regard to poor quality construction. Therefore, compensation need not be paid.

This particular study was conducted by collecting judicial cases for the pretext of identifying the major causes of disputes in the construction industry. Because of the peculiarity of the disputes (i.e., most of the disputes are different from each other), it is also important to understand the various factors for dispute arousal. By collecting the judicial cases along with the petitions, responses as well as judgements, factors leading to the arousal of disputes can be identified. The significance of collecting petitions and responses is understanding the perspective of conflict from both the disputed parties involved [53]. In Table 1, a simplified description of the point of argument is presented, which is versions of both disputed parties clubbed together. The judgment is also similar to the point of argument. From both of these, major causes are identified and categorized. Some of the cases have multiple causes for disputes while others might have only a singular cause. In this study, it ranged from as many as 4 causes in one dispute and descending to one cause per case. Table 1 shows a total of 65 cases which were analyzed for the present study.

From the case studies, the different causes of disputes are broadly classified into 8 types. The various intrinsic factors for causes are listed in Table 2. Intrinsic factors are attributes (variables) based on which the causes are affected by one another. These attributes are obtained from the case study analysis. Based on the versions of both disputed parties, these attributes are identified, some of which are inter related. Exploratory Factor Analysis (EFA) is done to identify the relationship among the causes and how they can be clubbed into groups which happen to have similarities among each other.

Table 2. Attributes of disputed causes.

Cause	Attributes
Poor performance	Delays on part of the contractor Unsatisfactory work quality Changes incorporated apart from contractual agreements. Material discrepancies
Non Payment	Changes in contractual agreements Adamant non payment Deductions Non releasing of deposits Unjustified delays for payment by the owner
Land Acquisition	Unjust acquiring of land Unfair Compensation Occupation without consent
Illegal	-
Contractual	Intermediate changes in contract Delays in approvals Insufficient documents Ambiguities in contracts
Insurance	-
Demolition of building	Illegal construction Lack of communication between the authorities and owners Differences between neighbors and owners Personal vengeance
Compensation	Denial of compensation Delays in compensation Compensated amount not satisfactory Increase interest rates for compensation

3.3. Statistical Analysis

To analyze the interrelationship between the disputed causes, statistical analysis is done using Statistical package of Social Sciences (SPSS v19). Among all the identified factors causing the disputes, which factors influenced the dispute in a particular case are categorized and are inputed accordingly. Multiple column structure is used for this purpose. The variables (factors) are coded as dichotomies with a single value of 1 or 0. Unlike, likert scale, which is used to represent the collected data that might have a particular range in this study, due to the judicial data being more theoretical, the factors (attributes) are identified in each case and are interpreted in the form of a multiple choice response system. Therefore, each case can be attributed to any of the eight identified causes from the case studies. Figure 1 shows the input of data for analysis.

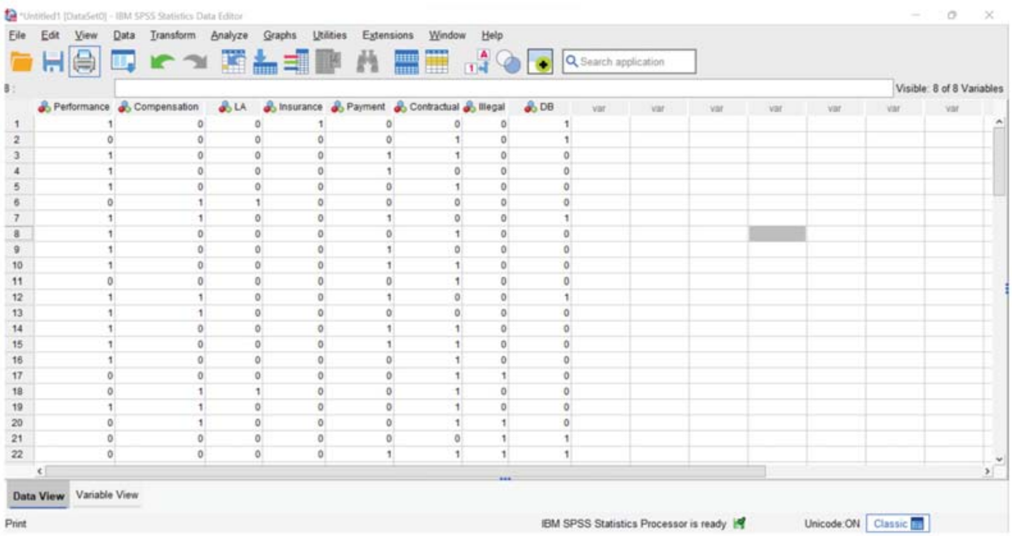

Figure 1. Data input into SPSS software.

Table 3 shows the no. of occurrences of each cause in the whole data set. As it is a multiple-response kind of interpretation, repetitions are observed in the occurrences of disputes. Out of the 65 cases studied for this research, the individual occurrence of each cause is observed, as shown in Table 3. Due to these repetitions and the combinations of causes having certain similarities, it is necessary to understand the relationship as well as the difference between the causes. Diverse data sets might help understand the problems in depth, but the surety of data being precise is not guaranteed. Therefore, while performing factor analysis using Principal Component Analysis (PCA) extraction method, commonalities are identified. It is done to analyze the permissible amount of information loss that might not affect the overall result. From the ranking of causes in Table 3, it is clearly understood that poor performance-related issues were in the majority of the cases. It does not mean it is the primary cause of that particular dispute, but it can be a contributing cause.

Table 3. Ranking of Cause of Disputes.

Causes	Occurrence (No. of Times)
Performance	41
Contractual	36
Payment	30

Table 3. *Cont.*

Causes	Occurrence (No. of Times)
Compensation	18
Demolition of building	15
Illegal	10
Land Acquisition	8
Insurance	2

4. Research Findings and Discussions

The analysis consisted of correlation using Spearman's rank order correlation between the disputed causes. Exploratory Factor Analysis (EFA) using the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO test) along with Bartlett's Test of Sphericity. Principal Component Analysis (PCA) extraction method was used for factor extraction.

4.1. Descriptive Statistics and Correlation

Statistical analysis is initiated by finding the descriptive statistics like mean and standard deviation as shown in Table 4, which are initial steps for further analysis. Performance cause has the highest mean among other causes and insurance has the least. This was evident with the number of occurrences of those causes in case study analysis.

Table 4. Descriptive Statistics of Cause of Disputes.

Causes	Mean	Standard Deviation
Performance	0.631	0.486
Compensation	0.277	0.451
Land Acquisition	0.123	0.331
Insurance	0.031	0.174
Payment	0.462	0.502
Contractual	0.554	0.501
Illegal	0.154	0.363
Demolition of building	0.231	0.424

Once the majority of causes are identified, the relation of individual causes needs to be understood. The correlation of causes helps to identify the connections each cause has with one other. By identifying the interrelationship among causes, a clear understanding of the implications each cause has on others is obtained.

A Spearman's rank-order correlation, to determine the relationship between components (i.e., performance to demolition of the building) was done in SPSS. There was a strong, positive correlation between Performance-Payment, Insurance-Demolition, strong negative correlation between performance-land acquisition, performance-contractual, performance-illegal, compensation- contractual, payment-land acquisition, payment- contractual which was statistically significant (highlighted in red colour) as shown in Table 5.

Positive correlation shows heavy interdependency among those causes, thus implying that disputes are more often than not a combination of those causes. Whereas negative correlation is the exact opposite. The negative values indicate minimum to no interdependency among the causes. It can be seen in Table 5, the significance of correlation was done in two stages at 0.01 and 0.05 levels. Significance level at two stages is identified by the star marks as superscripts next to the values. It is It is to be noted that these correlation results are considered for the causes when they are seen through individual spectrum. Once they are combined with another cause of dispute, the domain and interpretation might change.

Based on the values obtained for both 0.01 level and 0.05 level (2-tailed) there is a significant correlation among the various causes of disputes. The pictorial representation of the correlation can be seen in Figure 2. The chord diagram interpretation is to show the interdependency of causes (individually) with one another. Chords with thicker width conveys stronger relation. Similarly narrow chords interpret less interdependability. However, in the case of insurance, the thin line does not mean it has insignificant correlation. Within the present data set, it is comparitively less in a number of occurrences as opposed to other causes.

Table 5. Correlation matrix of causes.

			Performance	Compensation	Land Acquisition	Insurance	Payment	Contractual	Illegal	Demolition of Building
Spearman's rho	Performance	CC	1.000	0.046	−0.490 **	0.136	0.453 **	−0.302 *	−0.557 **	−0.035
		Sig. (2-tailed)	-	0.716	0.000	0.279	0.000	0.015	0.000	0.782
		N	65	65	65	65	65	65	65	65
	Compensation	CC	0.046	1.000	0.187	−0.110	−0.021	−0.275 *	−0.073	−0.013
		Sig. (2-tailed)	0.716	-	0.136	0.382	0.867	0.027	0.562	0.921
		N	65	65	65	65	65	65	65	65
	Land Acquisition	CC	−0.490 **	0.187	1.000	−0.067	−0.347 **	0.148	0.100	0.128
		Sig. (2-tailed)	0.000	0.136	-	0.597	0.005	0.240	0.429	0.309
		N	65	65	65	65	65	65	65	65
	Insurance	CC	0.136	−0.110	−0.067	1.000	−0.165	−0.199	−0.076	0.325 **
		Sig. (2-tailed)	0.279	0.0382	0.597	-	0.189	0.113	0.548	0.008
		N	65	65	65	65	65	65	65	65
	Payment	CC	0.453 **	−0.021	−0.347 **	−0.165	1.000	−0.411 **	−0.224	−0.068
		Sig. (2-tailed)	0.000	0.867	0.005	0.189	-	0.001	0.073	0.593
		N	65	65	65	65	65	65	65	65
	Contractual	CC	−0.302 *	−0.275 *	0.148	−0.199	−0.411 **	1.000	0.211	−0.096
		Sig. (2-tailed)	0.015	0.027	0.240	0.113	0.001	-	0.091	0.447
		N	65	65	65	65	65	65	65	65
	Illegal	CC	−0.557 **	−0.073	0.100	−0.076	−0.224	0.211	1.000	0.171
		Sig. (2-tailed)	0.000	0.562	0.429	0.548	0.073	0.091	-	0.173
		N	65	65	65	65	65	65	65	65
	Demolition of building	CC	−0.035	−0.013	0.128	0.325 **	−0.068	−0.096	0.171	1.000
		Sig. (2-tailed)	0.782	0.921	0.309	0.008	0.593	0.447	0.173	-
		N	65	65	65	65	65	65	65	65

CC—Correlation Coefficient, ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

4.2. KMO and Bartlett's Test

KMO test and Bartlett's Test of Sphericity were conducted to check the suitability of the collected data. Significant variance in the factors were identified as the KMO value was found to be 0.509 significance level of for the Bartlett's test was 0. The permissible limits of both KMO and Bartlett's test are above 0.500 and below 0.050 respectively. Table 6 indicates the same. The Bartlett's test of sphericity is a kind of validation test to confirm whether the results of factor analysis are considerable and whether we should continue with the analysis of research work. If the Bartlett's test of sphericity significant is obtained to a level of significance which is <0.001, then it is an indication that there is a high level of correlation between variables, which makes it sufficient enough to apply factor analysis.

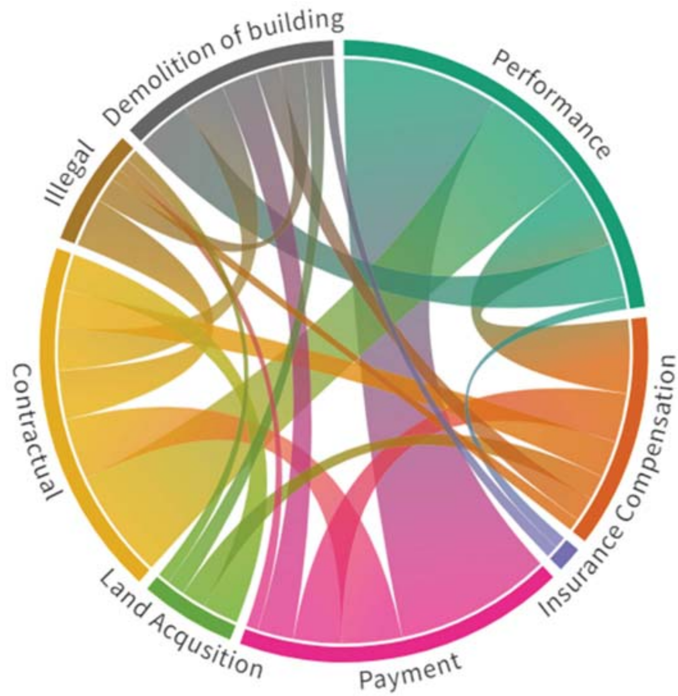

Figure 2. Chord diagram representation of correlation of various causes of disputes.

Table 6. KMO and Bartlett's Test.

Test		Values
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.509
Bartlett's Test of Sphericity	Approximate. Chi-Square	106.112
	df	28
	Sig.	0.000

Kaiser-Meyer-Olkin measure is the index which is useful in defining the sample adequacy. The obtained KMO test value is 0.509 which is more than 0.500. Therefore, it can be considered as good/suitable to conduct a data reduction technique.

4.3. Principal Component Analysis (Factor Analysis)

The statistical procedure to consolidate large data into smaller components to easily understand by the formation of certain patterns or combinations. Based on the interdependency of the variables, grouping of variables together with similarities can be achieved, which is called as Exploratory Factor Analysis (EFA).

4.3.1. Communalities

Communality values assess the efficacy of each variable is explained by the factors. When communality is close to 1, there is a better explanation of the variable by the factors. Table 7 shows the communalities of the factors identified. The variance determining the spread of the data set becomes the key in extracting the communalities. While correlation shows the interdependency of the causes of dispute, covariance gives the amount of difference each variable has with respect to each other.

Table 7. Communalities of factors.

Causes	Initial	Extraction
Performance	1.000	0.741
Compensation	1.000	0.764
Land Acquisition	1.000	0.632
Insurance	1.000	0.717
Payment	1.000	0.534
Contractual	1.000	0.646
Illegal	1.000	0.414
Demolition of building	1.000	0.620

4.3.2. Total Variance

The total variance is the summation of the variances. All individual principal components and their variances are used for this. Table 8 shows the total variance of the components. Total 8 components are obtained out of which only 3 components have eigen values greater than 1. Thus, even though results are obtained for a cumulative total of 100% variance, only those components which have eigen values greater than 1 are considered. Therefore, the total variance, constituted into 3 components is found to 63.3% as shown in Table 8. This is above the acceptable level (minimum threshold value is 50%), hence the analysis can be proceeded.

Table 8. Total Variance.

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	**Total**	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	2.364	29.552	29.552	2.364	29.552	29.552	2.361	29.511	29.511
2	1.426	17.829	47.381	1.426	17.829	47.381	1.423	17.786	47.297
3	1.278	15.975	63.356	1.278	15.975	63.356	1.285	16.059	63.356

4.3.3. Rotated Component Matrix

The rotated component matrix aids in determining representation of components. Adopting the varimax with the kaiser normalization rotation method, the three components with eigen values more than one are considered. In these rotation matrix, in the process of grouping the variables with similarities on a rotation bases, component 1 is found to have grouped 5 causes (performance, payment, land acquisition, illegal and contractual). Component 2 has two causes clubbed together (insurance and demolition of building). While the third component has only one cause, compensation. To interpret the data in simpler terms, the rotation was done in 5 iterations. The values shown in the table are loading to the cause that is being factored. The values of loading for all the causes are greater than 0.4 which is to show that all the values are relevant. Negative values of the loading (in the case of performance and payment) is due to the grouping of variables through 5 iteration process and due to the presence of bipolar dimension i.e., having the same factor in positive and negative dimensions. The negative or positive sign of the loading is irrelevant as the value of the loading is greater than 0.4. The values are shown in Table 9.

Pie chart representation of the components is shown in Figure 3. The pie chart is divided as per the component grouping obtained by rotated component matrix. Out of the whole data set, 21% of causes of dispute are categorized into 2 components (component 2 with insurance and demolition of building) and component 3 with compensation. The remaining causes are categorized from component 1 containing performance, payment, land acquisition, illegal and contractual related problems.

Table 9. Rotated Component Matrix.

Causes	Component 1	Component 2	Component 3
Performance	−0.854		
Payment	−0.713		
Land Acquisition	0.624		
Illegal	0.623		
Contractual	0.556		
Insurance		0.834	
Demolition of building		0.768	
Compensation			0.868

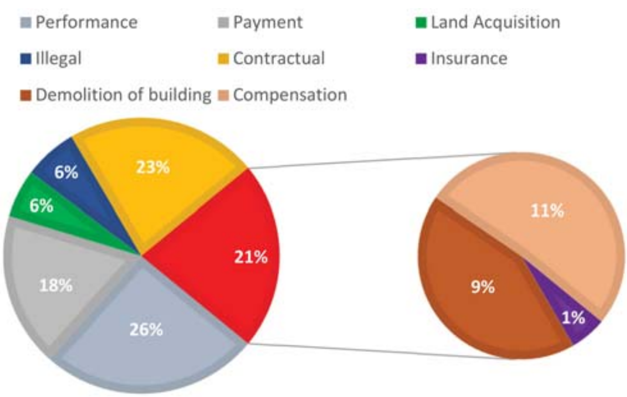

Figure 3. Pie chart representation of components and causes.

The Scree plot for total variance is shown in Figure 4 which indicates the factors that can be retained based on eigen values. The scree plots show the components as the x axis. Y axis is the representation of eigen values for the components. 3 components are considered (first 3) whose eigen value are greater than 1. These 3 components, because of having eigen values greater than 1 as well as sharing maximum variance, they are crucial in the study. Scree plot is generally used to find out the retainable factors out of the whole lot. Studies where there are many factors, it becomes easy through scree plot to identify the retainable factors. Since the present study has eight factors with all of them being grouped into 3 components with eigne values greater than 1, it is readily identifiable.

Exploratory factor analysis reduced 8 factors into 3 components based on co variance patterns. As mentioned earlier, all the factors are possessing factor loading greater than 0.4 which is acceptable. Total variance was found to 63.356% which is acceptable. Table 10 shows exploratory factor analysis with component score and percentage loading.

Table 10. Exploratory Factor Analysis.

Attribute/Variable Name	Factor Loading (Component Score)	% of Loading
Performance Payment Land Acquisition Illegal Contractual	0.854	29.511%
Insurance Demolition of building	0.834	17.786%

Table 10. *Cont.*

Attribute/Variable Name	Factor Loading (Component Score)	% of Loading
Compensation	0.868	16.059%
Total Variance Explained		63.356%

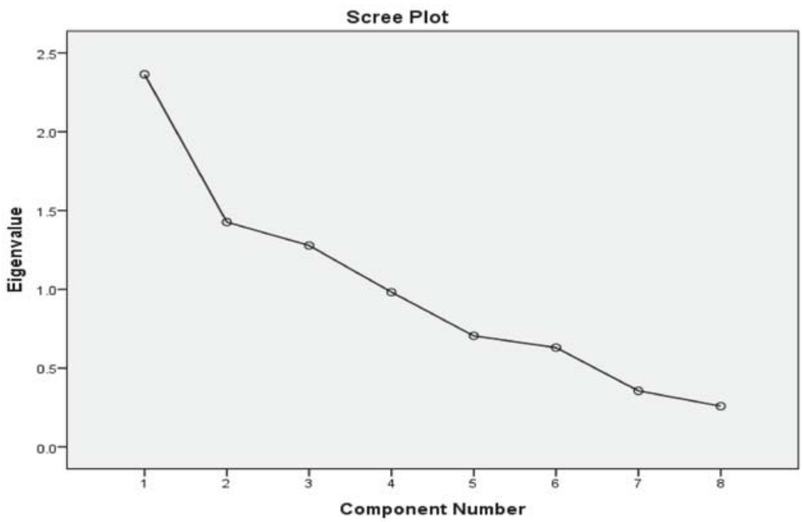

Figure 4. Scree plot causes of disputes.

5. Conclusions

Dispute-causing factors or causes, if identified, the scope for mitigating disputes is more. Broadly classified causes can give a wide picture, but in-depth analysis can be useful in recognizing the repetitive factors that are responsible for disputes in the construction industry. In this study, judicial cases were gathered, which form the data set to gain perspective from both the disputed parties as well as a judgment from the court. Case studies revealed that 8 major causes were responsible for the disputes. These include poor performance, payment, land acquisition, demolition of buildings, contractual, compensation, insurance and illegal. Upon thorough statistical analysis consisting of correlation and factor analysis by means of principal component analysis, it was found that poor performance of the contractors combined with payment delays constituted the majority of disputes and is one of the most recurring causes. Intrinsic factors such as delays on the part of the contractor, unsatisfactory work quality, changes incorporated apart from contractual agreements, and material discrepancies accounted for poor performance. At the same time, changes in contractual agreements, adamant non payments, deductions, non-releasing of deposits, and unjustified delays for payment by the owner come under payment.

Exploratory Factor Analysis was used to group the causes into 3 different components. The first group consists of performance, payment, land acquisition, and illegal and contractual-related problems. Other components consisted of the demolition of buildings and insurance clubbed together, and the final component had compensation alone. The grouping of causes suggests that the interdependency of those causes is high. A particular construction project having the possible factors might manifest into another cause pertaining to the same group. Future studies can be explored in the area with a larger and more diverse data set.

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Insights on the Performance of Public Procurement for Water Utilities Works

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Abstract: The availability of non-reimbursable funds for water supply networks has made the public procurement of construction work in this sector of particular interest in terms of performance. The purpose of this research is to identify key issues and patterns emerging from the engagement between Romanian contracting entities awarding such construction contracts and economic operators. The engagement is materialized through rounds of clarification requests during the offer preparation stage. Following the analysis of the specialized literature, it was found that the subject was not addressed in many scientific publications. The research undertaken was an empirical analysis of selected tenders. The research methodology focuses on the qualitative analysis of publicly available questions and responses, complemented by the analysis of numerical data relating to the same tenders. From the study, it results that a high percentage of all questions analyzed target the technical requirements of the contract notice documents. In some instances, the same questions are found in multiple tenders. Tender evaluation periods are lengthy. The tenders are published with a similar strategic profile (e.g., open tendering, no division into lots) and participation is dominated by bidder associations of multiple economic operators. This study concludes that the quality of the technical requirements does not support the type of strategic profile employed by the contracting entities. The rigidity of written communication makes it unsuitable to mitigate the negative effects of a flawed approach in developing technical requirements for high value, high complexity projects directly connected with Romania's public water supply challenges.

Keywords: public procurement; water networks; stakeholder management; clarification requests; technical requirements; risk management; social sustainability; contracting strategy

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1. Introduction

From a global to a European level, the work of many and various types of organizations reflects the importance of the global community of water resource management and the delivery of water services. Globally, the *clean water and sanitation* for all as the United Nations' 6th SDG out of the 17 is telling. On the 14 July 2021, the European Commission adopted the European Green Deal, with the objective of making Europe the first climate neutral continent by 2050 [1]. Amongst the targets of the Green Deal are the provision of fresh air, clean water, healthy soil, and biodiversity.

On such a backdrop of intense interest and high expectations, Romania is the European Union (EU) member state with the lowest percentage of population connected to a water service network [2]. Further, the country is constantly failing and is challenged with financing its compliance with the EU water acquis, lagging the other member states in terms of compliance with the Urban Waste Water Treatment Directive (UWWTD) [3]. Romania benefited from 35.2 billion EUR in European structural and investment funds to spend [4] in the 2014–2020 funding period.

This research takes cognizance of one of the Organization for Economic Co-operation and Development Council's 12 must-do principles on water governance. Specifically, it considers principle 10: *Promote stakeholder engagement for informed and outcome-oriented contributions to water policy design and implementation*. This research is contextualized upon the linkages between a well performing *water governance*, *public procurement governance*, *public procurement practices* [5] and the *principles* of designing and implementing effective, efficient, and inclusive water policies [6]. Hence, the public procurement practices, lessons learnt and improvements in the procurement process performance that arise from effective stakeholder engagement are connected.

The public procurement process includes mechanisms for stakeholder engagement to enable the collection of pro-active and re-active feedback, both explicit and implicit. A key stakeholder group is the for-profit economic operators in the supply chain, who are necessary for an improved water network, compliance with the EU's UWWDT, and improved water governance.

The public sector organizations to which we refer to in this paper are defined as contracting entities, a category of public sector organizations defined at letter b, article 4 of the Romanian public procurement Law 99/2016 as entities operating in a utilities sector (water, energy, transport, postal services) [7]. These contracting entities are responsible for improving the potable and waste-water infrastructure in Romania. The contracting entities undertake tendering for water infrastructure works to align such infrastructure to the EU mandated standards, mostly financed through EU funding.

One way to describe the procurement process is to consider three stages: the planning, tender and delivery/contract implementation. The *tender* stage is of particular interest in this work to consider the performance of the procurement process through the lens of the engagement with the economic operators.

The planned duration of the public *tender* stage is one in which the performance indicators present few difficulties to establish and monitor. The duration commences on the publication date of the tender documentation. This stage includes the offer preparation period by the interested economic operators and the subsequent evaluation of offers by the contracting entities. Durations of various activities and stages are clearly and transparently regulated through legislation, as minimal, maximal, or indicative. These durations have been established to be considered practical and proven benchmarks and targets for planning and performance monitoring.

For example, in Romania, the offer preparation period for an 'open tendering' procedure is 30 calendar days when using electronics mediums (i.e., the Public Procurement Electronic System—SEAP) and the evaluation period is set to 60 working days [7]. In contrast, the cost and quality performance indicators for undertaking the tender stage or, for that matter, of the entire procurement process, are not rigid and explicit. They are dependent on context and the scope of the contract in terms of planned benchmarks, when such planning is undertaken.

According to Freeman, 1984 [8], stakeholders are defined as any group or individual who can affect or is affected by achieving a firm's objectives. As such, in the public procurement context, the interested economic operators developing an offer within a procurement process are key stakeholders who can affect the achievement of a public sector organization's objectives. Intersecting Heath's 2006 [9] definition of engagement with the EU's provision for rounds of clarifications during the offer preparation stage, it results that the EU allows, and even mandates, two-way, relational, give-and-takes between economic operators and public sector organizations. It also defines the measure of the effectiveness of this type of engagement: the extent to which it improves understanding among interactants, the extent to which it positively supports mutually beneficial decision making and the extent to which it fosters a fully functioning contract implementation.

Therefore, it is our intention to explore facets of the stakeholder engagement with a view to understanding the key issues and patterns impacting on the materialization of the procurement process performance indicators. In particular, this study is concerned with if and how the engagement with the economic operators in the water infrastructure sector during the offer preparation period within the *tender* stage of the procurement processes, as undertaken by Romanian contracting entities, leads to an improved process performance.

This paper, following the introduction, is structured as follows. First, a background section reviewing the government and professional reports followed by a review of the academic literature. Government and professional reports provide value for illustrating auditable aspects of performance in public procurement and the mandated engagement between contracting entities and economic operators. The academic literature review focuses on searching for studies that have analyzed the written clarification requests and responses undertaken during the tender stage of a public procurement process.

Second, we present the methodology employed for the literature review and for our empirical research. Third, the methodology is followed by an extensive presentation of our empirical research results. The results are separated based on the source, and more specifically, the numerical data extracted from a selection of SEAP available contract notices and the text of clarification requests and responses of the same selected contract notices.

Fourth, we discuss our findings from several perspectives to inform the final section of conclusions. In Appendix A we provide tables of the readily available and devised data categories pertaining to the empirical research, in both English and Romanian.

2. Background

2.1. Review of Literature on Public Procurement Performance

The key efficiency indicators of the public procurement process are indicated in the text of the EU public procurement directives 2014/24/EU and 2014/25/EU. These indicators are established coherently, enabling any member state, with the resources available, to achieve the intended results. The single market scoreboard tracks the various quantitative procurement process performance indicators; examples of these indicators include single bidder, no calls for bids, decision speed, Small Medium Enterprises (SME) bids, etc. Further, the harmonized Red Amber Green type benchmarks are based on qualitative policy judgements of constituted good practice; examples of these include single bidder $\leq$ 10%, no calls for bids $\leq$ 5%, decision speed $\leq$ 120 days, SME bids > 80%, etc. [10].

At the country level, the National Council for Solving Complaints (CNSC) [11], the body with administrative-jurisdictional activity and jurisdiction to hear appeals lodged in the procurement process, before concluding the contract [11] and the National Agency for Public Procurement (ANAP) [12], both monitor a portfolio of quantitative indicators. Examples of quantitative indicators include number of appeals, topic of appeals, number of processes, values of processes, durations of processes, competition level, etc.

In 2020, 161 contracting entities published contract notices. Out of these 161 contracting entities, 49 contracting entities (i.e., 30.43%) were active in the water infrastructure sector. It is noted that there is a significant difference in the duration in 2020, of +166 days, compared to the average duration of a tender, regardless of the type of contract targeted (i.e., 93 days) and the average duration of the tender with the ANAP ex-ante verification for the same year (i.e., 259 days). The ANAP proposes that this difference in duration is due to the ANAP's selection methodology, which targets contracts with a high risk, indicating the complexity of the contracts, the multiple clarification questions, the appeals and the high number of offer submission durations. As an indicator for the suboptimal behavior of the contracting entities, the 'awarding the contracts based on a single bid received' indicator is used, which does not benefit from a qualitative assessment [13].

It is noted from the CNSC statistics that, in 2020, the percentage of appeals out of the total of contract notices published in SEAP is 7%, even before considering such filter categories of appeals related to: (a) the tender documentation; (b) EU funded tenders; (c) works contracts; and (d) works contracts for potable and waste-water infrastructure. The CNSC statistics are silent on appeals in the water infrastructure sector. Hence, there is a very narrow base of analysis for our research and thus scarce opportunities to analyze the perspective of the economic operators using CNSC as a source [14].

In 2020, 2983 appeals were registered to CNSC. Out of these, 24 appeals were prompted by a lack of clear, complete, and unambiguous response by the public sector organizations to clarification questions submitted by the economic operators. In addition, 97 appeals were prompted by perceived restrictive technical requirements. The sum of these two connected appeal categories represents 24.69% of the 490 appeals within the broader category of appeals related to the tender documentation. Nevertheless, the quality of technical requirements and the communication between economic operators and public sector organizations when clarifying written clarification questions is not addressed in the CNSC report in more detail beyond that described above [14].

The EU single market scoreboard provides a harmonized benchmark for the efficiency of the public procurement process, as sampled above. However, it is a "simplified reality" based on the data from the EU's online version of the 'Supplement to the Official Journal', dedicated to the European public procurement (TED) [15], which does not cover every aspect, such as "corruption, the administrative burden and professionalism". It is not readily apparent what the local CNSC and ANAP indicators' performance near and longer-term country specific targets should be. The local CNSC and ANAP reports also do not make a visible a connection to the simplified EU single market scoreboard targets.

Similarly, the European's Commission (EC) report on the implementation and best practices of national procurement policies in the internal market concludes that there are challenges in the formation of a coherent understanding of the performance of the public procurement process at the EU level. A lack of data, particularly in terms of disparities between the member states in the data collection for quantitative reporting, was one of the main insights [16].

2.2. Review of Literature on Public Procurement Engagement

As indicated in the ANAP 2020 public procurement efficiency indicator report [13], the Romanian public sector organizations exhibit a limited propensity to apply the more formal methods of engaging with economic operators. It is noted that the ANAP's report describes market consultations as good practice in tender packaging (division into lots). Nevertheless, market consultations are not illustrated in the report, quantitatively or qualitatively. Furthermore, a close reading of the ANAP report uncovered that partnerships for innovations and procedures entailing dialogue and negotiations are limited in number.

Specifically, the frequency of engagement entailing dyadic communication is found to be limited in the water infrastructure sector. The default procedure is the 'open tendering', a one-stage procedure which covers the qualification of the economic operators and the evaluation of their offers in the same sole evaluation stage. This type of procedure deliberately limits engagement to the written exchange of formal documentation for clarifications both during the offer preparation period and during the evaluation period [7].

2.3. Review of Literature on Clarification Requests

Formal written engagement takes place through clarification request rounds during the offer preparation period. Such clarifications from economic operators and the subsequent response from the contracting entity are publicly available. Art. 172 alin. (2) of the Romanian Public Procurement Law 99/2016 [7], with reference to the quality of responses issued by contracting entities during the offer preparation period, solely indicates the obligation for the response to be 'clear and complete'. Art. 108 alin. (2) of the HG 394/2016 [17] adds that the response must also be 'unambiguous'. Further, the EC's public procurement guidance for practitioners [18] does not address the rules of engagement with the economic operators during the offer preparation period.

A conclusion can be deduced that the country's quantitative indicators referenced in the sections above point towards issues within the offer preparation period. Romania's reporting under the Procurement Monitoring Report, in view of the Member States' reporting process under the Directives 2014/23/EU, 2014/24/EU and 2014/25/EU for the period between 1 January 2018 and 31 December 2020 [19], is silent on the quality of the engagement between the public sector organizations and economic operators during this subject period. The *Initiation* stage, as it is framed for the reporting exercise, is limited to the moment of and immediately connected to the tender's launch; that is, the publication of the contract notice. Further, in the *Bid* (offer) *evaluation* stage, the report recognizes and highlights the difficulties facing the evaluation committee in the offer evaluation process. The report states that it is mainly due to the management of the requests for clarifications by the committee, related to the submitted offers and associated responses from the economic operators.

In terms of the *Bid* submitted by the economic operator, it is regulated that any changes to the *Bids* as a result of clarification requests from the contracting authority/entity during the *Bid evaluation* stage should not entail changes to the essential aspects of the initial bid (Directive 2014/25/EU, Art. 48 alin. (6), second paragraph) [20]. However, there is no reference in the legislation to how the clarification requests submitted by the economic operators during their offers' preparation and the subsequent responses can lead to essential changes of the tender documentation. For example, there is no reference to the consequences for or measures to be taken by contracting entities when economic operators indicate misalignments with the principles of public procurement in the clarification requests.

2.4. Review of Academic Literature

Previous research has indicated that there have been few attempts in the academic literature to capture the relevant insights pertaining to the engagement between economic operators and public sector organizations. Specifically, research on the dyadic communication which occurs during the written clarification request rounds during the offer preparation period has not been identified in the academic literature. For completeness, it is noted that no academic literature has been identified that uses the publicly available raw secondary non-numerical written data pertaining to the clarification requests and subsequent responses as source data. However, other studies which consider supplier market insights from a range of stakeholders reveal findings which invite further analysis to inform this research.

One paper explored the perspective of the economic operators as part of a study on the barriers to innovation through public procurement [21]. In 2014, Uyarra et al. used a survey of suppliers to public sector organizations in the UK to identify the procurement process innovation drivers and barriers. Among these, suppliers have pointed towards the "lack of interaction with the procuring organizations" as one of the main barriers. Similarly, at EU level, one of the risks related to the 'response to clarification requests' is "providing evasive answers or answers that change the specifications included in the documentation without giving business operators enough time to adapt to the submitted clarifications" [22]. Through interviews of public procurement representatives and contractors taking part in procurement procedures, Zielina [23] explores the construction sector tenders in Poland. The author notes how the questions addressed to the public sector organization by the contractors may impact the quality of the offers and the course of the proceedings.

Using Google Scholar to search for 'clarification requests' in the title, over a timeframe of more than 20 years, resulted in 73 papers. The resulting cohort of papers mostly explore this type of corrective input in various child interaction contexts, not public sector procurement. In the same timeframe, only one paper explores the aspect of learning in the context of public procurement, with a view of presenting the formal integration of individual and organizational learning. It does, however, emphasize the value of the learning incurred from experience as opposed to learning from sterile intellectualizing and the value of the case studies method for capturing and disseminating 'lessons learned' [24]. A search for 'Romania public procurement challenges' in the title and the same timeframe returned two results, none of which touched on the tender clarification stage written exchanges.

Finally, search results with 'public procurement clarification requests' anywhere in the article returned an excess of 17,000 results for the 20 years search period.

3. Materials and Methods

The method of this research is twofold: (1) a review of academic literature; and (2) an empirical study, an examination of publicly available raw secondary data, focused on the clarification requests submitted by economic operators and the subsequent responses by contracting entities of 32 contract notices.

3.1. Literature Review and Empirical Research Methodology

The intent and impact of the communications of economic operators is relevant for the type of insights sought. Therefore, analysis of authentic self-serving content created by themselves on various topics, occasions, times, contexts, was considered the most appropriate for this research. The process of conducting this research uncovered a few more objective sources for the authors to capture data and information from a key stakeholder in order to identify key issues and potential patterns, which, combined, may lead to insights on the quality of the tender documentation published by the contracting entities and on the performance of the public procurement process.

To establish a robust method of collecting and analyzing the data, a literature review was undertaken. The purpose of the literature review was to identify any attempts at analyzing this area of study. The research framework is public procurement, in the business sector of water utilities (water supply and waste-water infrastructure projects) in Romania and across Europe. We searched data bases of academic journals and publications on key words, such as 'EU Water utilities', 'RO public procurement', 'clarification requests', 'public procurement effectiveness indicators', 'public procurement challenges', 'lessons learning in public procurement', 'learning curve in public procurement' in the 2001–2022 interval. The searched databases were primary (SEAP tender documents, government publications, legislation) and secondary (MDPI journals, Google Scholar, Clarivate).

As illustrated above, a significant literature gap has been identified. More precisely, disparate evidence points to reasons for concern, but no in depth-analysis quantitative and/or qualitative of clarification requests and responses of any public procurement process has been identified. Therefore, an inductive approach was applied to the study.

Subsequently, the analysis of the qualitative content of the clarification requests, responses, and context, was undertaken to identify the key issues, with the intent of generating insights and reflections regarding the theoretical themes that may be proposed.

The empirical study entailed the analysis of the content of published clarification requests and responses to contract notices for water utility works. Specifically, the contract notices which include the 45232150-8 Works related to water-distribution pipelines (Rev.2) as the main Common Procurement Vocabulary (CPV) code. A total of 32 of such contract notices were published in SEAP in 2020 and had an offer submission deadline during the year 2020, as the end of the EU funding period. In most cases, the evaluation of the offers was extended into the year 2021.

The data analyzed for this study is raw secondary documentary, numerical and non-numerical, written data available publicly and extracted from SEAP. This data is publicly available, in accordance with the principle of transparency of public procurement.

The types of data used are ranked based on ease of access (from 1 being the easiest to access) and are illustrated in Table 1 below.

As these types of data pertain to the offer preparation period, the names of the economic operators who are requesting clarifications are not published with the responses. The names of the contracting entities are public, as the initiators of each of the contract notices.

The raw secondary documentary non-numeric written data is available as open-ended questions and responses, thus defined as qualitative data. For the purposes of this research, this is the most important type of data, with the other types of data (e.g., types 1 and 2 as illustrated in Table 1) providing context. The open-ended questions and responses as qualitative data have intent and impact expressed through words, requiring classification into categories for analysis. The categorization and unitizing of the data provided opportunities for quantification and graphical representation.

The data were initially analyzed through exploration, seeking to generate propositions to be tested in alignment with the existing theory.

Table 1. Types of data used ranked based on ease of access.

Type of Data	Access
1. The standard contract notice fields (e.g., number, publication date, name of procedure, name of contracting entity, value, status, etc.).	Available for download as a SEAP excel report export for multiple contract notices based on selected filtering criteria.
2. Other process related information (e.g., offer preparation period, offer evaluation period, total tender duration, reason for cancellation, participants/economic operators who have submitted offers, number of questions asked by the economic operators).	Available either as a calculated field from the base SEAP excel report export fields or as information embedded in subsequent SEAP pages and other locations for each of the individual contract notices of interest.
3. The clarification questions submitted by the economic operators and subsequent responses by the contracting entities.	Available for download for each of the individual subject contract notices.

3.2. Coding and Analysis Sequence

The coding and analysis sequence consisted of 4 steps.

First, the data were categorized and divided into 2 groups. Group 1 is comprised of readily available categories and group 2 is comprised of devised categories. The former group consists of exports and unambiguous information available in SEAP, or data categories easily calculated based on this information. The group 1 data categories are included in Appendix A, Table A1. The latter group consists of data classified from textual questions and answers of clarifications sourced from SEAP. The group 2 categories are defined by the purpose of the research. The group 2 data categories are included in Appendix A, Table A2.

Second, for two of the devised data categories, namely *Question category* and *Targeted tender section*, it was necessary to manually configure the units of data informed by the textual data available in the more than 1000 questions and responses. The units of data for *Question category* are included in Appendix A, Table A3. The units of data for *Targeted tender section* are included in Appendix A, Table A4.

Third, several charts, tables and quotations have been deployed to effectively arrange and display the classified and raw data.

Fourth, we developed and tested a hypothesis to inform the study's conclusions. All of the data were consolidated and analyzed using the Microsoft Office Suite Excel application to ensure the traceability from the raw data to the interpreted units of data. Sections of the questions and responses which were pertinent and supported the research have been transcribed in Excel.

The following hypothesis emerged: requesting clarifications by economic operators and the receipt of responses from the contracting entities (i.e., engagement between the two parties) during the offer preparation does not lead to an improved performance of the public procurement process when tendering for water utilities works in Romania.

The testing of this hypothesis is predicated upon collecting and analyzing the empirical data inductively.

Applying the described coding process to the raw text voluminous data has simplified the complexity, enabling a more manageable and comprehensible body of data. The coding and analysis were undertaken manually, as the clarification requests and their responses consist of an excessive number of pages, numbering into hundreds of pages that are available electronically. The reference pages included scanned versions of the documents with handwritten signatures and no possibility of using software to extract the content for ease of analysis.

The focus has been on analyzing *what* was communicated on both sides, as this is more aligned with the objective of this research; *how* it has been communicated (e.g., perceived attitude, tone, etc.) is also of interest for further discourse analysis type research, however, this is beyond this paper's scope.

4. Results

The results are presented below. First, an overview of four quantitative public procurement performance indicators pertaining to Romania, as measured by the EU and by ANAP, is given. Furthermore, the same indicators are measured within the limits of the 32 contract notices analyzed. Second, the results obtained specifically from the analysis of the 32 contract notices and the analysis of their numerical and non-numerical data are presented.

4.1. Comparison with the EU and Romania Monitored Performance Indicators

The four indicators in Table 2 are part of the set of indicators monitored by the EU [10] for all member states. The four indicators are practical in enabling a performance comparison through the analysis of the SEAP data extracted and calculated for the purposes of this research. The performance benchmarks relevant to the indicators pertain to the year 2020 [13].

Table 2. EU and Romania monitored performance indicators.

Indicator	RO General TED 2020	RO ANAP Report 2020	SEAP Export 2020 (the 32 Notices)	EU Benchmark	
				Green	Red
A. Single bidder	41% [1]	36%	29.41% [2]	≤10%	>20%
B. Award criteria (contracts awarded based solely on the lowest price)	93%	77.98% [3]	0%	≤80%	>80%
C. Decision speed	89 days	65 days [4]	213 days [5]	≤120 days	>120 days
D. Procedures divided into lots	52%	25% [6]	0	≤40%	>25%

[1] 8.5% (2060) are works contracts awarded on the basis of one bid. [2] Out of the 17 contract notices with CPV code 45232150-8 awarded, 29,41% have one bidder. [3] 76.89% out of all construction contracts with the 45 CPV code. [4] 122 days for works contracts. [5] Average duration. [6] 11% for works contracts.

4.2. Results from the Analysis of the SEAP Data

The numerical and non-numerical analysis of the content of the written clarification requests extracted from SEAP are presented in the two following sections.

4.2.1. Numerical Data Analysis Results

Overall, 32 contract notices were analyzed, pertaining to 25 works contracts. Of these, 15 notices were cancelled, pertaining to 11 works contracts. Notable repeat examples of cancellations are provided below.

A works contract was launched in 2019 on one occasion. Subsequently, the very same works contract was launched on four occasions in 2020 with increasingly higher estimated values. The works contract was cancelled all five times due to no participation. It was launched again for a sixth occasion in 2021 (31 December 2020), with an estimated value higher than the original 2019 value, by 27.82% (the equivalent of an extra 12,960,727 LEI). It was successfully awarded to the sole bidder who submitted an offer lower, 26,006 LEI below the estimated value.

A works contract was launched in 2020 on two occasions with the same estimated value and cancelled both times due to no participation. It was launched a third time, also in 2020, with an estimated value 22.97% higher than the previous value (the equivalent of an extra 13,171,199 LEI). It was successfully awarded to one of three bidders, who submitted an offer 5,758,968 LEI lower than the estimated value.

For the above two mentioned notable works contracts, the economic operators submitted a total of 44 clarification questions. For all 15 notices cancelled in 2020, the economic operators submitted a total of 270 clarification questions.

For all 32 contract notices published in 2020, the economic operators submitted a total of 1010 clarification questions.

The following findings, based on the number of clarification questions, illustrate a situation of some concern:

- Average number of clarification questions per contract notice for the 32 published contract notices is 31.56;
- Average number of clarification questions per contract for the 25 works contracts (pertaining to the 32 contract notices) is 40.40;
- Total number of clarification questions for the 17 awarded contract notices is 740;
- Average number of clarification questions per awarded contract notice is 43.52;
- Total number of clarification questions for the 15 cancelled contract notices is 270;
- Average number of clarification questions per cancelled notice is 18.

The average number of clarification questions per cancelled notice is 18 and lower than the average number of clarification questions per awarded contract notice, which was 43.52. Out of the 15 cancelled notices (Figure 1), only two had a high number of clarification questions (76 and 82). The remaining 13 had an average of eight clarification questions $(270 - 82 - 76)/13$. Therefore, there is a tentative correlation between the low number of clarification questions and the negative result, evidenced through the lack of participants as the main reason for cancellation. Out of the 15 cancelled notices, 11 were cancelled due to no participation.

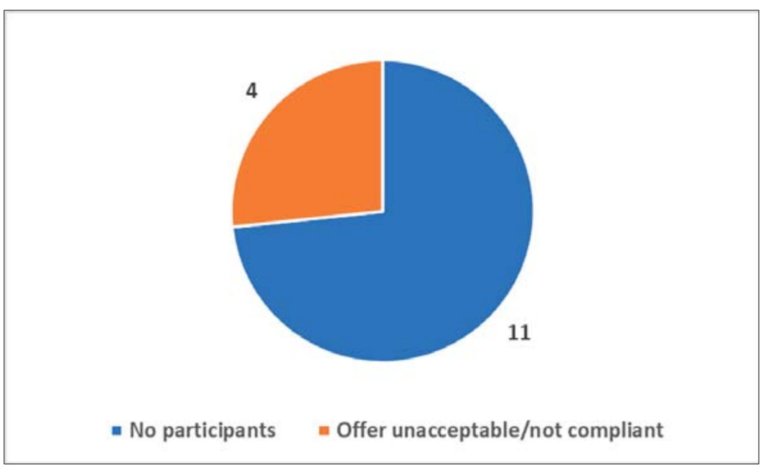

Figure 1. Cancelled contract notices and motive of cancellation.

Figure 2 illustrates the distribution of the number of clarification questions for each of the 17 contract notices that were awarded, with a total of 740 clarification questions. We found that 23.5% of the awarded contract notices (top four contract notices) accumulated 74% of the total number of clarification questions.

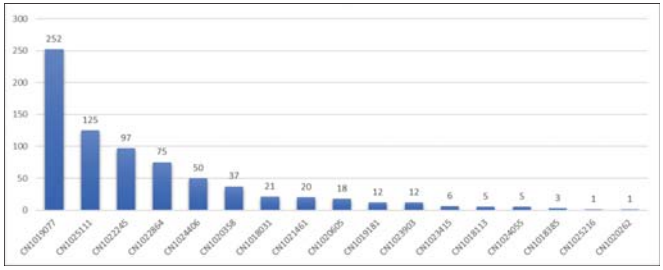

Figure 2. Clarification questions per awarded contract notices.

Figure 3 illustrates that, for all 32 published contract notices, 31.20% (top 10 notices based on the 1010 total number of clarification questions) attracted 83.96% (848 questions) of all the clarification questions.

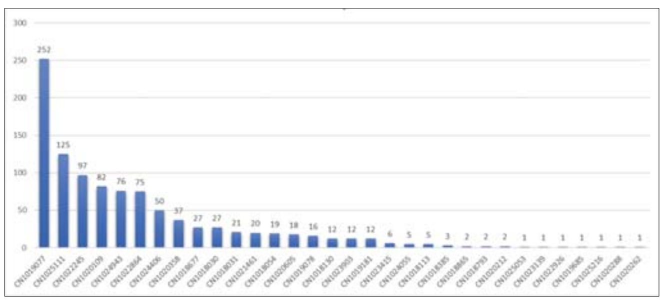

Figure 3. Clarification questions for all 32 published contract notices.

Figure 4 illustrates that 891 clarification questions were submitted for the 21 contract notices published by the Compania de Apa Somes S.A. The 21 contract notices cover 16 works contracts; eight of these were cancelled on at least one occasion. The total estimated value of the 16 works contracts at their last launch is 947,770,979.16 LEI (194 million EUR).

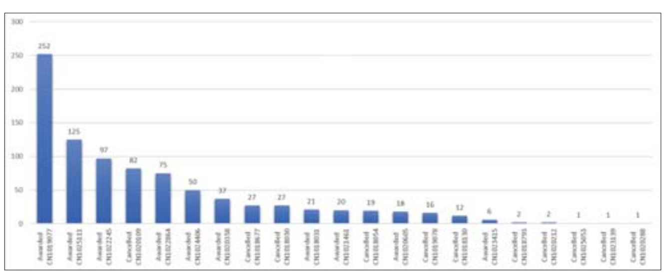

Figure 4. Clarification questions submitted to Compania de Apa Somes S.A.

Figure 5 illustrates the estimated value of the contract notices and the number of clarification questions. The conclusions drawn are that there is a weak correlation between the value of the contract notice/contract and the number of clarification questions. However, we notice a general upward trend in the number of clarification questions as the value of the contract increases. The factors influencing this trend may include the quality of the tender documentation. There are higher difficulties in preparing a good quality tender documentation for complex projects, complexity being correlated with high estimated values of the projects.

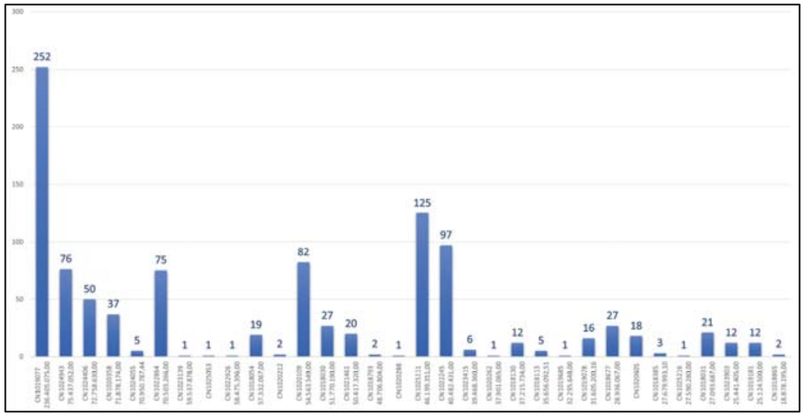

Figure 5. Estimated value of the contract notice and the number of clarification questions.

Further, it is noted that the contract notice with the highest estimated value has the highest number of clarification questions (252). This is a significant delta difference from the average of the remaining contract notices (758/31 = 24.45). It could be concluded that such a value motivates economic operators to invest resources in offer preparation, evidenced through the high number of clarification questions and through the appeals (including High Court appeals), which resulted in an evaluation period of 648 days.

Figure 6 illustrates the questions targeting the documentation and the number of questions per targeted tender section. Overall, 77.32% of the total 1010 clarification questions targeted the technical requirements on which the economic operators are expected to base their offer on.

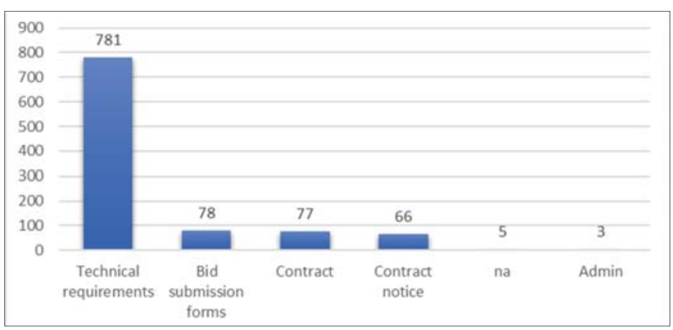

Figure 6. Number of questions per targeted tender section.

Figure 7 illustrates the categories of the 781 questions pertaining to the technical requirements. The volume of questions tentatively indicates the failure of the technical capabilities of the contracting entities.

Figure 8 illustrates all of the question categories, comprising 1010 questions, which targeted the various tender sections.

Figure 9 illustrates that, of the 32 contract notices, 14 have had at least one request for the bid submission deadline to be extended.

Figure 10 illustrates the duration of offer preparation and decision speed for the 17 awarded contracts. In summary, there is an average of 55.5 calendar days for the offer preparation period and an average of 213.2 calendar days for the evaluation period (decision speed).

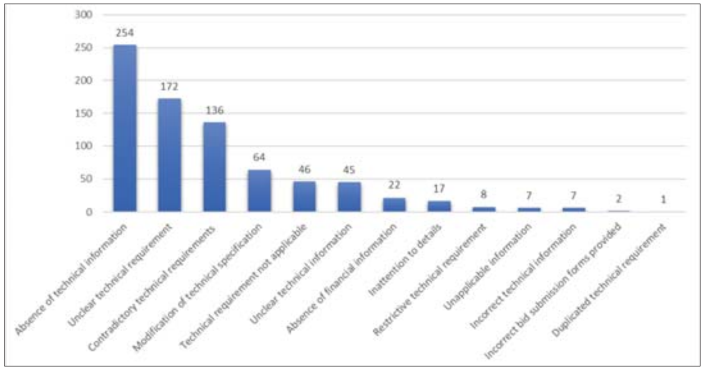

Figure 7. Questions targeting the technical requirements.

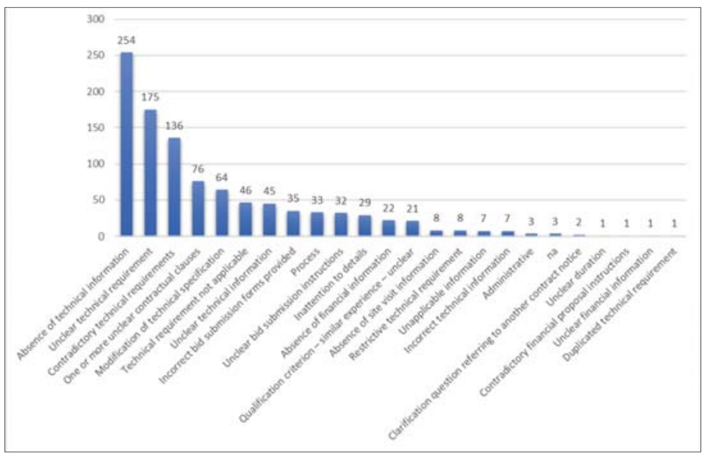

Figure 8. Question categories across all tender sections.

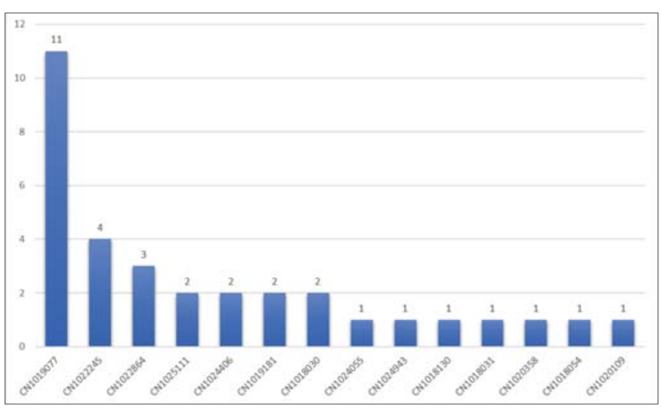

Figure 9. Number of requests to extend the submission deadline illustrated by contract notice.

Contract notice no.	Offer preparation period	Decision speed
CN1018031	45	105
CN1018113	53	398
CN1018385	31	169
CN1019077	108	648
CN1019181	71	153
CN1020262	51	298
CN1020358	72	149
CN1020605	58	140
CN1021461	45	125
CN1022245	55	183
CN1022864	51	210
CN1023415	45	109
CN1023903	44	177
CN1024055	56	211
CN1024406	48	110
CN1025111	56	215
CN1025216	55	225
Grand Total	**944**	**3625**

Figure 10. Duration of offer preparation and decision speed.

Figure 11a illustrates the offer preparation period versus decision speed per contract notice. Figure 11b illustrates the offer preparation period versus decision speed per contracting entity and contract value. In summary, for the 32 contract notices launched in 2020, there is an average of 56.34 calendar days for the offer preparation period and an average of 113.28 calendar days for the evaluation period (decision speed).

Contract notice no.	Offer preparation period	Decision speed
CN1018030	66	
CN1018031	45	105
CN1018054	55	
CN1018113	53	398
CN1018130	55	
CN1018385	31	169
CN1018677	44	
CN1018793	46	
CN1018865	59	
CN1019077	108	648
CN1019078	80	
CN1019181	71	153
CN1019685	59	
CN1020109	71	
CN1020212	52	
CN1020262	51	298
CN1020288	54	
CN1020358	72	149
CN1020605	58	140
CN1021461	45	125
CN1022245	55	183
CN1022864	51	210
CN1022926	62	
CN1023139	41	
CN1023415	45	109
CN1023903	44	177
CN1024055	56	211
CN1024406	48	110
CN1024943	75	
CN1025053	40	
CN1025111	56	215
CN1025216	55	225
Grand Total	**1803**	**3625**

(**a**)

Contracting entity/estimated value	Offer preparation period	Decision speed
16579635 - COMUNA IPOTESTI (PRIMARIA COMUNEI IPOTESTI OLT)		
27,679,993.10	31	169
RO 11400673 - Compania de Apa Oltenia SA		
37,901,065.00	51	298
25,124,500.00	71	153
RO 201217 - Compania de Apa Somes S.A.		
236,405,075.00	108	648
72,758,630.00	48	110
71,878,174.00	72	149
70,503,266.00	51	210
59,537,878.00	81	
57,332,067.00	107	
54,563,549.00	71	
51,770,190.00	66	
50,417,320.00	45	125
48,706,804.00	100	
46,199,351.00	56	215
40,482,431.00	55	183
39,468,360.00	45	109
37,215,734.00	55	
31,605,200.16	80	
28,936,067.00	102	140
27,093,687.00	45	105
RO 20330054 - COMPANIA DE APA "ARIES" S.A.		
70,950,787.44	56	211
35,656,092.51	53	398
RO 22987337 - COMPANIA DE APA		
75,437,052.00	75	
RO 3041480 - AQUATIM S.A. Timisoara		
58,475,396.00	62	
32,295,648.00	59	
27,590,280.00	55	225
25,441,405.00	44	177
18,878,195.00	59	
Grand Total	**1803**	**3625**

(**b**)

Figure 11. (**a**) Offer period versus decision speed per contract notice; (**b**) Offer period versus decision speed per contracting entity and contract value.

Figure 12 illustrates the total offer preparation days and number of questions for the cancelled notices. For the 15 contract notices launched and cancelled in 2020, a total of 859 days has been allocated to the offer preparation period. During this period, the economic operators submitted 270 clarification questions.

Contract notice	Offer preparation period	Number of questions per notice
CN1018030	66	27
CN1018054	55	19
CN1018130	55	12
CN1018677	44	27
CN1018793	46	2
CN1018865	59	2
CN1019078	80	16
CN1019685	59	1
CN1020109	71	82
CN1020212	52	2
CN1020288	54	1
CN1022926	62	1
CN1023139	41	1
CN1024943	75	76
CN1025053	40	1
Grand Total	**859**	**270**

Figure 12. Total of offer preparation days and questions for the cancelled notices.

The procedure type of all 45232150-8 CPV contract notices launched and with a deadline in 2019, 2020 and 2021 was the 'open tendering' procedure.

A total number of 135 economic operators were involved, in some form (associate, leader), in 48 bidder associations across the 17 awarded contracts (an average of 2.77 economic operators for each association). An independent economic operator, not associated with any association, submitted an offer on only two occasions. The two examples are WTE Wassertechnik GmbH and TEHNODOMUS (WTE Wassertechnik GmbH—procedure cancelled/TEHNODOMUS—unsuccessful). Hence, for the 17 awarded contracts, the average competition is 2.88 bidders (48 associations and 1 sole bidder) or 7.94 economic operators.

At the country level, Romania shows negative values for the single bidder indicator (meaning a lower unhealthy competition, although not complemented by any further analyses/recommendations), both in the EU scoreboard and the ANAP report. Similar negative results appear based on the same single bidder indicator calculation of the data; however, with an improvement (see Table 1 above). It is important to highlight the five awarded contracts to the single bidder had a participation of 32 economic operators. Therefore, such granular analysis of the data leads to a finding with a completely different perspective. This finding serves, paradoxically, as both a contradiction and a confirmation of the single bidder quantitative indicators in the official reports.

Page 6 of the WTE Wassertchnik GmbH's CNSC procedure result appeal (registered by the contracting entity no. 34110/19.10.2020) states: "Given the nature of the contract, its estimated value and minimum qualification requirements, demonstrating these is a challenge for medium and small companies".

4.2.2. Non-Numerical Data Analysis Results

The following section provides groups of findings to consider in gathering insights and conclusions from the research undertaken.

GROUP 1

The first group of findings to consider are clarification requests regarding the duration of the contract, on-site visits and on the cost of water needed for the commissioning tests. These are just a sample of the many questions which induced resource deployment for clarifying simple aspects which could have been avoided through minimal planning effort on the part of the contracting entity.

Contract notice number CN1019077 includes a question to clarify the duration of the contract, with origins in several durations referenced in the Data Sheet (contract notice).

Although this question was clarified by the contracting entity by invoking the impact of various components and possible configurations which determine the duration of the contract, the information was not presented clearly. This led the economic operator to submit a question about a key and basic contractual piece of information which should have been unambiguously communicated by the contracting entity. The consequences were for both parties to expend resources on reaching a shared understanding of a key and basic contractual piece of information.

Multiple clarifications were raised around the site visits to be undertaken during the offer preparation period. In total, seven of the 32 contract notices received such questions. The contracting entity appears to have lacked the ability to plan site visits and/or clearly communicate the coordination of site visits to and with the economic operators.

Compania de Apa Somes S.A. received seven questions on the cost of the water necessary for the technological tests of the network prior to handover. Three of these questions were submitted in the same contract notice. Therefore, the same question was submitted by multiple economic operators expressing interest in submitting a proposal. It is noted that this very same question is repeatedly submitted in five contract notices published at different points in time (January, February, April, June, and September 2020) (Table 3). The resulting finding is that the contracting entity neglects to address this aspect repeatedly and does not evidence a lesson learned culture of continuous improvement. The consequences are reputationally damaging to the contracting entity.

Table 3. Questions on the cost of test water.

Contract Notice	Publication Date/Time
CN1024406	11.09.2020 01:35:34
CN1022245	30.06.2020 01:35:35
CN1022245	30.06.2020 01:35:35
CN1022245	30.06.2020 01:35:35
CN1020358	11.04.2020 01:35:16
CN1019077	22.02.2020 01:37:53
CN1018031	03.01.2020 01:35:50

GROUP 2

Seven of the contract notices include multiple clarification questions targeting the technical requirements and bringing attention to what the economic operators perceive as conflicts with the public procurement principles. More precisely, the economic operators refer in their clarification questions to the obligations of the contracting entities to ensure equal access, to ensure and promote competition, equal treatment and not to discriminate (Table 4).

Table 4. Contract notices with questions mentioning conflicts with public procurement principles.

Contract Notice	Publication Date	Contracting Entity
CN1025053	07.10.2020 01:35:17	Compania de Apa Somes S.A.
CN1024943	02.10.2020 01:37:24	Compania de Apa (Buzau)
CN1024406	11.09.2020 01:35:34	Compania de Apa Somes S.A.
CN1019077	22.02.2020 01:37:53	Compania de Apa Somes S.A.
CN1018677	08.02.2020 01:36:24	Compania de Apa Somes S.A.
CN1018054	07.01.2020 01:35:00	Compania de Apa Somes S.A.
CN1018030	03.01.2020 01:35:40	Compania de Apa Somes S.A.

GROUP 3

From the below examples, based on the way the clarification questions are formulated, we deduce that the same economic operator notices the same requirements perceived as restrictive and repeatedly reminds the same contracting entity, on contract notices pertaining to different work contracts, of its obligation to align with public procurement principles.

The following is the same lead statement preceding the questions themselves. "[. . .], we request the contracting authority, [. . .], to instruct that the scope of works to be developed in line with the principles of promoting competition, of guaranteeing equal treatment and non-discriminatory of economic operators, and in line with the principle of efficient use of public funds [art. 2, art. 155, ar. 156 of Law no. 98/2016 regarding public procurement] [. . .]".

CN1018030—published on the 3 January 2020

With regards to:

- The requirement to present a CE Certificate for the ductile iron pipes, pipes manufactured according to EN 545 standards, but EN is not harmonized and, consequently, does not have CE marking;
- The specific method to coat the ductile iron pipes requested (a very specific technical requirement made by the contracting entity), where the economic operator has presented arguments for the added value of using another type of coating and the industry standard which addresses the recommended coating methods.

It is worth noting that the request of the economic operator for the contracting entity to revise these requirements and others associated with it, as well as the way the economic operator has requested for the requirement to be revised, were accepted by the contracting entity. Moreover, with regards to modifying the iron pipes coating method, the contracting entity accepted the arguments of the economic operator and revised this requirement by accepting any coverage method recommended by the ISO 13470 standard as long as the pipe is protected 'accordingly'. Such a revision from a 'technical specification' to a 'performance requirement' was not accompanied by a definition of the term 'accordingly'.

CN1018677—published on 8 February 2020

and

CN1024406—published on the 11 September 2020

With regards to:

- The polyvinyl chloride pipe wall, initially requested by the contracting entity to be compact, and the economic operator requests to have the option to use piping with structured wall.

In both contract notices, the response of the contracting entity (the same contracting entity) was the same. The ambiguous response is constituted partially by a reproduction of the requirements already stated in the technical documentation. Further, the response referred to an adjustment of the piping's testing requirements and had no references to the 'structured' wall option, which was the subject of the clarification question. Therefore, a practice of responding to questions in a way that does not clarify and/or does not address the essence of the clarification question submitted by the economic operator was noticed in this case and in others.

CN1019077—published on the 22 February 2020

With regards to:

- The requirement to present a CE Certificate for the ductile iron pipes, pipes manufactured according to EN 545 standards, but EN is not harmonized and, consequently, does not have CE marking.

The same question was submitted in the contract notice CN1018030 pertaining to another works contract launched by the same contracting entity one month previously, in January of the same year. The repetition indicates that the same technical team produced both technical documentations.

A number of other clarification questions highlighted simple errors out of a lack of attention to details, such as location references in one project pertaining to another project, thus indicating a general negligent and copy/paste practice in the technical teams that develop technical documentation for multiple projects for the same contracting entity.

GROUP 4

CN1019077—published on 22 February 2022

With regards to:

- The lack of information about the exact number of fittings necessary to execute the pipeline's orientation, items identified by the contracting entity solely based through a financial criterion.

The clarification question is: "We believe that this percentage of approximately 5% of the estimated value of the Contract can be a defining percentage for the submitted offers, even more, by abiding by the principle of equal treatment and proportionality (Law 99/2016) all bidders should have at the tender preparation time all the necessary elements for the financial quantification of all contract components. By omitting the information indicated above, we believe that the bidders and the evaluation committee are deprived of vital information necessary to develop a unitary quantitative bid, respectively, a unitary evaluation based on equal quantities made available to the bidders".

The contracting entity has an obligation to describe the characteristics of the works through performance requirements, technical specifications, or a clear combination of these [7]. Describing line items by referring to their value conflicts with these legal requirements negatively impacts the procurement process. It is noted that the response to this question was clear, through which the contracting entity indicated exactly the type and quantity of the items brought into question.

With regards to:

- The request to remove the GSK certification requirement of the valves, requirement considered restrictive by the economic operator, point of view supported through referring to a CNSC 2018 decision on the same topic. GSK is an association of certain producers which represents the general and intellectual interests of its members.

The clarification question is: ''The CNSC decision 1329/C7/1048 of 18.05.2018 shows that, when European standards regulating the requirements of internal and external epoxydic coating, respectively, EN 14901, based on which there are existing independent organization issuing certifications, the requirement regarding the GSK certification (private body) represents a breach of art. 2, art. 155 of Law 98/2016, regarding the principles of competition, of guaranteeing equal treatment, of not discriminating economic operators and of effective use of public funds".

It is worth noting that the contracting entity rejected this request to exclude the restrictive GSK certification. Further, the contracting entity justified this decision by its vast and positive experience in using GSK valves as compared to non-GSK certified fittings, therefore ignoring the CNSC decision invoked by the economic operator without further explanation.

The response is: "It is accepted the use of valves which correspond to the requirements of technical sheets No. 1.3, 1.4, 2.1 and 2.3, including the requirement regarding GSK certification, this certification being based on the vast experience of the contracting authority with regards the performance of products used within the potable water supply systems, the Beneficiary having a positive experience in exploiting products with GSK accreditation compared to products which do not have this certificate. The request is not a restrictive one, it is a request based on performance criteria, confirmed through the lengthy exploitation of various types of products." (Researchers' emboldened text).

GROUP 5

The following examples illustrate the propagation of the same error within the tender's technical documentation (a technical requirement considered restrictive by the economic operators), within multiple contract notices launched by the same contracting entity in different months of the year 2020.

CN1018054—published on the 7 January 2020

"[. . .], we request the contracting authority, [. . .], to instruct that the scope of works to be developed in line with the principles of promoting competition, of guaranteeing equal treatment and non-discriminatory of economic operators, and in line with the principle of efficient use of public funds [art. 2, art. 155, ar. 156 of Law no. 98/2016 regarding public procurement]".

With regards to:

- Specific requirements regarding the manufacturing method of PAFSIN joints.

It is worth noting that the request of the economic operator for the contracting entity to revise these requirements and other associated with it in the way the economic operator has requested for the requirement to be revised was accepted by the contracting entity.

The same clarification question, with minor variations, with regards to the specific manufacturing method of PAFSIN joints targets the technical documentation of the contracting entity, in the contract notices: CN1018677 (CL7), published in February 2020; CN1024406 (CL23), published in September 2020; and CN1025053 (CL17), published in October 2020.

CN1024943—published on the 2 October 2020

"The provisions of Art. 165 alin. 6) from Law no. 99/2016 which provide that 'Technical specifications must allow all economic operators equal access to the tender procedure and must not lead to the introduction of unjustified obstacles to ensuring an effective competition amongst economic operators' [...] to allow an as possibly numerous participations of bidders [...] ensuring competition [...] effective use of public funds [...]. The technical requirements included in the tender documentation must be prepared in line with the principles of promoting competition, of guaranteeing equal and nondiscriminatory treatment of economic operators, however the requirements highlighted above impose restrictive technical conditions for the PAFSIN joints, the effect of this measure being the elimination of those manufacturers and/or distributors of PAFSIN pipes and of related joints which do not fall under such restrictive requirements".

It is noted that the request of the economic operator for the contracting entity to revise these requirements and other associated with it in the way the economic operator has requested for the requirement to be revised was accepted by the contracting entity.

Considering that these similar technical requirements have been highlighted as restrictive by at least two different economic operators and in multiple contract notices published by two different contracting entities in different months of the year 2020, the missed opportunities for lessons learned by these contracting entities is noticeable. Further, the propagation of errors, as illustrated by finding the same restrictive technical requirement in different technical documentations launched by different contracting entities, suggests that these documentations were prepared by the same technical team.

GROUP 6

This example is of the same clarification question submitted in two different contract notices (for two different works contracts), launched by the same contracting entity at a difference of four days.

CN1018030—published on the 3 January 2020

and

CN1018054—published on the 7 January 2020

Question: "Please confirm that only the works included in the Bill of Quantities will be executed".

Contracting entity response: "All works necessary to ensure the functionality of the system will be executed, these works to be undertaken in accordance with the instructions of the technical specifications, the instructions of the technical project and the current legislation, and payment will be made based on the actual quantities executed during implementation, according with the contractual conditions".

5. Discussion

5.1. From the Perspective of Reviewed Literature

The intent of this research is to explore facets of stakeholder engagement with a view to understanding the key issues and patterns impacting the materialization of the procurement process performance indicators.

The performance of the procurement process, both at EU and country level, is monitored through quantitative indicators, which are typically a result of applying mathematical formulae to the TED or SEAP data base as a first point of call extracts. The research presented in this paper focused on measuring the effectiveness of EU non-reimbursable funding of public spending aimed at increasing the percentage of the Romanian population connected to a water service network. Key benchmarks for quantitative indicators do not exist at the local level. Further, when applying qualitative analysis, it is found that the key quantitative indicators are in some cases redundant (i.e., the award criterion) and insufficient (i.e., the single bidder indicator). Critically, the revised values calculated in this research provide evidence of noncompliance by contracting entities with the public procurement legislative framework (i.e., the practice of not dividing into lots and restrictive access to SMEs).

In procuring water utility works in Romania, a decision speed of 213 days to award one works contract is high. This is in contrast with the overall performance of the Romanian public sector organizations. Additionally, when considering the use of 'the lowest price', it is noted that the apparent positive indicator of practice is due to the constraints applicable to the procurement processes for contracts with estimated values above the legal threshold [7]. Hence, the positive indicator is not due to proactive good practice on the part of the contracting entities.

The strategic decision by the contracting entities to not divide into lots, restricting access to SMEs, is evidenced by one of the most remarkable findings of this study, whereby 135 economic operators were linked to 48 associations as consortia bidders and only two were sole bidders. The evidence of improvements via the competition indicator when analyzing the number of bidders, consortia, or sole bidders, in water infrastructure work tenders illustrates a competition level for such contracts above the country average. However, it is paradoxically undermined by the number of actual economic operators who must pursue an association model to obtain access. There is causation between restricting the access of SMEs and obstructing the amplification of competition levels due to the decision making of contracting entities.

In previous research, encouraging bidding in consortia was deemed to be a sign of compliance with policies aimed at supporting SMEs [25]. Our research finds that, when tendering for water infrastructure works in Romania, bidding in consortia of a high number of economic operators coupled with the provision of low-quality ambiguous inconsistent technical documentation introduces friction and barriers for the SMEs and economic operators.

As initially discussed above, the strategic profile of the procurement processes show consistent themes. Apart from not dividing the high-value, complex contracts into lots, the default procedure is 'open tendering'. A total of 10 out of the 17 awarded contracts had 'duration of the works' as the technical evaluation factor. Such dimensions led to the need for economic operators to form a consortium to be able to prepare an offer. This is a challenge for both SMEs and established companies (e.g., Strabag AG [26], company which participated only in two tenders, on both occasions as an associate).

Such research findings can support EU policy makers to review the monitoring of the use of EU funding. Further, the findings can support local monitoring bodies to be more vigilant and prescriptive on public sector organizations' performance when engaging with economic operators.

We find ourselves in agreement with Melon's 2020 recognition of the importance of market engagement through innovative public procurement procedures in order for procurement as a function to contribute effectively to the sustainability quest [27]. Further, Romania has been placed in a cluster of EU member states that are significantly behind in achieving the EU's vision for sustainable development [28], also evidenced by the lack of green and social evaluation factors in the contract notices analyzed during this research.

Hence, we highlight the value of a more prescriptive approach to market engagement. An example of a measure to catalyze sustainable procurement is introducing a mandated form of green public procurement as an entry in the familiar 'open tendering' procedure [27]. It is stressed that such a tactical change, without effective market engagement and thoughtful contracting strategy, would perpetuate immature levels of sustainability performance, as uncovered by the research herein.

A similar perspective is promulgated for the integration of social agenda. A notable absence in the analyzed contract notices is the social evaluation factors. The literature review confirms that contracts with high value and long execution duration are most likely to integrate social evaluation factors, albeit with low weightings [29]. The social implications of the Romanian populations' limited water access and the related challenges in the procurement processes are exacerbated by the absence of the water sector contracting entities' practices of socially responsible procurement.

The engagement between public sector organizations and the market occasioned by written clarification requests in the offer preparation period is not addressed by the EU or Romanian legal framework, neither as specific rules of engagement nor monitored. We have found that this vacuum of governance enables an imbalance of power and allows flexibility to the public sector organizations to the point that it exhibits as a form of abuse of power. Lennerfors' 2007 [30] reference to corruption is not traditional (i.e., corruption for private gain), but as deviations from pristine standards. We have seen these deviations presented through perceived conflicts with the principles of public procurement, unjustified restrictive technical requirements, and disregard for the legal obligations.

Previous findings mentioned in the literature review on the lack of interaction with public sector organizations as a barrier to innovation are confirmed. It is evidenced by the engagement being limited to written correspondence, a trait of the traditional 'open tendering'. In addition, it is evidenced by the difficulty of contracting entities to plan and clearly communicate the details of site visits during the offer preparation period. Many of the responses to the clarification questions are indeed evasive. In contrast, requests for extensions of the bid submission deadlines, albeit ubiquitous and eventually proving nevertheless insufficient to mitigate a negative result, are always accepted. This is evidence of the tacit agreement on the high complexity of the tenders. However, cognizance of complexity is not readily apparent in any other procurement strategy decisions explored in this research.

5.2. From the Perspective of the Working Hypothesis

The hypothesis resulting from the study of existing literature was that economic operations submitting clarifications and the receipt of responses from the contracting entities (i.e., engagement between the two parties) during offer preparation does not lead to the improved performance of the public procurement process when tendering for water infrastructure works in Romania.

We have illustrated in the section above how certain established performance indicators present even more negative values than the EU and Romanian averages when narrowing down the monitoring population to processes in the water utilities sector. In addition, the findings of several themes that have not previously been considered in the same monitoring population contribute to the negative findings related to the performance of the procurement processes.

A key finding is the voluminous quantity of questions submitted by the economic operators. Without discounting the effort of the contracting entities to respond to each of these questions, it nevertheless illustrates that there is considerable interest from the market for winning public water infrastructure works contracts to maintain the persistence in repeatedly submitting clarification questions related to tender documents, which are considered by the economic operators to be flawed.

With 77.32% of questions targeting the technical requirements, we conclude that it is of suboptimal quality, conflating with a previously found barrier to procurement process innovations [21]. The technical documentation is over-specified and exhibits frequently irrelevant, incorrect, and unapplicable elements. The onus of responsibility is put on the economic operators not only for the implementation of the future works contract, but also for the preparation of their offer based on this suboptimal quality documentation.

The separation of the design stage from the construction stage is a traditional form of completing works in the execution of a project. Hence, there is a dependency of a qualitative offer for the construction stage on the quality of the technical documentation resulting from the design stage [31]. The contracting entities typically outsource the design services. The deliverables are content-heavy technical documentations, with hundreds of pages, and are difficult to analyze and evaluate in terms of quality by the client contracting entity. Sporrong 2011 [32] explores extensively the selection context of such design consultants, as a stakeholder group with a strong influence on the quality and cost of built facilities. Fazekas et al. 2013 [33] draw similar conclusions that public buyers have a limited ability to evaluate the competence of architectural and engineering consultants. There is a lack of understanding of the difference between selecting and assessing the competence of a design firm and selecting and assessing the competence of the individual consultant [33].

A combination of failures by the contracting entity and consultants results in suboptimal, reoccurring documentation. It is reasonable to assume that the same errors in different technical documentation pertaining to different contracting entities entail the use of the same pool of external consultants. Therefore, the responsibility for the quality of the technical documentation is on the external consultant, while the lack of clarity of the definition of 'similar experience', offer presentation requirements, contractual clauses, typographic errors, and site visits confirms a previously emerged suppliers' perspective [21] associated with failures of the procurement teams of the contracting entities themselves. However, the contracting entity, and not the external consultants, is accountable for the overall effectiveness, or lack thereof, of the procurement process [34].

5.3. Limitations

The data analysis highlighted examples of flaws in the content of the technical documentation. It is nevertheless possible that other technical aspects have been highlighted by the economic operators as incorrect, incomplete, restrictive, etc. An exhaustive and correct analysis of more than 1000 questions and answers requires extensive technical expertise not comprehensively available within the research team, as well as the availability of native, editable manipulative formats. In addition, the applied SEAP CPV code filter resulted in a limited list of six water utilities companies, with one dominating in terms of the number of published contract notices, the number of clarification questions received, cancellations, and total contract estimated values. Nevertheless, the ANAP 2020 report indicated 49 contracting entities active in the water sector, each with a coverage and significant impact in their respective regions. Therefore, even one of them has a major influence in driving the progress in terms of water network coverage and the quality of the life of the population.

6. Conclusions

This study formulated a hypothesis that the request for clarifications by economic operators and the receipt of responses from the contracting entities (i.e., engagement between the two parties) during offer preparation does not lead to the improved performance of the public procurement process when tendering for water utility works in Romania.

Overall, we discovered that our hypothesis was simplistic, and a binary response is insufficient to characterize the complexity of the findings. It is not enough to conclude that the type of engagement we analyzed does not lead to the improved performance of the public procurement process when tendering for water infrastructure works. Indeed, we have a strong reason to conclude that it is not an effective engagement, as it did not lead to an improved understanding among interactants. It did not positively support mutually beneficial decision making.

However, we associate the ineffectiveness of the engagement and the ensuing suboptimal performance of the procurement process with an absence or ineffective contracting strategy. In the analyzed procurement processes, the decision-making is grounded firstly in a culture of established and familiar standards. A clear example is the exclusive use of the 'open tendering' procedure despite evidence of scope complexity (e.g., cancellations, submission extensions, lengthy evaluations). The negative consequences of not aligning the strategic profile of the procurement process with the profile of the scope and that of the market are exacerbated by the suboptimal quality of the technical documentation. Furthermore, lessons learned do not appear to inform continuous improvement, and errors are repeated.

We conclude that the procurement processes are conducted more as an administrative exercise, regardless of the results, rather than with a mindset to fulfill the duty of care of the contracting entities undertaking procurement by including considerations of social and economic effectiveness.

Therefore, a written exchange of hundreds of clarification questions and subsequent responses in one or a maximum of two rounds cannot mitigate the risks posed by a complex scope, suboptimal quality technical documentation. Finally, we have illustrated that written correspondence between the contracting entities and economic operators was ineffective, lacking good governance and exhibited an imbalance of power to the detriment of the participating economic operators and, indeed, the population of Romania.

7. Future Research

We encourage scholars from the EU member states to build upon the analysis of the qualitative nature of communications between public sector organizations and economic operators during the offer preparation period. Specifically, to explore how a qualitative or less qualitative dialogue relates to the qualitative or less qualitative implementation of the contract. It would be advantageous to better understand the rationale and sources of the breakdown in dialogue to identify pragmatic and sustainable solutions.

At the public procurement policy level, it would be beneficial to explore governance models on the rules of engagement applicable to all procedures and especially during the written exchanges associated with certain procedures.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Data categories readily available.

English	Romanian
Contract notice number	Numar anunt
Publication date	Data publicare
Errata	Erata
Contract name	Denumire contract
Procedure type	Tip procedura
Contract type	Tipul contractului
Status_Online procedure phase on 4 June 2022	Medium
Contract awarding manner	Modalitatea de atribuire
CPV code	Cod CPV
Contracting entity	Autoritate contractanta
Receipt deadline	Data limita de depunere
Estimated value	Valoarea estimate
Appeal	Contestatie
Lots	Lotizare

Table A1. *Cont.*

English	Romanian
Cancellation motive (where applicable)	Motiv anulare (unde e cazul)
Offer submission period	Durata perioada pregatire oferta
Decision speed	Durata perioada evaluare
Participants	Participanti
Participant type	Calitate participant
Outcome for the participant	Rezultat pentru participant
Award notice date (where applicable)	Data anuntului de atribuire (unde e cazul)

Table A2. Data categories devised.

English	Romanian
Total number of questions per contract notice (for all clarification rounds)	Numar total de intrebari per anunt
Clarification round (clarifications issued proactively by the contracting entities have been ignored)	Runda de clarificari
Question # within the clarification round	Numarul intrebarii in cadrul rundei de clarificari
Question (short text extract, where possible and necessary for interpretation)	Intrebare/solicitare clarificari
Question category	Categoria intrebarii
Targeted tender section	Sectiune anunt vizata

Table A3. Units of data for *Question category*.

English	Romanian
Administrative	Administrativa
Qualification criterion—similar experience—unclear	Cerinta de calificare—experienta similara—neclara
Unclear offer presentation instructions	Cerinta prezentare oferta neclara
Duplicated technical requirement	Cerinta tehnica dublata
Technical requirement not applicable	Cerinta tehnica neaplicabila
Unclear technical requirement	Cerinta tehnica neclara
Restrictive technical requirement	Cerinta tehnica restrictiva
Clarification question referring to another contract notice	Intrebarea se refera la un alt anunt
Contradictory financial proposal instructions	Contradictie cerinte prezentare oferta financiara
Contradictory technical requirements	Contradictie in cerintele tehnice
Unclear duration	Durate neclare
Inattention to details	Eroare de neatentie
Incorrect offer submission forms provided	Formulare incorecte
Absence of financial information	Informatie financiara lipsa
Unclear financial information	Informatie financiara neclara
Unapplicable information	Informatie neaplicabila
Incorrect technical information	Informatie tehnica incorecta
Absence of technical information	Informatie tehnica lipsa
Unclear technical information	Informatie tehnica neclara
Absence of site visit information	Informatii vizita amplasament lipsa
Modification of technical specification	Modificare specificatie tehnica
Process	Proces
One or more unclear contractual clauses	Neclaritati pe una sau mai multe prevederi contractuale

Table A4. Units of data for *Targeted tender section*.

English	Romanian
Technical requirements (including technical drawings, bills of quantities, technical sheets, technical descriptions)	Cerinte tehnice (incluzand desenele tehnice, liste de cantitati, fise tehnice, caiet de sarcini)
Contract	Contract
Submission forms	Formulare

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Article

The Cooperation Establishment Mechanism of EPC Project Consortium in Context of China: Form the Perspective of Trust

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Abstract: The purpose of this paper is to explore the establishment mechanism of an EPC consortium from the perspective of trust. Questionnaire surveys were undertaken to collect data from the experienced project managers of a design company group and a construction contractor group. Structural equation modeling was used to test the hypotheses in this research. The results reveal that reputation and communication are important factors in the generation of trust (including calculative trust and relational trust) from the design company perspective. Meanwhile, reputation, reciprocity and communication are important factors for the generation of trust from the construction company perspective. Both calculative trust and relational trust are positive factors that affect the intent of both the design company and the construction contractor to cooperate. This research has innovatively added to and contributed to the existing knowledge of EPC consortium establishment mechanisms.

Keywords: engineering; procurement and construction; project consortium; trust; intention to cooperate

1. Introduction

The construction industry is moving towards becoming highly integrated, modernizing through a professional division of labor [1]. This modern integration is different from the original forms of integration. For example, in the past, the contractor did both design and construction work. Modern integration is a re-integration, based on the professional division of labor. Under this background, the engineering, procurement and construction (EPC) mode is greatly advocated and promoted, both at home and abroad [2]. In 2019, the Ministry of Housing and Urban-Rural Development of China issued "Measures for the administration of general contracting of housing construction and municipal infrastructure projects" [3]. This new policy pushed the EPC mode into a new historical development stage in China.

An EPC project is a complex process involving a set of products (materials, equipment), services, and construction tasks. Each element is specifically designed to complete a particular output for a customer within a certain period of time: a building, a power plant, a turnkey factory, or something similar [4]. The EPC mode has been increasingly adopted in projects, because of its high efficiency in terms of simultaneously integrating diverse design, procurement, and construction processes. However, only a limited number of companies are competent enough to fulfill the relevant EPC tasks by relying only on their own capacities [5]. In addition, a great number of EPC contractors—called consortiums—are being set up by design companies and construction companies. For example, in 2020, 69% of EPC project contractors involved in Shenzhen government investment projects were in consortiums [6]. A consortium generally has two forms: being led by design companies or being led by construction contractors.

In studies of EPC consortiums, much of the existing research focuses on the distribution of benefits [7], risks [8], performance evaluation [9], and risk management [10]. However, to date, very little research has examined how to establish a consortium relationship. In addition, the difference between the establishment of an EPC consortium led by a

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design company, as opposed to one led by a construction contractor, is also a research area blind spot. Trust is indispensable for the establishment of a cooperative relationship in a consortium. There are two research questions needed to be resolved. The first question is that, how can trust be established in the process of setting up a consortium constituted by a design company and construction contractor. The second question is what impact will that trust have on the intent to establish consortium cooperation. The purpose of this study is to resolve the above research questions.

2. Literature Review

2.1. EPC in China

2.1.1. EPC Development History in China

Policies and laws have played a very important role in guiding the development of EPC projects in China. The following subsection describes the development history of EPC projects in China, mainly from the perspective of relevant policies and laws.

- Introduction period (1984–2001)

In 1984, the State Council of China promulgated the "Interim Provisions on Several Issues Concerning the Reform of the Construction Industry and Major Construction Management System". This policy referred to the EPC mode for the first time, opening the way for EPC practice in China [11]. In 1987, the National Development and Reform Commission issued a document requiring the promotion of Lubuge project management experience. This signaled the beginning of learning the classic case of the EPC mode [12]. In 1997, the Construction Law of China clearly stipulated that the implementation of EPC was being advocated, thus strengthening the promotion of the EPC mode [13].

- Pilot promotion period (2002–2008)

In 2003, the Ministry of Construction of China promulgated its opinions on cultivating and developing EPC and project management enterprises. The ministry clearly stipulated that general contracting includes both EPC and DB (design and build) [14]. In 2007, the Ministry of Construction issued "The measures for general contracting of railway construction projects". The aim of this policy was to popularize the general contracting mode in railway construction [15]. The EPC mode has been extended from the initial petroleum and chemical field to now encompassing highway, railway, water conservancy, electric power and other fields.

- Adjustment period (2009–2013)

Affected by the financial storm triggered in part by the 2008 global economic crisis in 2008, China's construction industry continued to be depressed for several years. During this period, the heat behind the EPC trend decreased greatly. However, the model text of EPC contracts for construction projects (for trial implementation) and the standard EPC bidding documents had been successively issued. These contracts and documents determine the preliminary specifications for EPC contract and bidding behavior in China [16].

- Acceleration period (2014–present)

Since 2014, accelerating general contracting (as represented by EPC) has become a top priority in the reform of China's construction industry. In 2016, the Ministry of Housing and Construction issued several opinions that further promote the development of EPC. The ministry stressed that general contracting should be actively adopted in projects in which the government has invested. Also, those involved in the construction of prefabricated buildings, and project owners should be encouraged to give priority to the EPC mode of construction [17]. In 2017, the State Council issued its opinions on promoting the healthy development of the construction industry, and proposed accelerating the implementation of the general contracting of projects [18]. The general contracting management specification for construction projects was officially implemented in 2018. In 2020, the general contracting management measures for housing construction and municipal infrastructure projects were formally implemented. The EPC mode is developing rapidly due to the government's encouraging policies [19].

2.1.2. EPC Application

- Overall Performance

The use of the EPC method is accelerating but has not yet been fully rolled out. According to public data from the Ministry of Construction, EPC projects in China's construction industry show a trend of rapid increase in business volume and continuous expansion of project scale. In 2018, the output value of the construction industry was 27 trillion RMB, and the general contracting income was about 2.7 trillion RMB, accounting for only 10% of the total [12]. As can be seen, therefore, the promotion of the EPC mode in China is effective, but its use still faces significant challenges.

At present, two directions, namely design-led and construction-led have been formed in terms of EPC practice. Taking design as the leading direction clearly puts forward that EPC practice takes the designer as the leader, thereby giving full play to the leading role of design. Conversely, taking construction as the leading direction is the choice of most construction enterprises. In practice, there are currently more EPC projects led by construction enterprises than by design companies [20,21].

- EPC application scope

The "General Contracting Management Measures for Housing Construction and Municipal Infrastructure Projects" policy stipulates that projects in which the government has invested and projects controlled or dominated by state-owned funds must give priority to EPC. Projects using BIM technology must actively adopt EPC, and prefabricated building manufacturers shall adopt EPC in principle [22].

The time points of EPC contractors' involvement in the project vary in different parts of China. Generally, however, the owner can only contract the EPC project after the project scope, construction scale, construction standards, functional requirements, investment quota, project quality and progress requirements are determined [12,23]. As shown in Figure 1 below, the owners generally complete the project proposal and feasibility study before contracting out the work.

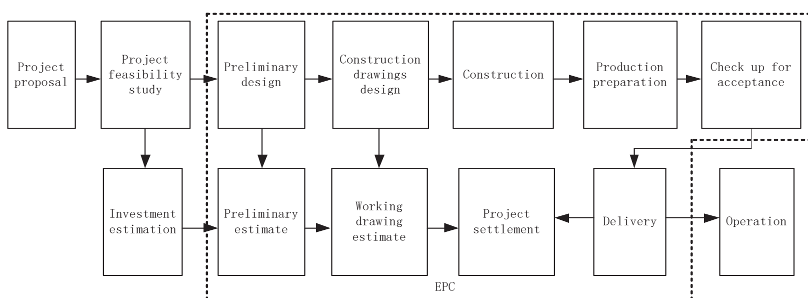

Figure 1. Project phases relevant to EPC.

Policies and laws have played a very important role in guiding the development of EPC projects in China. The following subsection describes the development history of EPC projects in China, mainly from the perspective of relevant policies and laws.

2.1.3. Consortium Application

Few enterprises in the market can have adequate design and construction capabilities at the same time. Therefore, the consortium mode accounts for a high proportion of EPC projects [24]. At the national level, taking design as the leader and implementing the architect responsibility system has been advocated. However, in reality, not many projects are actually being led by design; such projects that are led by design are mainly concentrated in petrochemical projects. In housing and municipal projects, the EPC projects led by the construction companies are in the majority.

In addition, as a consortium is a temporary and one-time organization, which is not conducive to the accumulation of project experience, and because there are inevitably disputes over risk sharing and profit distribution, some local governments do not advocate the consortium mode [12,25].

2.2. *Trust Theory*

Trust research is approaching maturity, as shown in Figure 2 below, which itself is the basic framework of trust theory.

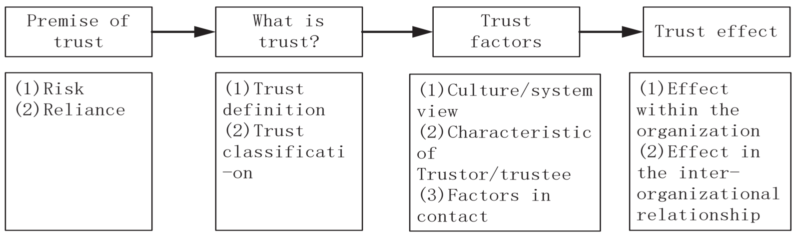

Figure 2. Framework of trust theory.

2.2.1. Premise of Trust

Risk and dependence are generally recognized as the premise of trust [26]. Where there is no risk, there is likewise no need to trust others. When the result of something is certain, there is no need to generate trust. In many definitions, trust is regarded as a psychological state under risk conditions [26,27]. Some studies even regard trust as a behavioral risk-taking act [28,29]. In short, risk is one of the preconditions of trust.

In addition, one must rely on others to have the need for trust. If something is risky, but you can deal with it yourself and you don't need to rely on others, there's also no need to trust others. When there is nothing you can do to deal with things, you must trust others. It is reasonable to believe that the higher the degree of dependence is, the higher will be the degree of trust. Indeed, some studies have measured trust through dependence [30].

Trust only exists when risk and dependence both exist at the same time. However, it must be noted that dependence means letting go. That is, as the turstor, has no competence or opportunity to exert control on the trustee. However, in reality, trust and control often coexist, but to different degrees [31].

2.2.2. Connotation of Trust

After clarifying the premise of trust, the connotation of trust actually becomes clear. There are many definitions of trust, involving many different fields, such as economics and management; the definitions are quite similar. Rousseau et al. [26] put forward an authoritative definition. That study maintained that trust is a psychological state comprised of the intention of one person to accept vulnerability based upon positive expectations of the intentions or behavior of another. However, the composition of trust (i.e. the fundamental elements of trust's definition) are comparable across research and theory. Definitions of trust focus on parties both inside and outside firms, and studies have investigated trust relations from different disciplinary advantage points. As Table 1 shows, there are different types of trust.

Table 1. Types of trust (adapted form [32]).

Scholars	Type of Trust
Rousseau et al. [26]	Calculative; relational; institutional
Williamson [33]	Calculative; personal; institutional
Shapiro et al. [34]	Knowledge-based; identification-based; deterrence-based
Lewis and Weigert [35]	Cognition-based; affect-based
Lewicki and Bunker [36]	Economy-based; knowledge-based; identification-based
Sako [37]	Competence-based; goodwill-based; contractually-based
Hartman [38]	Competence based; integrity-based; intuitive-based
Cheung et al. [39]	Cognition-based; affect-based; system-based

In fact, all these types of trust are universally aligned with the classification developed by Rousseau et al. [26]. That study classified trust into calculative, relational, and institutional trust, forming the basis of subsequent research.

Calculative trust is based on rational calculations and is derived from credible information or competence obtained through certification or reputation [32]. Calculative trust is fragile, as it is limited to discrete exchanges reinforced by the existence of deterrents [26]. In construction projects, contractors are generally trusted because of their certifications, which indicate the contractors' competency. Relational trust is emotional and based on information acquired through long-term and frequent communication. The essence of relational trust is a kind of relational exchange; that is, the two sides have relationships with each other [40], such as feelings and family affection. Relational trust is different from calculative trust. Relational trust is both long-term and sustainable. Calculative trust will terminate once the interests of either party are damaged. Institutional trust is the trust of the two parties involved in the social system, law, or the culture of one of the parties that governs behavior and actions. Institutional trust can help to facilitate either calculative or relational trust [26]. There is no doubt that institutional trust can be used as the basic trust of any given society, which in turn is conducive to the establishment of both calculative and relational trust. However, in Chinese society and culture, the awareness of the system is weak, and the system is often unstable, frequently changing with people and things change [41]. Trust is more so built on relation sanctions [42]. Consequently, institutional trust is not concerned and discussed in this paper. Rather, the role of calculative trust and relational trust will be discussed in further detail.

2.2.3. The Antecedent of Trust

There are many factors required to generate trust. From a systematic point of view, there are mainly three aspects, namely (1) the characteristics of the trustee and trustor, (2) bilateral relationships, and (3) environmental factors. In many studies, both the characteristics of the trustor and environmental factors (such as the degree of social legalization and social moral level) are regarded as the control variables [43]. In this study, the researcher also agrees with this approach and will no longer consider the characteristics of the trustor and environmental factors; the antecedents of trust in construction inter-organizations are shown in Table 2.

Table 2. The antecedents of trust in construction inter-organizations (adapted from [43]).

Types	Antecedents of Trust	Reference
The characteristic of trustees	Commitment, risk-taking, knowledge, honesty and benevolence	Cheung et al. [44]
	Results, integrity and concern	Wong and Skitmore [45]
	Reliable behavior, communication skills, sincerity, showing commitment, benevolence and competence, showing and acting with integrity, working toward reaching project milestones	Karlsen [46]
	Accomplished results, integrity between words and behavior, and the showing of care	Shaw [47]; Wong and Skitmore [45]
	Goodwill, commitment, and "sacrificing behavior"	Wood and McDermott [48]
	Sacrificing behavior, problem solving, and reputation	Wood and McDermott [48]
	Reputation, competency, and integrity	Jiang et al. [43]
The characteristic of the relationship between trustors and trustees	Communication	Karlsen [46]; Wood et al. [49]
	Communication and long-term relationship	Wood and McDermott [48]
	Establishing common goals	Karlsen [46]
	Past experience, problem resolving, shared goals, and reciprocity	Khalfan et al. [50]; Wood and McDermott [48]
	The contract	Jannadia et al. [51]; Thompson and Anderson [52]
	Contract, communication, and reciprocity	Jiang et al. [43]

In terms of trustees' characteristics, many factors may induce people to trust the trustors, including commitment, risk-taking, knowledge, honesty, benevolence, integrity, concern, reputation, competency and so on [44–47,49]. Reputation always be seen as the reflection of past performance and historical records [48], and is cumulative. Similarly, competency is also cumulative, and the the competency of one party may not be largely improved at one time [43,46]. Integrity reflects the behavioral characteristics of the trading party [46]. While a deceptive party's words and deeds can pretended to be temporary, they always show the true face in when key interest arise. Therefore, the characteristics of the trustee basically represent the static factors, with no significant changes during the whole project life cycle [32].

The relationship between the two parties is dynamic, whereby the process and results of communication are constantly changing [46,49]. Reciprocity is also dynamic. Perhaps, at a given time, one party's sacrifice for the other party is returned in a timely manner with gratitude and the reciprocity is strong [48]. The same is true for contracts, people like contracts with clear terms. However, contracts that have been signed can be changed with project progress [43,51]. Therefore, the characteristics of the relationship between the two parties represent dynamic factors, which are constantly changing throughout the whole project life [32].

This paper studies trust building between design companies and contractors in constituting consortiums in EPC projects. The factors of competency and contract are not selected in this study as the factors that affect the cooperation between the two sides. This is because the contract has not been signed, and the design company and the contractor have not worked together in the past. Moreover, as the embodiment of past performance, reputation has already reflected the ability of the companies. Generally speaking, those with strong ability will have a good reputation [52]. In addition, the communication that occurs before determining the cooperative relationship between the two sides also plays a very important role in the establishment of trust. Only after sufficient communication and understanding can trust be generated [53]. Finally, reciprocity is also an important factor in the building of trust between EPC consortium members. In addition, communication, mutual assistance and mutual benefit are undoubtedly conducive to the establishment of trust. Therefore, this paper selects reputation, communication and reciprocity as the antecedents of trust.

2.2.4. Effects of Trust

Although different disciplines have different perspectives with regard to the role of trust, the positive role of trust is universally recognized. Sociologists understand trust to be a simplified social mechanism [54,55]. Economists believe that trust can reduce costs and opportunistic behavior [33]. Management experts believe that trust can reduce organizational conflict and improve team and organizational performance [28,40].

Previous research on the role of trust in construction projects is mostly empirically-based. Jiang et al. [43] demonstrated the role of trust in project success in China. Pinto et al. [56] demonstrated the role of trust in large-scale construction projects in Canada. The results show that trust has different meanings for the owner and the contractor. For the owner, trust based on integrity and trust based on ability are both important factors for establishing a healthy relationship between both parties. However, only trust based on integrity is believed to have an important and direct impact on project success. For the contractor, trust based on integrity is the only important determinant of the relationship between the two parties. Lau and Rowlinson [57] believed that trust can reduce claims, save time and cost, and improve project quality. The role of trust in existing research is mostly concerned with the cooperative relations that have been established. How trust can help the establishment of cooperative relationships is still under discussion, and there is a lack of empirical research related to this question.

2.3. Cooperation Theory

This is an era in which competition and cooperation coexist. It is not easy to reach a state of cooperation. Conditions of cooperation include: (1) one party relies on the other [58]. In this regard, trust and cooperation are similar. (2) The interests of each party will not be harmed by the other [59]. Transaction cost theory, game theory and strategic alliance theory can all explain the existence of cooperation.

From the perspective of transaction cost theory, when the outsourcing cost is higher than a party's own production cost, internal vertical production is adopted. If the production cost is higher than the market price, the cooperation method is adopted [33]. From the perspective of game theory, in a temporary cooperation, opportunistic behavior opportunities may appear. However, multiple cooperation or even long-term cooperation is in place, an equilibrium solution will exist, and mutual cooperation will benefit both parties [60]. The strategic alliance theory is actually an extension of game theory. That is, many companies establish long-term cooperative relationships to protect the interests of all parties. In the construction field, due to the one-time nature of construction projects and the diversity of project characteristics, there are few long-term cooperative relationships. Rather, most of the relationships are one-time in nature.

The development history of EPC in China is not long. At present, very few enterprises can independently undertake EPC projects [61]. It is common to undertake EPC projects in the form of a consortium [7]. How to establish a consortium between design and construction units is a research gap worthy of discussion and a problem that has not yet been solved. This paper will discuss the generation of trust in the process of consortium establishment, as well as the impact of trust on the cooperation intention from the perspectives of design companies and construction contractors. The research results will be beneficial to the smooth building of EPC consortiums and the rapid promotion of EPC projects in China's construction industry. In addition, this study will theoretically enrich the existing research on trust in the construction industry and help to understand the differences between trust mechanisms in different cooperative relationships (such as owners and contractors, and design companies and construction contractors).

3. Research Hypotheses

3.1. Antecedents of Trust and the Creation of Trust

3.1.1. Reputation and Trust

Reputation is defined as the impression a person makes on others because of his or her characteristics and trade behavior [43]. Reputation is also closely related to time and is an intangible asset formed over the long-term accumulation of experiences [62]. In the field of economics, those with good reputations can make credit loans. In inter-organizational cooperation, there is reason to believe that reputation plays a positive role in trust. Many studies have confirmed the positive correlation between reputation and trust [63,64]. For a trustor, the reputation of the trustee is seen as reliability, and there will be a reliable guarantee of the trustor's cooperation [65]. The trustee is also willing to communicate with the trustor and maintain a long-term cooperative relationship [66]. In view of the above discussion, we assume the following:

H1a. *The better the reputation a trustee has, the more calculative trust the trustee will receive from a trustor.*

H1b. *The better the reputation a trustee has, the more relational trust the trustee will receive from a trustor.*

3.1.2. Communication and Trust

Communication is another important factor in building trust [43]. Karlsen [46] stated that project communication skills play an important role in developing stakeholders' trust. Good communication can promote both parties' full understanding. High-quality communication can also easily enhance understanding and feelings, which are conducive to increasing calculative trust and relational trust, respectively. In addition, good communication delivers accurate and timely information, allowing the two parties to understand each other's requirements. Simply put, good communication promotes the building of trust [43]. Poor communication not only leads to information blockage and untimely information transmission, but to suspicion between both parties. As such, poor communication has a bad impact on trust. As an extreme example, trust quickly disappears and cannot be recovered when one party lies. However, research has found that poor communication can lead to the breakdown of all four major trust issues: circumstances beyond control, understanding that mistakes can happen, fair representation, and fixing problems [50]. Therefore, it is reasonable to put forward the hypotheses concerning the relationship between communication and trust as follows:

H1c. *The better the communication is, the more calculative trust a trustee will receive from a trustor.*

H1d. *The better the communication is, the more relational trust a trustee will receive from a trustor.*

3.1.3. Reciprocity and Trust

Reciprocity means that, when one party makes contributions to the other party, the other party should return the gesture. That is, the recipient of the initial contribution should also take an action that is beneficial to the other party [67]. Reciprocity has been widely studied in game theory. The basic view of game theory is that, when one party makes a contribution to another party, the second party will not necessarily make a corresponding contribution. Rather, that second party will weigh its own interests. Only when an action is beneficial to itself will the second party make the response expected by the first party [68]. However, if one party cannot get the corresponding expected response, the cooperative relationship may not last for long. Other studies have shown that people do tend to take responsive actions, even if those actions are contrary to their own interests [69,70]. Therefore, when deciding whether to trust the other party, one party must consider the reciprocity between the two parties; that is, whether the other party is willing to return contributory gestures. Research has shown that organizations (or individuals) tend to trust organizations (or individuals) who respect and return trust [71–73].

In the EPC consortium covered in this study, it is obvious that the two parties use each other's advantages equally, in order to satisfy their own interests [9]. The design company and the construction contractor jointly signed a contract with the owner as a whole. The two sides already have a closer relationship than the traditional project management mode [24]. In this relationship, both parties will need to face various uncertainties related to the project. When unforeseen circumstances arise, reciprocity must play a role in resolving problems. For example, when an unforeseen problem occurs, that problem needs to be solved through consultation between the design company and the construction contractor. The design scheme may need to be changed, or, conversely, the construction scheme may need to be changed. Therefore, the hypotheses are put forward as follows:

H1e. *The more reciprocity there is, the more calculative trust a trustee will receive from a trustor.*

H1f. *The more reciprocity there is, the more relational trust a trustee will receive from a trustor.*

3.2. Trust and Cooperation Intention

Many studies have explored the relationship between trust and cooperation. The main point of these studies is that trust is conducive to promoting cooperation [9,31,43,74]. As mentioned earlier, trust and cooperation have a common premise; that is, one party needs to rely on others to accomplish what they want to do. Trust is actually the result of a series of screenings. It has been said that, when a person is trusted, it means that person is reliable and capable. Therefore, one can cooperate with this person. Mashima [74] found that trust plays a signaling role in promoting mutual cooperation, even in relationships with unfixed or temporary partners.

In the studied EPC consortium, the design company and construction contractor are generally familiar with each other from prior contacts [9]. The design company contacts the contractor, or the construction contractor contacts the design company; this is a kind of trust behavior. Of course, the design company or construction contractor may also contact several other units at the same time, for investigation purposes [10]. The decision to choose which unit to cooperate with is made after comprehensive consideration of various factors. However, one thing that is certain is that only when one party has enough trust will that party finally decide to cooperate with the other unit. Therefore, the hypotheses are as put forward as follows:

H2a. *The more calculative trust there is, the more cooperation intention a trustee will receive from a trustor.*

H2b. *The more relational trust there is, the more cooperation intention a trustee will receive from a trustor.*

4. Research Methodology

The survey method was adopted to test the hypotheses proposed in this research. The survey method generally contains three stages, namely questionnaire design, sampling, data collection and model validation [43].

4.1. Questionnaire Design

The measures used in this study were first obtained from a literature review. The measures were modified after the project review. As a considerable part of the original questionnaire was written in English, we translated the questionnaire into Chinese and then translated Chinese back to English for comparison purposes, in order to ensure the accuracy of the translation. In addition, project management experts were hired to propose modifications to the Chinese version of the questionnaire and to better adapt to the Chinese situation.

A pilot test was conducted to validate the measures [75]. A total of 115 questionnaires were sent to the project managers of design companies and construction companies, all of whom were representatives in the setting up of EPC consortiums. A total of 66 completed questionnaires were returned, and the author conducted a preliminary data analysis to determine the reliability. We then modified the questionnaire to improve the reliability. Eventually, a questionnaire that could be used for sampling was created, as shown in Table 3. The questionnaire used a 5-point Likert scale, ranging from "1" for "strongly disagree" to "5" for "strongly agree. The responses therefore indicated the extent of the agreement of the respondents.

Table 3. Questionnaire: Construct, description and references(Adapted from [39]).

Construct	Description	Reference
Reputation	The other party has a reputation for being honest (REP1). The other party is known to care about others' interests (REP2). The other party is considered in the industry to be fair (REP3).	Jiang et al. [43]
Communication	Two parties communicate with high frequency and good effect (COM1). Two parties efficiently and adequately share information (COM2). Two parties communicate in a timely manner (COM3). The information exchanged in communication is accurate (COM4). Conflicts can be resolved through communication (COM5).	Jiang et al. [43]; Wood et al. [49]; Wong and Chen [76]
Reciprocity	When dealing with uncertainty, the other party will consider our interests (REC1). The other party would provide help when we face problems (REC2). The other party would return the favor to us when we provide the help (REC3). When we make sacrifices for the project, the other party will also make similar sacrifices (REC4).	Jiang et al. [43]
Calculative trust	We are sure that the party has the ability to effectively perform the work (CAL1).	Jiang and Lu [31]; Lui and Ngo [77]
	We believe that project staff members of the party are competent (CAL2).	
	Given the previous track record of the other party, we see no reason to doubt the competency and preparation for this project (CAL3).	
Relational trust	We believe that the other party will make good on their promises during the project's execution (REL1).	Jiang and Lu [31]; McAllister [40]; Lui and Ngo [77]
	We believe that the other party will follow moral standards during the project's execution (REL2).	
	We believe that the other party can be trusted (REL3).	
	We believe that the other party is fair (REL4).	
	We believe that the other party will take us into consideration during the project's execution (REL5).	
	We believe that the other party will not exploit us to maximize profits (REL6).	
	We believe that the other party is professional and dedicated to the project (REL7).	
Intention to cooperate	In order to establish a cooperative relationship, we are willing to give some preferential terms (INT1).	Jiang and Zhao [32]
	We are willing to invest resources in this cooperation (INT2).	
	We hope to maintain long-term cooperation with the other partner (INT3).	

4.2. Sampling and Data Collection

The research survey was carried out in 2020, in Shenzhen and Guangzhou. These are highly-developed cities with relatively more EPC projects than other cities. Questionnaires were sent to the design institute and the construction contractor, respectively. Since a consortium is generally established by the project manager of the lead unit before project bidding, the questionnaire was sent to the project manager of both the design unit and the contractor. Questionnaires were sent to the design companies and the construction contractors, respectively. Of the 320 questionnaires mailed out to the design companies, 221 usable questionnaires were received back. That total represented a 69.06 percent response rate, which is a little lower than that of the construction contractors group. The response rates of Shenzhen and Guangzhou were both more than 40 percent of the completed questionnaires. See Table 4 for details of the response rate.

Table 4. Questionnaire response rate.

Group	City	Number of Questionnaires Received	Response: Total Questionnaires Sent (%)	Response: Total Questionnaires Received (%)
Design companies group	Shengzhen	112	35.00	50.68
	Guangzhou	109	34.06	49.32
	Total	221	69.06	100.00
Construction contractors group	Shengzhen	123	38.44	52.12
	Guangzhou	113	35.31	47.88
	Total	236	73.75	100.00

4.3. Model Validation

For model validation, a series of analyses were used to test the reliability and validity of the constructs. By following the research of Jiang and Lu [31], an exploratory factor analysis (EFA) was utilized to test the unidimensionality of the constructs; Cronbach's α was employed to assess the reliability [78].

The EFA was used with a principal component analysis to analyze the data; SPSS 26 was also used. Moreover, varimax rotation with Kaiser normalization was used for each factor [79]. Cronbach's α was then used to test the internal consistency of the constructs. All of the measurements had strong loadings on the constructs. All of the Cronbach's α values were above the threshold value (0.7) suggested by Sharma [80], as shown in Table 5. Therefore, the constructs' unidimensionality and reliability were confirmed.

Table 5. Measurement validity assessment.

Construct	Cronbach's α (Design Companies/Construction Contractors)	CR (Design Companies/Construction Contractors)	AVE (Design Companies/Construction Contractors)
Reputation	0.85/0.84	0.85/0.84	0.65/0.59
Communication	0.82/0.80	0.82/0.80	0.55/056
Reciprocity	0.83/0.84	0.83/0.84	0.58/0.55
Calculative trust	0.82/0.80	0.82/0.80	0.71/0.69
Relational trust	0.81/0.82	0.81/0.82	0.52/0.51
Intention to cooperate	0.85/0.86	0.85/0.86	0.69/0.64

Then, AMOS software was used for the confirmatory factor analysis, in order to test the model. For the design companies group, model fit indices were derived from $\chi^2/df = 1.87$, root mean square error of approximation (RMSEA) = 0.05, incremental fit index (IFI) = 0.970, comparative fix index (CFI) = 0.970, and goodness of fit index (GFI) = 0.905, indicating an adequate fit of the model to the data [81]. The result for the construction contractors also demonstrated the good fit of the model.

The average variance exacted (AVE) was calculated for each construct to assess convergent validity; construct reliability (CR) was calculated to assess discriminant validity [82]. If the CR value is above 0.6, and AVE > 0.5, then the AVE and CR values of the constructs are all above the thresholds. The result is shown in Table 5.

Structural equation modeling (SEM) was used to assess the causal relationships among the constructs. The model fit indices are shown in Table 6. For the design company group, although the model fitting index is good, the path coefficients from reciprocity to calculative trust and relational trust are not significant. After the paths were deleted by modifying the model, the fitting index of the model improved. Therefore, we have reason to believe that the revised model is accurate. For the construction contractors group, the model fitting index is good, and the path coefficients are significant. The final SEM models for the design company and construction contractor are shown in Figures 3 and 4, respectively.

Table 6. Results of the original model and the revised model.

Relationship among Variables	Hypothesis	Original Model		Revised Model
		Design Company's Response	Contractor's Response	Design Company's Response
Independent variables' impact on intermediate variables	H1a	0.301 *	0.255 *	0.302 *
	H1b	0.211 *	0.200 *	0.210 *
	H1c	0.148 *	0.188 *	0.150 *
	H1d	0.150 *	0.148 *	0.165 *
	H1e	0.007	0.112 *	N/A
	H1f	0.007	0.108 *	N/A
Impact of intermediate variables on dependent variables	H2a	0.304 *	0.311 *	0.310 *
	H2b	0.406 *	0.389 *	0.411 *
Goodness of fit indexes	Chi-square	1.870	1.901	1.852
	RMSEA	0.050	0.052	0.049
	IFI	0.970	0.955	0.975
	CFI	0.970	0.955	0.975
	GFI	0.905	0.900	0.911

* Significance level is less than 0.05.

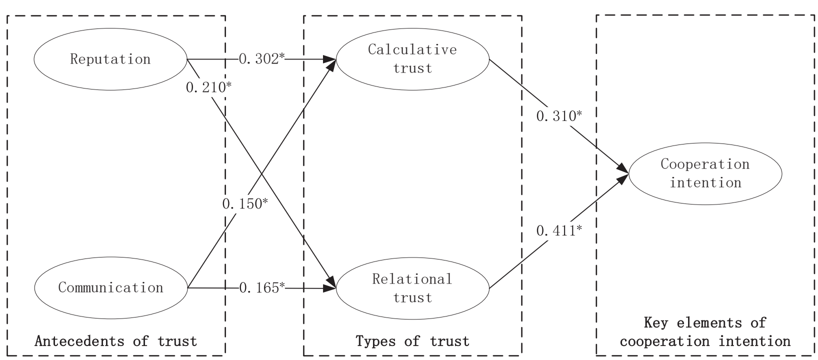

Figure 3. Final SEM model for design company's perception of the trust relationship. * Significance level is less than 0.05.

Figures 3 and 4 show that reputation has a positive impact on both calculative trust and relational trust. One can infer from this finding that, for both design companies and construction contractors, when one party has a good reputation, the other party will generate high calculative trust and relational trust. Thus, H1a and H1b are supported. The path coefficients of Figures 3 and 4 also reveal that communication has a positive impact on both calculative trust and relational trust, thus supporting H1c and H1d. This further indicates that, when communication is abundant and effective, calculative trust and relational trust will be either generated or increased. However, for the design company group, Figure 3 reveals that there are no significant coefficients for the paths from reciprocity to calculative trust and relational trust. Therefore, for the design companies group, H1e and H1f are not supported. For the construction contractor group, Figure 4 shows that reciprocity has a positive impact on both calculative trust and relational trust, thus supporting H1e and H1f. Moreover, Figures 3 and 4 show that both calculative trust and relational trust have a positive impact on cooperation intention, thus supporting H2a and H2b.

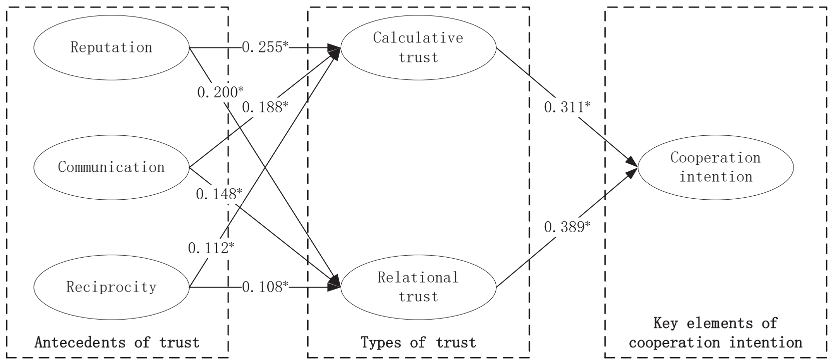

Figure 4. Final SEM model for construction contractor's perception of the trust relationship. * Significance level is less than 0.05.

5. Discussion

5.1. Reputation and Trust

The positive effect of reputation on trust is proved in this study. However, for the design companies and the construction contractors, differences in trust exist. Design companies seem to prefer to use the reputation mechanism to choose cooperation partners, because for the design companies, reputation has a greater influence coefficient on calculative trust and relational trust. This finding is basically consistent with the conclusions of existing research on EPC consortiums. In the studied EPC consortium, the design company and the construction contractor are considered to have information asymmetry [83]. Specifically, the design company may not know much about construction procedures and construction technology. In contrast, the construction contractor knows relatively much more about the construction process [84]. Therefore, the design company relies more on the reputation mechanism to select the construction contractor as a partner.

In addition, reputation has different effects on calculative trust and relational trust. Reputation, as is well understood, has a greater impact on calculative trust. When cooperating with reputable companies, our rights and interests are highly protected. Reputation is an asset that is accumulated over the long-term [31]. A reputable company rarely takes opportunistic actions that may destroy its reputation [85]. The design companies and construction contractors interviewed for this study said that, in the construction field, reputation is very important for attracting business. Design companies must provide high-quality designs to maintain their reputations, while the construction contractor must ensure the construction quality, resources, and progress of the project to maintain its reputation.

5.2. Communication and Trust

The positive effect of communication on trust is confirmed in this study. The empirical results of this study clearly show that communication is one of the most important means to generate trust, both for the design company and the construction contractor. In the course of communications, one party will come to understand more about the other partner, generating an "echo in the hearts" of the partners. Eventually, trust between the two partners will be generated through clear and effective communication [43,86].

In project reviews, project managers from the design companies and construction contractors both recognize the important role of communication in trust. The project manager of one design company admitted that, "when we build a consortium with the construction contractor, we mainly know each other and our internal members through meetings, emails and private conversations". Whether or not communication is sufficient is one of the important bases upon which cooperative decisions can be made. The project manager of a construction contractor said that an EPC project requires both parties of the consortium to give full play to their strengths and advantages. Each hopes to understand the other in the communication process, and each must put forward his own views and requirements. Communication is conducive to promoting mutual understanding, enhancing feelings and quickly reaching a cooperation scheme, all of which is conducive to the generation of trust.

5.3. Reciprocity and Trust

The positive relationship between reciprocity and trust is testified to in the construction contractor group, but not in the design company group. Why reciprocity does not play an important role in trust generation for the design company is a question that deserves to be explored. After several project reviews, the main reason was found. The design comes first, and the construction follows behind. The design company does not have the benefit of relying on the work already performed by the construction contractor. However, for the construction contractor, in the project cooperation, a large number of design changes must be completed by the design company, in some cases even before the construction work has commenced. Therefore, the construction contractor pays more attention to the reciprocity of the design company. Just as one design manager said, "We mainly complete the design, (but) we have not so much to cooperate with the contractor on in the project construction phase".

However, the construction contractor group is completely different from the design company group. The positive relationship of reciprocity and trust is confirmed in the contractor group. Jiang et al. [43] also confirmed that, in the relationship between the owner and the contractor, reciprocity will be conducive to the establishment of their mutual trust relationship. Moreover, by carefully analyzing the effect of reciprocity on trust, one can find that good interaction between the two partners will accelerate the development of trust, as shown in Figure 5 below. After Unit 1 makes a sacrifice, Unit 2 has a corresponding response. If Unit 1 accepts that response, the trust in Unit 2 will increase. After being trusted, Unit 2 will be more willing to make sacrifices. After an effective response, if Unit 1's work is recognized by Unit 2 and trust is obtained from Unit 2, then Unit 1 will continue to make sacrifices, thereby forming a virtuous circle. One contractor's project manager said that, "We attach great importance to the interaction between the design unit and us. A benign cooperative relationship will help us promote the progress of the project. During the design change phase of the project, we very much hope that the design unit will cooperate to provide design changes in time and provide effective guidance for construction".

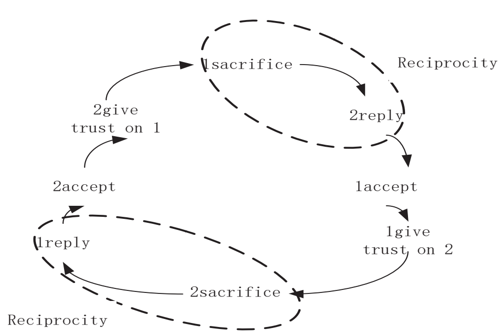

Figure 5. The relationship between reciprocity and trust.

5.4. Trust and the Intention to Cooperate

Although many factors affect the intention to cooperate, trust plays a vital role in cooperation. The positive effects of calculative trust and relational trust on the intention to cooperate have been confirmed in both design companies and construction contractors. Calculative trust is the result of calculation, which is based on future economic considerations and risk estimates [32]. In a sense, the higher the level of calculative trust is, the better the benefits of future cooperation will be. Therefore, calculative trust has a significant positive effect on the willingness to set up a consortium. As a project manager of a design company said, "When the contractor is competent and provides assurance against risks, we can dispel our worries about the future and tend to cooperate with the contractor." A project manager of a construction contractor said that, "As long as the future expectations of cooperation are positive and profitable, we are willing to cooperate with the design company to jointly complete the project."

Relational trust is the result of identification and affection [67]. When one internalizes the other's attitude (especially values), cooperation will be greatly facilitated [32]. China is a relational society, a feature which is particularly prominent in project cooperation [87]. Under certain circumstances, it is the relationship and not ability that determines whether a cooperative relationship can be established. Therefore, relational trust is more important under specific circumstances. During an interview, one design manager said that, when setting up an EPC consortium, he will consider whether the contractor can correspond with the design company. If the contractor can, this will significantly improve the efficiency of cooperation and improve both parties' ability to jointly deal with problems in the future. A project manager of the construction contractor said that they pay special attention to the relationship with the design company. The integration of design and construction requires good communication and a cooperation relationship with the design company.

6. Conclusions

Based on China's national conditions, this research explores the cooperation formation mechanism of EPC consortiums in the construction industry from the perspective of trust. Reputation and communication are found to be important factors in the generation of trust (including calculative trust and relational trust) from the design company perspective. Meanwhile, reputation, reciprocity and communication are important factors for the generation of trust from the construction company perspective. In addition, both calculative trust and relational trust are positive factors that affect the intention to cooperate for both the design company and the construction contractor.

This research has innovatively added to and contributed to the existing knowledge of EPC consortium establishment mechanisms, to a certain extent. Existing EPC consortium research focuses on benefit distribution, the integration of design and construction, cooperation risk, etc. However, no formal or systematic attention has been paid to how EPC consortium cooperation relationships can be established. This study establishes a theoretical model of the influencing factors of trust, as well as the effect of trust on the intention to cooperate in an EPC consortium. The results show that the establishment of an EPC consortium relationship is affected by the level of trust. In EPC theoretical research, adequate attention should be paid to trust; attention should also be paid to the theoretical research on trust cultivation. In particular, the difference in trust between the design company and the construction contractor provides a reference and inspiration for future research.

Moreover, this research also supplies guidance for design companies and construction contractors seeking to set up EPC consortiums. In China, a large number of projects are already using the EPC consortium mode. A practical problem is how to improve the quality of cooperation selection and how to establish a high-level benign relationship. This research can provide guidance to design companies and construction contractors on how to establish a good cooperative relationship. For the design company, when deciding whether to trust the construction contractor, the reputation of the contractor and the communication state will be the main considerations. For the construction contractor, the consideration of relevant information before cooperation commences is not only for the direct purpose of establishing cooperative relations, but also for the smooth sailing of good cooperation ventures in the future.

This research has several limitations that need to be addressed in future research. First of all, owing to the limitations of investigation conditions, the design company and the construction contractor cannot conduct a paired comparative analysis; neither can they get targeted and valuable suggestions on the relationship between the two sides. Secondly, the relevant conclusions come from the situation of China's construction industry, so these conclusions may only be applied to situations in China. Few enterprises in China have independent design, construction and management capacity and capability. Foreign countries, especially developed western countries, with their mature construction markets and large comprehensive groups, may not be suitable for the applications recommended in this study. Finally, the impact of trust in the cooperation selection stage on the success of the cooperation still needs relevant empirical research, in order to establish the connection between the two stages.

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Unpacking the "Black Box": Understanding the Effect of Strength of Ties on Inter-Team Conflict and Project Success in Megaprojects

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Abstract: Megaprojects have been redefined as dynamic collaboration networks, which are characterized by the strength of the ties between teams. In China, megaprojects have long been criticized for low productivity, poor project implementation processes, and inter-team confrontation. Few studies in the construction domain have explored the relationship between the strength of ties, inter-team conflict, and project success. This research aims to investigate the relationship between the strength of ties, inter-team conflict, and project success in megaprojects. Strong ties and weak ties reflect the strength of ties. Inter-team conflict is measured by task-related conflict and relationship-related conflict. A questionnaire survey was conducted on Chinese megaprojects, and 306 questionnaires were collected. The data were analyzed by a structural equation model. The results indicate that strong ties positively impact task-related conflict while negatively impacting relationship-related conflict. Weak ties positively impact inter-team conflict. Task-related conflict and relationship-related conflict have positive and negative effects on project success, respectively. The effect of the strength of the ties on a project's success is mediated by conflict. This study adds to existing research on the strength of ties and emphasizes the significance of megaproject network governance. The results reveal the constructive effects of the strength of ties and task-related conflict, as well as the non-constructive effects of relationship-related conflict. This provides a reference for megaproject managers to implement project governance.

Keywords: strength of ties; inter-team conflict; project success; megaprojects

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1. Introduction

Over the last two decades, with the rapid development of the world economy and the increase of global infrastructure investment, the number of megaprojects has increased dramatically [1]. According to existing studies, no less than US $50 trillion will be invested in megaprojects around the world between 2010 and 2030 [2,3]. Megaprojects involve more than US $1 bn in investments and have significant social, economic, and environmental impacts [4]. Typical megaprojects include airports, bridges, railways, tunnels, dams, hydropower plants, and Olympic venues [5]. Megaprojects involve a long construction period, a variety of technologies, and numerous participating teams (e.g., the owner team, the contractor team, the design team, the supervision team, and the consulting team) [6]. The participating teams of megaprojects have various disciplinary backgrounds and capabilities. No single team possesses all of the knowledge and capabilities required to complete a megaproject [2]. As a result, to achieve the successful delivery of megaprojects, different teams establish cooperative ties and form a large cooperative network (i.e., a megaproject network) [7].

The megaproject network is critical to the implementation and delivery of megaprojects [2,7]. The tie between the nodes in the megaproject network is an important channel through which the team can obtain information, knowledge, and resources [8]. However, according to social capital theory, ties of varying strength (e.g., strong ties and weak ties) have varying effects on the team's acquisition of information, knowledge, and resources [9]. Strong ties in megaproject networks may help to promote communication and interaction between teams, improving the efficiency and effectiveness of inter-team cooperation [10]. Weak ties may bring non-redundant and diverse knowledge, information, and resources to the team, facilitating project task implementation [11]. As a result, in the context of megaproject networks, strong and weak ties may have an impact on project task implementation and project success.

Megaprojects are characterized by high complexity, changing environments, and incomplete contracts [4]. The participating teams of megaprojects have different professional knowledge, core capabilities, and interest demands [7]. Therefore, inter-team conflicts are frequently unavoidable. Failure to address or resolve conflicts on time may impede inter-team cooperation. This has a negative impact on project task completion and the realization of project objectives (i.e., quality, duration, and cost) and ultimately interferes with megaproject success [12]. To mitigate this negative impact, it is necessary to investigate the relationship between inter-team conflict and project success in the context of megaprojects. Furthermore, the strength of ties in a megaproject network may influence conflict and project success. Strong ties aid in the establishment of shared values and action norms, as well as high levels of trust and efficient communication [8]. This facilitates the exchange of information and knowledge between teams, increases task-related conflicts between teams, while decreasing relationship-related conflicts, and ultimately promotes project task implementation and project success [11].

The weak ties between teams in megaproject networks indicate that the teams are unfamiliar with each other [2]. This makes it difficult for teams to develop a high level of trust, as well as shared values and rules [7]. Furthermore, there is less interaction and communication between teams in weakly connected networks [8]. Miscommunication, tension, and hostility between teams are more likely in this situation [5]. This may increase inter-team relationship-related conflict and impede project task implementation and project success [13]. As a result, it is of great significance to investigate the influence of the strength of ties on inter-team conflict and project success in the context of megaprojects. Previous research has primarily focused on the impact of network positions and network structure characteristics on project performance in megaproject networks [2,7,9]. However, research on the impacting mechanism of the strength of ties on inter-team conflict and project success in megaproject networks is still limited. This research explores the impact of the strength of ties on inter-team conflict and project success. This research adds to existing research on the relationship between the strength of ties, conflict, and project success and emphasizes the importance of network governance. The research findings can help megaproject managers develop effective project management strategies from the standpoint of network and conflict, thereby promoting megaproject success.

2. Research Background

2.1. Strength of Ties

The strength of ties is an important network indicator that reflects the degree of connection between two network nodes [14,15]. Previous research found that: (1) the duration and frequency of the interaction between nodes reflect the strength of ties [16]; and (2) the interaction history and previous cooperation experience affect the strength of ties [17]. The strength of ties in the context of megaprojects is reflected by a "combination of the closeness of contact, frequency of interaction, level of input resources, and reciprocal services" [16]. The strength of ties is divided into two dimensions in this study, i.e., strong ties and weak ties [11]. Teams with strong ties have close emotional relationships, frequent interactions, and previous cooperative relationships. Weak ties reflect the teams' infrequent interaction and estrangement [14]. Teams in a strong-connected network are familiar with one another. This aids in the formation of shared values and rules, as well as the improvement of efficiency and effectiveness of team communication [2]. From the perspective of intimacy, strong ties facilitate the integration of information, knowledge, and resources. Weak ties are distinguished by a lack of prior collaboration and low trust [8]. Weak ties provide access to novel and non-repetitive information and knowledge by connecting otherwise disjointed nodes [7]. In general, strong ties aid in the establishment of common concepts, values, and norms, as well as the development of high-level trust and efficient communication between teams in the context of megaproject networks. Weak ties aid teams in acquiring diverse and non-repetitive information, knowledge, and resources.

2.2. Inter-Team Conflict

Inter-team conflict refers to incompatible states or confrontational behaviors between teams [18]. Megaprojects are complex, time-consuming, and fraught with risk [10]. Megaproject teams (e.g., the owner team, the contractor team, the design team, the consulting team, the supervision team, and the supplier team) have varying knowledge backgrounds and interest demands [2]. This frequently results in divergent interpretations of the project plan, disparities in project task priorities and implementation methods, and contradictions in project process arrangements, all of which lead to inter-team conflicts [7]. Furthermore, a one-time construction process, a constantly changing project environment, and unforeseeable difficulties can lead to inter-team conflicts [6]. There are two types of conflict in megaprojects: task-related conflict involving task implementation and relationship-related conflict involving emotion [19]. Task-related conflict is associated with rational behavior, whereas relationship-related conflict is associated with perceptual behavior [13]. These two types of inter-team conflicts are common during the implementation of megaprojects. Task-related conflict involves the team's differing perspectives, ideas, or judgments on project task implementation methods and solutions, as well as the team's disagreement on the project process arrangement (e.g., construction period, project plan, and resource allocation) [20]. Task-related conflict is concerned with what a task is and how it is accomplished. The relationship-related conflict reflects inter-team incompatibility and hostile behaviors [21].

2.3. Project Success

Scholars have shown a keen interest in the topic of project success over the last two decades [22,23]. Many studies have focused on the success criteria for megaprojects [13,24]. The "golden triangle" indicator system establishes key project success criteria: duration, cost, and quality [22,25]. As technology has rapidly developed, megaprojects have become increasingly complex, with longer duration, more dynamic environments, and wider social impacts [1,12]. As such, overemphasizing the "golden triangle" may lead to too much focus on short-term goals, rather than longer-term impacts [13]. As a result, researchers reassessed the success criteria for megaprojects. In addition to the "golden triangle", other factors are used to evaluate megaproject success [24,25]. Examples of hard factors are safety, resource utilization efficiency, and social impact. Examples of soft factors are trust, collaborative efficiency, and owner and user satisfaction. These factors highlight the multidimensional evaluation of success [22]. From a time perspective, megaproject success should be assessed over the long term [26,27]. From a stakeholder perspective, project success should be assessed from the perspective of the project participants, users, and the public [28]. This research divides the success criteria for megaprojects into two categories: soft factors and hard factors. Hard factors include quality, cost, duration, and safety. Soft factors include the growth of knowledge and experience, trust, satisfaction, and the intent of teams to collaborate in the future.

3. Theoretical Model and Hypotheses

3.1. Theoretical Model

The input/mediation/output model was used in this study to investigate the relationship between the strength of ties, inter-team conflict, and project success in the context of megaprojects [29]. According to the connotation of the strength of ties, conflict, and project success, as well as the characteristics of megaprojects, the theoretical model of this study (see Figure 1) has been established. First, the theoretical model proposes that strong ties positively impact task-related conflict while negatively impacting relationship-related conflict. Weak ties positively impact task-related conflict and relationship-related conflict. Second, the theoretical model proposes that both strong ties and weak ties have a positive impact on project success. Third, the theoretical model proposes that task-related conflict has a positive impact on project success, whereas relationship-related conflict has a negative impact on project success.

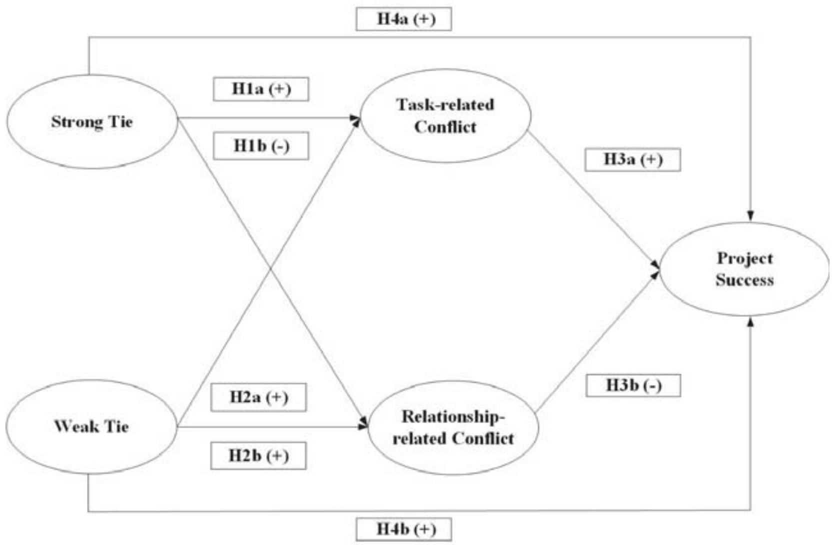

Figure 1. Theoretical model.

3.2. Research Hypotheses

3.2.1. Strong Ties and Inter-Team Conflict

Teams with prior cooperative relationships are more likely to establish strong relationships, i.e., strong ties [8]. Strong ties transform the megaproject network from a loose cooperative relationship network to a close cooperative relationship network with high-level communication [10]. There are more communication frequencies and interaction times between teams in a strong-connected network [30]. Because each team has different knowledge backgrounds, core competencies, and interest demands, it is easy for the team to have different perspectives, ideas, and judgments on the project's task implementation and project process arrangement during the interaction process, resulting in more task-related conflicts [2]. Megaproject networks with strong ties tend to produce shared norms [11]. This aids in the reduction of opportunistic behavior and inter-team confrontation during project implementation. Meanwhile, megaproject networks with strong ties are associated with high levels of trust [15]. This promotes inter-team information sharing and the development of a harmonious project environment [13]. In this case, the project's participating team is more likely to avoid ambiguous behaviors, reducing relationship-related conflict. In general, strong ties are closely related to the development of effective communication and the establishment of high levels of trust. In megaprojects, effective communication, high levels of trust, and shared norms can help increase task-related conflicts while decreasing relationship-related conflicts [20].

Hypothesis 1 (H1a). *Strong ties positively impact task-related conflict.*

Hypothesis 1 (H1b). *Strong ties negatively impact relationship-related conflict.*

3.2.2. Weak Ties and Inter-Team Conflict

Megaprojects involve a large number of project participation teams with varying knowledge backgrounds and core competencies [12]. Many of these teams have never worked together. As a result, they usually have weak relationships (i.e., weak ties) in the first project. In this case, the teams' diverse experience, knowledge, and core capabilities improve the depth and breadth of information and knowledge in a megaproject [2]. This contributes to the formation of new perspectives, ideas, and judgments about task implementation and process arrangement, resulting in task-related conflicts [13]. Furthermore, unlike traditional construction projects, megaprojects involve longer construction cycles and the more frequent movement of the project's participating teams, resulting in constantly changing nodes (i.e., the project's participating teams) [6]. During the course of a megaproject's implementation, new nodes may appear in the project network, while old nodes may exit [12]. However, the cognition, knowledge, and experience of the new nodes are frequently different from those of the original node [10]. As a result, differences in the project's task implementation and project process arrangement may grow, potentially leading to task-related conflicts. There is a loose relationship between teams in the weakly connected megaproject network [14]. This makes it difficult for teams to develop shared values and norms, leading to discord and incompatibility [11]. Furthermore, weakly connected teams are less familiar with each other than closely connected teams, and it is difficult for teams to interact continuously [16]. As a result, miscommunication, tension, and hostility are more likely to occur between teams, leading to relationship-related conflicts.

Hypothesis 2 (H2a). *Weak ties have a positive impact on task-related conflict.*

Hypothesis 2 (H2b). *Weak ties have a positive impact on relationship-related conflict.*

3.2.3. Inter-Team Conflict and Project Success

Various inter-team conflicts have varying effects on megaproject success [2]. Relationship-related conflicts frequently impair inter-team cooperation, which has a detrimental effect on the success of megaprojects [13]. Specifically, the tension caused by relationship-related conflict causes teams to hide their true views and ideas, impeding inter-team communication [31]. Meanwhile, relationship-related conflict causes negative emotions in the team and shifts the team's focus away from the task at hand, harming inter-team cooperation [32]. Relationship-related conflict also erodes mutual understanding between teams and exacerbates differences and confrontation [33]. In general, relationship-related conflict impairs effective communication and cooperation between teams, negatively impacting megaproject success. Task-related conflict occurs when teams disagree on specific task content, implementation methods, and solutions [34]. Due to the different knowledge backgrounds and capabilities of different teams, task-related conflicts are common in megaprojects [35]. Previous research has shown that task-related conflict can help improve organizational performance [36]. In megaprojects, task-related conflicts increase the team's critical opinions on task objectives, content, and solutions, promoting the implementation of the tasks [2]. Furthermore, task-related conflict can improve team cohesion, improve team relationships, and encourage teams to complete challenging tasks, thereby promoting task implementation and megaproject success [13].

Hypothesis 3 (H3a). *Task-related conflict positively impacts megaproject success.*

Hypothesis 3 (H3b). *Relationship-related conflict negatively impacts megaproject success.*

3.2.4. Strength of Ties and Project Success

The network ties serve as the foundation for interaction among project teams [15]. Previous research has found that the strength of ties impacts the type, quantity, and quality of resources obtained by the organization, which in turn affects the organization's output [16,17]. Gilsing and Nooteboom (2005) proposed that strong ties help to improve the level of trust and the effect of cooperation between organizations, thereby increasing organizational performance and project performance [16]. Wu et al. (2020) pointed out that a strong tie means frequent contact, which helps the team understand each other's work content and interest demands, promoting the implementation of tasks [11]. Hu et al. (2020) pointed out that the strength of ties positively impacts project performance [10]. Megaprojects are distinguished by their high complexity, uncertainty, and risk, as well as unforeseeable difficulties and challenges [4]. Through network ties, the team embedded in the megaproject network obtains project-related information, knowledge, and resources and then implements corresponding tasks [13]. Strong ties provide more opportunities for teams to interact during the implementation of megaprojects. This allows the team to fully communicate any difficulties or problems that may arise during project implementation, promoting the smooth execution of megaprojects [8]. Furthermore, strong ties reduce opportunity risks and interaction costs and aid in the formation of alliance relationships between teams, thereby promoting team resource complementarity [10]. This contributes to the success of megaprojects. Weak ties in megaproject networks may bring more diverse viewpoints, ideas, and judgments. This contributes to a broader implementation plan for project tasks, positively impacting megaproject implementation and success.

Hypothesis 4 (H4a). *Strong ties positively impact megaproject success.*

Hypothesis 4 (H4b). *Weak ties positively impact megaproject success.*

4. Method

4.1. Questionnaire Development

To measure the research variables, a questionnaire was developed. The research variables included the strength of ties, inter-team conflict, and project success. The following steps were used to develop the measurement items for the research variables. First, this study cited items that have been shown to have high reliability in previous studies [2]. Second, the items were modified to reflect the current state of megaprojects in China [8]. Third, on-site discussions with experts were used to confirm the items [10].

4.2. Pilot Test

The initial questionnaire was tested using the pilot test [13]. The pilot test was carried out in various megaprojects in China's Guangxi, Guangdong, and Fujian provinces. A total of 300 questionnaires were distributed via email and courier, with 148 recovered. After screening the 148 questionnaires, 104 were found to be valid. The normal quantile-quantile (Q-Q) plot was used to test the normal distribution of valid data [2,19]. The results of the tests show that the sample distribution of each study variable is nearly linear (see Figure 2). As a result, the valid samples follow the normal distribution and can be tested using the pilot test.

The pilot test consists of three steps. First, the coefficients of the corrected-item total correlation (CITC) and Cronbach's α were used to test the reliability of all the items [13]. The CITC value reflects the reliability of the item and should be greater than 0.5 [37]. Cronbach's α reflects the internal consistency of the items and should be greater than 0.7 [38]. Second, the Kaiser–Meyer–Olkin (KMO) test was used to determine whether an exploratory factor analysis (EFA) was feasible. Each variable's KMO value should be greater than 0.6 [39]. Third, the EFA was carried out. After the pilot test, a formal questionnaire was created (see Table 1).

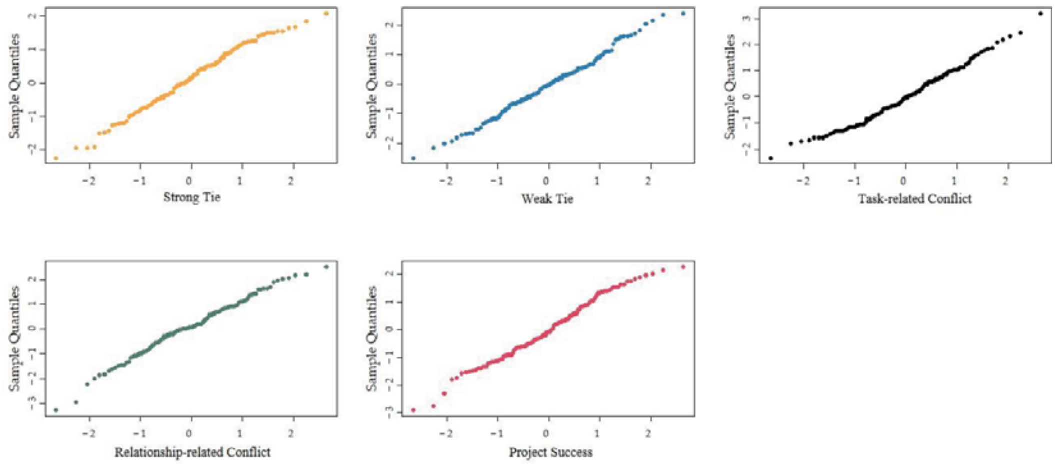

Figure 2. Normal distribution test.

Table 1. Measurement items.

Variables	Items	References
Strong Tie	Formal communication between teams lasts for many years Informal communication between teams lasts for many years Formal communication between teams is very frequent Informal communication between teams is very frequent Communication between teams involves knowledge and management Collaboration between teams is beneficial to both parties	Hu et al., 2021 [10]; Evald et al., 2006 [17]; Wu et al., 2020 [11]
Weak Tie	Formal communication between teams is uncommon Informal communication between teams is uncommon The team has invested a lot of capital resources to keep the collaborative relationship Inter-team communication is limited to technology and projects Project participating teams monitor each other's actions	
Relationship-related Conflict	There is tension between teams There is animosity between teams There is disharmony between teams There are numerous emotional clashes between teams There are numerous disagreements between teams During communication, teams do not respect each other's feelings Different teams have various management philosophies Different teams have various interest demands	Liu et al., 2022 [2]; Lu et al., 2011 [19]; De and Van, 2001 [21]; de et al., 2013 [31]
Task-related Conflict	Teams frequently disagree on the content of tasks Teams frequently disagree on how to achieve project objectives Power distribution is viewed differently by different teams Different teams have different ideas about how responsibility should be distributed Teams have differing perspectives on project resource allocation Teams have different perspectives on work difficulties	

Table 1. *Cont.*

Variables	Items	References
Project Success	The project meets three goals: quality, cost, and duration The project's resource utilization efficiency is high Project teams gain new skills and experience The level of trust between teams has increased The effectiveness and results of inter-team cooperation are favorable The project has received positive feedback from the public The project management is excellent The teams are pleased with the project's implementation process and outcomes The teams are eager to work together again in the future	Wu et al. (2019) [13]; Prabhakar (2008) [23]; Imam (2021) [24]; Angus et al., (2005) [25]

4.3. Data Collection

A non-probabilistic sampling technique was utilized to collect the samples [13]. The respondents were technical and management personnel from the owner team, contractor team, design team, supervision team, consulting team, and supplier team of various megaprojects in the Guangxi, Guangdong, and Fujian provinces in China. A total of 900 questionnaires were distributed via email and courier. After screening 357 returned questionnaires, 306 questionnaires were found to be valid. The valid data were used in confirmatory factor analysis (CFA) [11]. Table 2 shows the sample structure of the valid data.

Table 2. Sample structure.

Characteristic	Category	Number	%
Project type	Infrastructure project	110	35.7
	Industrial project	82	26.9
	Public project	114	37.4
Job position	Project engineer	118	38.5
	Department manager	69	22.7
	Professional manager Manager	89	29.2
	Project manager	30	9.6
Work experience	<5 years	38	12.4
	5–10 years	79	25.8
	11–15 years	101	32.6
	16–20 years	51	16.8
	>20 years	37	12.4
Project party	Owner team	65	21.2
	Contractor team	84	27.5
	Design team	61	19.8
	Consulting team	55	18.1
	Supervision team	32	10.3
	Supplier team	9	3.2

4.4. Confirmatory Factor Analysis

CFA was used to validate the items' applicability [8]. The construct reliability (CR) and average variance extraction (AVE) values were generated by the CFA. A CR value greater than 0.7 indicates that the items' overall reliability is high [40]. An AVE value greater than 0.5 indicates that the items have a high degree of convergence validity [41]. Table 3 displays the CFA results. The CR value is greater than 0.7, indicating that the items' overall reliability is high. The AVE value is greater than 0.6, indicating that the items' convergence validity is high. As a result, the theoretical model can be tested.

Table 3. SEM analysis.

Category	Coefficient	Critical Ratio	S.E.	*p* Value
ST→TC	0.172 *	2.209	0.042	0.017
ST→RC	−0.117 *	−2.271	0.037	0.013
WT→TC	0.670 *	2.332	0.029	0.016
WT→RC	0.263 ***	5.058	0.030	0.000
TC→PS	0.125 **	2.616	0.052	0.007
RC→PS	−0.261 ***	−4.820	0.064	0.000
ST→PS	0.127 *	2.586	0.051	0.004
WT→PS	0.159 *	2.194	0.036	0.025
Fit indices		GFI = 0.95; NFI = 0.93; IFI = 0.91		

Note: ST, strong tie; WT, weak tie; TC, task-related conflict; RC, relationship-related conflict; PS, project success. *, $p < 0.05$. **, $p < 0.01$. ***, $p < 0.001$.

5. Model Test

5.1. SEM Test

Structural equation modeling (SEM) is an effective tool for investigating the relationship between multiple variables [10]. The theoretical model of this study was tested using SEM. AMOS 21.0 was used to carry out the SEM analysis. Tables 3 and 4 display the fit indices and hypotheses test results, respectively. The goodness-of-fit index (GFI), normed fit index (NFI), and incremental fit index (IFI) were 0.95, 0.93, and 0.91, respectively, and they all exceeded the threshold of 0.9 [13].

Table 4. Hypotheses test results.

Hypothesis	Hypothesis Decision
H1a. Strong ties positively impact task-related conflict	H1a: Supported
H1b. Strong ties negatively impact relationship-related conflict	H1b: Supported
H2a. Weak ties have a positive impact on task-related conflict	H2a: Supported
H2b. Weak ties have a positive impact on relationship-related conflict	H2b: Supported
H3a. Task-related conflict positively impacts megaproject success	H3a: Supported
H3b. Relationship-related conflict negatively impacts megaproject success	H3b: Supported
H4a. Strong ties positively impact megaproject success	H4a: Supported
H4b. Weak ties positively impact megaproject success	H4b: Supported

The SEM analysis produced the following results (see Figure 3). First, strong ties have positive and negative effects on task-related conflict and relationship-related conflict, respectively (strong tie→task-related conflict, 0.172, $p < 0.05$; strong tie→relationship-related conflict, −0.117, $p < 0.05$). Second, weak ties have a positive impact on inter-team conflict (weak tie→task-related conflict, 0.670, $p < 0.05$; weak tie→relationship-related conflict, 0.263, $p < 0.001$). Third, task-related conflict has a positive effect on project success, whereas relationship-related conflict has a negative effect on project success (task-related conflict→project success, 0.125, $p < 0.01$; relationship-related conflict→project success, −0.261, $p < 0.001$). Fourth, both strong and weak ties contribute to project success (strong tie→project success, 0.127, $p < 0.05$; weak tie→project success, 0.159, $p < 0.05$).

5.2. Mediating Effect Test

Mediating effects were deemed significant when the boot 95% confidence interval (CI) did not include 0 [42]. The mediating effect analysis yielded the following results (see Table 5). First, task-related conflict has a positive effect on the relationship between strong ties and project success, whereas relationship-related conflict has a negative effect on the relationship between strong ties and project success (0.113, boot 95% CI = [0.158, 0.214]; −0.137, boot 95% CI = [0.147, 0.236]). Second, task-related conflict has a positive effect on the relationship between weak ties and project success, whereas relationship-related conflict has a negative effect on the relationship between weak ties and project success (0.107, boot 95% CI = [0.101, 0.270]; −0.210, boot 95% CI = [0.182, 0.322]).

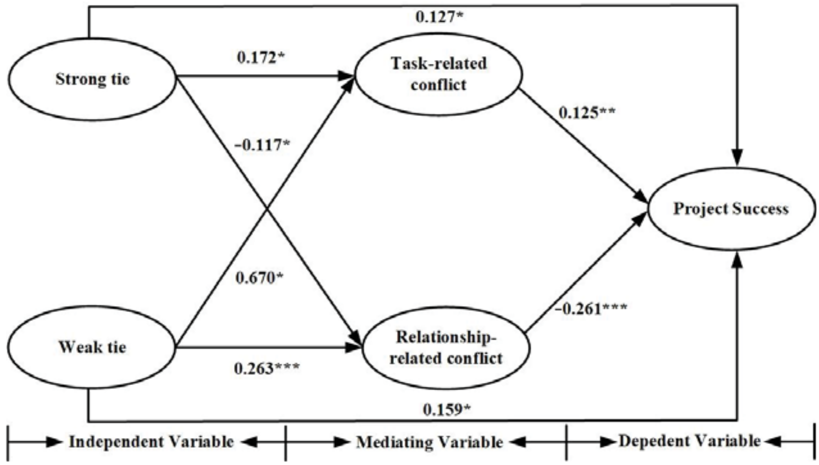

Figure 3. Results of theoretical model analysis. *, $p < 0.05$. **, $p < 0.01$. ***, $p < 0.001$.

Table 5. Mediating effect test.

Category	Coefficient		CI		Existence of a Mediating Effect
	Estimate	S.E.	Lower	Upper	
Variable: TC					
Between ST and PS	0.113	0.027	0.158	0.214	√
Between WT and PS	0.107	0.022	0.101	0.270	√
Variable: RC					
Between ST and PS	−0.137	0.019	0.147	0.236	√
Between WT and PS	−0.210	0.038	0.182	0.322	√

Note: ST, strong tie; WT, weak tie; TC, task-related conflict; RC, relationship-related conflict; PS, project success.

6. Discussions

6.1. Strength of Ties and Inter-Team Conflict

The results show that strong ties are positively related to task-related conflict but negatively related to relationship-related conflict. Weak ties are positively related to task-related conflict and relationship-related conflict. This conclusion is inconsistent with the finding of Wu et al. (2021) [30], i.e., the strength of ties has a negative impact on relationship conflicts. The specific reasons are as follows. There are more communication frequencies and interaction times between teams in a strong-connected megaproject network [10]. Because each project's participating team has different knowledge backgrounds and interest demands, it is easy for teams to have different views, ideas, and judgments on project task implementation, resulting in more task-related conflicts [13]. Strong-connected megaproject networks frequently generate shared values and norms [11]. This helps to reduce negative inter-team confrontation during the megaproject's implementation. Meanwhile, a strong-connected megaproject network promotes information sharing among teams and the creation of a harmonious megaproject atmosphere [15]. This contributes to fewer inter-team relationship-related conflicts.

The familiarity between teams in a weak-connected megaproject network is lower than in a strong-connected megaproject network, and the teams frequently do not interact frequently [14]. As a result, teams do not fully understand each other's knowledge, capabilities, and preferences. In this case, different teams' experiences, knowledge, and capabilities frequently result in heterogeneous views, ideas, and judgments about the project's task implementation and project process arrangement, resulting in task-related conflicts [19]. The loose relationship between teams in a weak-connected megaproject network makes it difficult to generate common values and norms, which easily leads to disharmony and incompatibility between teams [10]. Furthermore, in a weak-connected megaproject network, there is less communication between teams, and it is difficult for teams to interact continuously [15]. As a result, miscommunication, tension, and hostility are more likely to occur between teams, leading to relationship-related conflicts.

6.2. Strength of Ties and Project Success

The results indicate that both strong ties and weak ties have a significant positive impact on project success. This finding supports the conclusion of Hu et al. (2021) [10], i.e., the strength of ties positively impacts project success. The specific reasons are as follows. The teams in megaproject networks obtain the necessary information, knowledge, and resources through network ties [2]. Megaprojects, however, are distinct from traditional construction projects. Megaprojects involve more cutting-edge technology and knowledge, as well as greater complexity and uncertainty [30]. Megaprojects, therefore, demand exceptional innovation skills from the project's teams. Because of the openness of weak-connected megaproject networks, teams can gain access to more diverse knowledge and resources [7]. This aids in the development of new project task implementation plans and solutions. Meanwhile, structural holes with "bridge" functions exist in weak-connected megaproject networks [30]. This is conducive to breaking free from the constraints of the inherent mode and providing solutions for unconventional tasks to meet the breakthrough innovation requirements of megaprojects. This promotes the megaproject's smooth implementation and achievement of the megaproject's success. There are more communication frequencies and interaction times between teams in a strong-connected network, which helps teams fully communicate the difficulties and potential problems of megaprojects, promoting the smooth implementation of the megaproject [11]. Furthermore, a strong-connected network is associated with a high level of trust, which promotes information sharing among teams and the development of a positive project atmosphere. This contributes to the success of megaprojects.

6.3. Inter-Team Conflict's Effects

The research results show that task-related conflict has a significant positive impact on project success, whereas relationship-related conflict has a significant negative impact on project success. This conclusion is consistent with previous research on the relationship between organizational conflict and project performance, i.e., task conflict is a constructive conflict that promotes project performance, while relationship-related conflict is a destructive conflict that reduces project performance [2,13]. Furthermore, the research results indicate that task-related conflict strengthens the relationship between the strength of ties and project success, whereas relationship-related conflict weakens the relationship between the strength of ties and project success. The impact of inter-team conflict is summarized as follows. Task-related conflict encourages the development of new ideas, insights, and judgments about task objectives, contents, and solutions, thereby stimulating the resolution of complex problems [11]. Furthermore, task-related conflict encourages frequent interaction among teams, resulting in the multidisciplinary evaluation and in-depth consideration of project tasks [19]. This contributes to project success by increasing the efficiency of collaboration. Relationship-related conflict diverts the team's attention away from the project task and destroys inter-team mutual understanding [20]. This has a negative impact on the team's cognitive function, inter-team cooperation, project task implementation, and ultimately, the success of megaprojects.

7. Implications

7.1. Theoretical Implications

This study has the following theoretical implications. First, this research empirically investigates the relationship between the strength of ties, inter-team conflict, and project success. This adds to the existing network-related literature on megaprojects and broadens the understanding of the strength of ties. Second, this study contributes to the ongoing discussion about network research in construction management [2,7,9]. Previous studies have highlighted the potential role of network governance in the traditional construction industry [12,43]. The hypotheses and findings of this research broaden the discussion on the influence of the strength of ties. Third, by examining the relationship between inter-team conflict and project implementation in the context of megaprojects, this study adds to the existing literature on conflict management and expands the understanding of the impact of conflict on project implementation. The results of this research reveal the constructive and non-constructive effects of inter-team conflict, as well as the mediating role of inter-team conflict between the strength of ties and project success. Specifically, task-related conflict strengthens the positive impact of the strength of ties on project success while relationship-related conflict weakens it. As a result, a megaproject network with high-level task-related conflicts and low-level relationship-related conflicts is conducive to the smooth implementation of megaprojects and the achievement of megaproject success [2,13].

7.2. Practical Implications

Strong and weak ties can provide various types of resources to promote megaproject success. The project's participating teams can achieve efficient communication and high-level trust in the context of strong ties, promoting the completion of project tasks and the smooth delivery of megaprojects. In the context of weak ties, projects' participating teams can obtain more diverse knowledge, information, and experience to develop multiple-task solutions, thereby promoting the smooth implementation of megaprojects and achieving megaproject success. Megaproject managers should identify the megaproject network's strength of ties and encourage the healthy development of those ties [10]. Second, megaproject networks necessitate a high level of maintenance. Establishing effective communication mechanisms (e.g., formal and informal communication) with projects' participating teams can provide project managers with early warning [2]. Effective communication methods encourage task-related conflicts and increase the cohesion of networks. Furthermore, effective communication allows project managers to quickly grasp the implementation of megaprojects, as well as the interests, demands, and difficulties of various teams [8]. This helps to resolve inter-team divergences and reduces relationship-related conflicts.

8. Conclusions

This research investigates the relationship between the strength of ties, inter-team conflict, and project success, as well as how the strength of ties affects project success through inter-team conflict, in the context of megaprojects. The results indicate that: (1) both strong ties and weak ties have a positive impact on task-related conflict; (2) weak ties have a positive impact on relationship-related conflict, while strong ties have a negative impact on relationship-related conflict; (3) both strong ties and weak ties have a positive impact on project success; (4) inter-team conflict is a double-edged sword, which has both constructive and non-constructive effects; and (5) inter-team conflict mediates the impact of the strength of ties on project success. This study adds to the body of knowledge about megaproject networks, inter-team conflict, and project success. The results of this study provide a new perspective on network governance and conflict management for megaproject managers.

9. Limitations and Future Work

This research has the following limitations. First, different types of inter-team conflicts may transform into each other under certain conditions. This study did not explore the transition mechanism of different types of conflicts and their potential impact on project success. Future research should explore the transition mechanism of different types of conflicts and their impact on project success. Second, the implementation of megaprojects is a dynamic process, and the strength of ties may change over time. Future research should explore the dynamic change of the strength of ties and how it affects project success. Third, the data of this study are limited to megaprojects in specific regions of China. Future research should cover megaprojects in more countries and regions to expand the conclusions of this study.

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Knowledge Transfer Characteristics of Construction Workers Based on Social Network Analysis

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Abstract: Effects of traditional training methods are not obvious when transferring competent knowledge to construction workers to allow them to deal with new technology and intelligent equipment. The purpose of this study was to explore knowledge transfer paths and transfer characteristics within worker groups and to provide a theoretical basis for formulating new measures to improve knowledge and skills in worker groups. Firstly, we analyzed and verified the group characteristics of workers. Then, the social network analysis (SNA) method was used to study the knowledge transfer characteristics of worker groups, and the following conclusions were drawn: (1) construction workers have obvious group closure and regional concentration, which have significant impacts on knowledge transfer; (2) team leaders are the core and authority of knowledge transfer within entire networks, so improving the knowledge and skills of team leaders has a significant impact on promoting the overall knowledge and skills of workers; (3) it is very difficult for expatriate technical instructors with high levels of education but no blood or geographical relationships with other workers to establish knowledge authority among workers; and (4) due to the large gaps in knowledge and skills among workers, one-way flows of knowledge occur easily within groups.

Keywords: construction workers; group characteristics; knowledge transfer; social network analysis; team leaders

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1. Introduction

Labor intensity and low productivity have always been vexing issues entrenched in China's construction industry [1]. In recent years, on the one hand, the Chinese government has promoted serious measures to transform the construction industry from extensive to intensive in order to enhance the applications of advanced technology and to mitigate the dependence on labor. These measures consider building industrialization [2] and construction informatization [3] as new ways to improve traditional construction due to their potential to increase construction efficiency and sustainability [4]. On the other hand, low-carbon ecological and durable building materials have been developed to alleviate labor dependence and to reduce environmental pollution [5,6]. The application of industrialization and information technology has effectively reduced the need for on-site skilled workers [7]; however, conditions and circumstances external to worker knowledge and skills are crucial [8]. This raises new requirements for worker knowledge and skills because of the higher intelligence needed to operate construction equipment and the rapid development of construction technology [9]. The knowledge and skills of construction workers play important roles in improving construction productivity and project quality within the labor- and knowledge-intensive construction industry [10].

In China, most construction workers are rural migrants without professional training. According to data from the National Bureau of Statistics of China, in 2021, the construction industry employed about 19.0% of the total migrant workers, a total of 55.58 million people [11]. Most migrant workers are less educated, and their knowledge levels are generally low [9]. Improving the learning ability and knowledge levels of construction workers is one of the key factors for promoting the transformation and upgrade of the construction industry. However, the group closure and frequent mobility of migrant workers have been great obstacles for re-education and skills training because worker knowledge from one project cannot be fully reused for different projects due to high turnover rates and frequent reassignment [12]. To improve the knowledge levels and labor skills of this special group, the government has introduced training measures performed through formal classes and on-the-job training [13]. However, the willingness of construction workers to participate in this skills training is very low, and the training effects are not obvious [14]. Traditional methods and techniques are ineffective at transferring enough knowledge for construction workers to eliminate many common mistakes, and thus, new methods for knowledge transfer are urgently needed [15]. Therefore, it is crucial to identify the deep-seated reasons that affect the willingness of construction workers to learn and the characteristics of knowledge transfer among them in order to develop measures to promote learning enthusiasm and efficiency. Several researchers have addressed the importance of the knowledge levels of construction workers for the development of the construction industry. Wang et al. (2016) [16] used structural equation modeling (SEM) to identify the critical factors and paths that influence workers' safety risk tolerance and to explore how they contribute to accident causal models from a system thinking perspective. Chen et al. (2017) [17] used the social network analysis method to analyze safety knowledge dissemination among construction workers and put forward suggestions to promote the effective dissemination of safety knowledge. Zhang et al. (2017) [18] analyzed the factors that influence construction workers sharing safety knowledge and found that an organizational atmosphere has the greatest influence. Previous studies have mainly focused on safety knowledge transfer, and very few studies have addressed the importance of the comprehensive knowledge and skills of construction workers and the influence of worker group characteristics on knowledge transfer. In addition, significant benefits could be reaped by improving the comprehensive knowledge levels of workers for both companies and the workers themselves. The merits for companies include decreased construction costs, safer work sites, improved quality of projects, etc. The positive impacts on workers include improvements in employment prospects, income, job competency, etc. [19]. Considering these factors, the objectives of this paper were set out as follows:

- To analyze the group characteristics of construction workers and their influence on knowledge transfer;
- To explore the knowledge transfer characteristics and paths of construction workers and the influence of workers with different roles on knowledge transfer networks;
- To provide a useful reference to help decision-makers to formulate effective policies and measures to improve the knowledge and skills of construction workers.

2. Group Characteristics and Types of Knowledge

The individual and group characteristics of construction workers have direct impacts on the dissemination and transfer of knowledge; therefore, understanding the group characteristics of construction workers is an important step toward identifying the characteristics of knowledge transfer and common learning approaches. Migrant workers account for the largest proportion of construction workers within the Chinese construction industry. Migrant workers are a specific group of rural farmers who forsake their land and migrate to cities in the hope of increasing their opportunities and receiving higher incomes; they have the common characteristics of having less education [20], regional concentration, group closure and frequent migration [21].

2.1. Regional Concentration

Before migrant workers migrate to cities, most of their contacts are confined to relatives or villagers in the same village. When they move to work in cities, they are usually guided by a familiar leader who contracts work from a larger contractor and lives a collective life on construction sites. Most of the construction workers within the same construction group have the same regional characteristics, such as consanguinity, fellow countrymen, friendship, etc. Zhang and Feng (2015) [22] divided the social relations of migrant workers into kinship (i.e., blood relationships, such as parents, spouses and other relatives), geographic relationships (such as fellow townsmen) and friendship without consanguinity. These three types of relationships form links between migrant workers and can even replace formal labor contracts.

2.2. Group Closure

Han et al. (2015) [23] divided the group closure of Chinese construction workers into structural closure and relational closure. Construction workers live semiclosed lives on construction sites and have less contact with the outside world. They are mostly led by their group leaders and the construction groups are their basic units. Because they work and live together, the members of the same group are closely related and contact between different groups is rare. Group leaders have more contact with ordinary workers and become the core figures within construction groups. Most migrant workers migrate for work for the sole purpose of earning money, without considering integration into local societies [24]. They have full confidence in the group leaders and tend to communicate with workers with similar geographical and family backgrounds, adopting their suggestions both on work and life [25].

2.3. Frequent Migration

A clear majority of migrant workers move to work in cities to make money to improve the lives of their families in their hometowns. At the same time, they need to take responsibility as part of the family. When their family members encounter problems, they need to give up their jobs in the cities and return home to assume their responsibilities and obligations, which leads to job instability. Construction workers generally belong to different labor subcontracting companies, but there are no fixed personnel relationships within these labor companies. Workplaces change according to different project schedules, which causes frequent migration between jobs. According to the research of Sun et al. (2018) [26], 82% of construction workers in China have abnormal mobility, 73.3% of construction workers have changed jobs within the industry and the turnover rate of construction workers is at the forefront of all industries. The frequent migration of construction workers not only affects the willingness of government and enterprises to offer training, but also their willingness to upgrade industrial structures and the sustainable development of the construction industry [27].

2.4. Types of Knowledge

Individuals complete the effective transfer of knowledge through interpersonal communication, inquiry, theory and practice. Knowledge types have important impacts on knowledge transfer [26]. Knowledge can be generally classified into two types: explicit and tacit. Explicit knowledge is knowledge that can be formalized and stored, including standard operating procedures, best practice guides, reports and manuals [28,29]. Explicit knowledge is usually summarized and refined using language or pictures and other easy-to-understand communication forms to make the knowledge clear and easy to disseminate [30]. In contrast, tacit knowledge refers to personal context-specific knowledge that resides within people's minds and is difficult to formalize, express or articulate to other people [31]. Because tacit knowledge is based on the skills, experience and talent of individual people, it is difficult to code in order for it to be shared, as with explicit knowledge [32]. The transfer of tacit knowledge can only be achieved by the knowledge acquirer learning from the knowledge owner through the interpersonal interactions or common practice of the knowledge owner and the knowledge acquirer [31]. We studied the comprehensive knowledge and skills that construction workers need in their daily work, as well as their ability to learn to use new technology and equipment in a timely manner.

Because of their low educational levels and their group characteristics being different from general organizations, it is difficult for construction workers to acquire knowledge through systematic and formal textbook learning or professional training. Conversely, they rely more extensively on informal guidance and experience to acquire knowledge and skills; thus, "one-on-one" skills teaching between teachers and apprentices is considered to be the most effective way of learning skills on construction sites [33]. Learning while doing is a major feature of construction workers obtaining knowledge, which is greatly influenced by the people and environments around them. Therefore, the knowledge of construction workers comes largely from the working experience of group leaders and workmates, which is mainly tacit knowledge. The way workers acquire knowledge and the amount of knowledge obtained are greatly influenced by group characteristics and the roles and status of individuals within knowledge transfer networks.

3. Methodology

Social network analysis (SNA) is a structural analysis method that analyzes the structure and attributes of social relationships formed by different social units, such as individuals, groups or societies. It can provide quantitative tools for exploring various relationships within networks, accurately analyzing individual attributes and overall network attributes and building bridges between micro-relationships and macro-social systems [34]. Chen et al. (2017) [17] studied the influence of social networks on safety knowledge dissemination among construction workers in subway projects and concluded that the effect of safety knowledge dissemination among construction workers is positively related to the degree of centrality within the social network. Li et al. (2017) [35] used SNA to build a relationship network model for various unsafe behaviors among construction workers and studied their structural characteristics, node attributes, influences and clustering levels. Wang et al. (2018) [36] applied SNA to construct a network communication model of unsafe behavior among construction team members and analyzed the characteristics of the communication paths of unsafe behaviors among construction workers. The above research shows that SNA is an effective method for studying the behavior and knowledge transfer of workers. Construction workers are not only independent individuals, but they are also embedded into the networks of their groups and are affected by these networks. The group characteristics of construction workers show the characteristics of the social network; thus, social network analysis can be applied to model worker knowledge transfer networks and analyze knowledge transfer characteristics.

Considering that a significant number of construction workers in China are poorly educated and some are even illiterate [14], a two-step investigation based on a questionnaire survey was developed to achieve the three objectives of this paper, which were set out in Section 1. The first step of the investigation was to analyze and verify the regional concentration, group closure and frequent mobility of construction workers. The second step of the investigation was to build a social network model of worker knowledge transfer according to group characteristics and study the knowledge transfer features of the workers and the effects of different roles within the network. A flow chart of the research [37] is shown in Figure 1. The questionnaire was designed according to the following two basic principles:

- The language was easy for the construction workers to understand. Limited by their educational levels and knowledge, construction workers tend to refuse to answer questions that they do not understand or answer them indiscriminately, which results in the invalidity of questionnaires. Therefore, using easy-to-understand language for questionnaires could enhance the validity of the results.
- The questionnaire was simple and the number of items was small. Most construction workers work long hours and highly labor-intensive jobs, and therefore, they are unwilling to spend too much time on other things. If there were too many items on the questionnaire, it would have occupied the working and rest time of the workers

and they would have easily become tired of completing them, thus affecting the authenticity of the results of the survey.

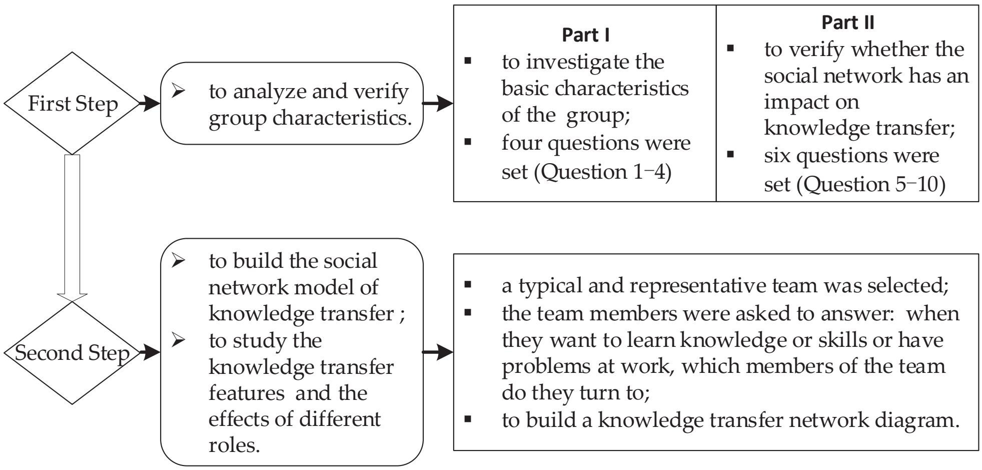

Figure 1. The flow chart of the research.

The questionnaire in the first step of the investigation consisted of two parts. The first part investigated the basic characteristics of the construction worker group. The second part evaluated the structural closure, relational closure, mobility and collaboration of the construction worker group and the personal experiences of the construction workers in the social network to verify whether the social network formed among members of the same team had an impact on knowledge transfer. This provided a research basis for using SNA in the second step of the investigation. In the first part of the questionnaire, four questions were set, as shown in Table 1. The second part contained six questions, as shown in Table 2.

Table 1. Questions to investigate the basic characteristics of the workers.

Q1	Please select your age: under 30 ( ); 30–40 ( ); 40–50 ( ); over 50 ( ).
Q2	Please select your length of service: less than 5 years ( ); 6–10 years ( ); 11–20 years ( ); more than 20 years ( ).
Q3	Please select your education background: primary school and below ( ); junior middle school or senior middle school ( ); junior college ( ); bachelor's degree or above ( ).
Q4	Please select your position: group leader ( ); technical instructor ( ); common worker ( ).

Questions 5–7 in Table 2 were included to verify whether the group characteristics of the workers met the requirements of social network characteristics; in particular, Q5 was used to verify the group's structural closure, Q6 was used to verify the group's relational closure and Q7 was used to verify the internal cooperation of the workers. Questions 8–10 were included to verify whether the social network formed among members of the same team had an impact on knowledge transfer among the construction workers by studying the effect of knowledge transfer among them. Cummings and Teng (2003) [38] pointed out that knowledge transfer not only impacts the enhancement of knowledge mastery, but also the activity and satisfaction of individual construction workers involved in the knowledge exchange. Based on the above research and combined with the group characteristics of worker networks, this questionnaire studied the effects of social networks on knowledge transfer from three aspects: the degree of knowledge accumulation, the degree of benefit and the degree of satisfaction among construction workers. The degree of accumulation

was mainly reflected by whether personal life or work problems could be solved reliably by the team, as measured by Q8. The degree of benefit was reflected by communication within the team, helping workers to master and understand all aspects of information and knowledge, as measured by Q9. Satisfaction was expressed on the form and effect of communication within the team, as measured by Q10.

Table 2. Questions to verify the group characteristics of workers and their impact on knowledge transfer.

Q5	I have close contact with my team members.
Q6	I have kinships or geographical relationships with closely connected workers on my team.
Q7	I cooperate with members of my team and learn from them to complete tasks.
Q8	My life problems and work problems can be solved by my team and I seldom turn to people outside my team.
Q9	Communicating with my team members helps me to master and understand all aspects of the required information and knowledge.
Q10	I am very satisfied with the form and effect of communication among my team members.

A 5-point Likert scale from "strongly disagree" to "strongly agree" was adopted to express the perceived importance of the questions among the respondents.

In the second step of the investigation, a typical and representative team was selected; the team members were required to learn some new knowledge related to their daily work and then go to their work site for practical operation. If they encountered problems in this process, they could ask other members of the team for help, according to their daily habits. After that, they needed to answer the following question on the questionnaire: when you want to learn knowledge or skills or have problems at work, which members of the team do you turn to? This was to determine the knowledge transfer relationships among the workers. To protect the privacy of the workers, they were labeled according to their positions: "L" represented "group leader", "T" represented "technical instructor" and "C" represented "common worker". As shown in Table 3, the respondents were asked to provide the labels of people who provided work assistance.

Table 3. The question to build the knowledge transfer network of workers.

Member Code	Who to Ask for Help
L1	
T1	
T2	
...	
Tn	
C1	
C2	
...	
Cn	

4. Data Research and Analysis

4.1. Data Survey and Basic Information

The questionnaire was distributed in four provinces: Shandong, Sichuan, Jiangxi and Hainan. This was to ensure that the collected data comprehensively reflected the overall characteristics of Chinese construction workers. In each province, different construction sites were selected to conduct the research at in order to avoid the homogeneity of the questionnaire, which could be caused by having too many respondents from the same site.

From November 2017 to August 2018, our research team visited eight construction sites across the four provinces, distributed 340 questionnaires and recovered 307 completed questionnaires. Finally, 19 ambiguous or incomplete questionnaires were eliminated and 288 valid questionnaires were obtained for the data analysis. The response rate was 84.7%.

The Statistical Package for Social Sciences (SPSS26.0) software was applied for the data analysis. The basic information of the surveyed workers is shown in Table 4.

Table 4. The basic information of the surveyed workers.

Age				Service Years				Educational Levels		
≤30 years	31–40 years	41–50 years	>50 years	≤5 years	6–10 years	11–20 years	>20 years	Primary school or below	Junior or senior high school	Junior college
9	15	138	26	87	112	72	17	63	217	8

The age of the construction workers was mainly between 30–50 years old, accounting for 88% of the total number of respondents. The number of workers under 30 years old was the lowest (only nine), accounting for 3% of the total number of respondents. There were 26 construction workers over 50 years old, accounting for only 9% of the total number of surveyed workers. Most of the workers had worked for 6–20 years, accounting for 64% of the total number of respondents. Only 30% of the respondents had worked for less than 5 years and 6% had worked for more than 20 years. Most of the respondents had a junior high school or senior high school education (217), accounting for 75% of the total number of respondents. There were 63 people with a primary school education or below, accounting for 22% of the total number of respondents, and there were only 8 people with a junior college education, accounting for 3% of the total number of respondents. None of the workers had a bachelor's degree or above.

Of the 288 construction workers surveyed, 26 were team leaders, 40 were technical instructors and 223 were common workers. The number of common workers was nine times that of team leaders and six times that of technical instructors, which was in line with the actual structure of worker groups on construction sites.

The lack of young people and the low levels of education accorded with the overall situation of Chinese construction workers [11], which showed that the selected survey samples were very representative and could truly and objectively reflect the research content of this paper. Meanwhile, the work experience of the workers in these samples was relatively long; therefore, the workers had a good understanding of knowledge transfer and could provide objective and real data for the research.

4.2. Verification of the Effects of Social Networks on Knowledge Transfer

Cronbach's alpha and corrected item-total correlation (CITC) were used to measure the internal consistency and interrelatedness among the initial variables. According to the results calculated using SPSS, as shown in Table 5, the Cronbach's alpha of the group closure of construction workers was 0.714, which was higher than 0.70, indicating that the internal reliability of this scale was high. Generally speaking, when the CITC is less than 0.3, this indicates that the test item has a weak correlation with other items and needs to be deleted [2]. In this test, the CITC of all items was greater than 0.3 and the coefficient after deleting items was less than the original coefficient, which showed that the internal consistency and reliability of the items were high. In addition, the average score for each item was greater than 3.7, indicating that the survey samples showed obvious group closure and internal cooperation. In particular, the average score for Q7 reached 3.94, indicating that cooperation within the groups of workers was very significant. The above results proved that the group characteristics of the workers conformed to the characteristics of social networks, meaning that the use of SNA would be effective for studying the internal mechanisms of knowledge transfer by constructing the connections between construction workers on the same team.

Table 5. The reliability analysis of group closure of construction workers.

Items	Cronbach's Alpha	CITC	Cronbach's Alpha If the Item Deleted	Mean Value
Q5	0.714	0.499	0.655	3.74
Q6		0.504	0.651	3.88
Q7		0.527	0.637	3.94

According to the results calculated using SPSS, as shown in Table 6, the Cronbach's alpha of the knowledge transfer effect was 0.829, which was higher than 0.80, indicating that the internal reliability of this scale was very high [39]. The CITC of all items was greater than 0.3 and the coefficient after deleting items was less than the original coefficient, which showed that the internal consistency and reliability of the items were high. In addition, the average score for each item was greater than 3.7, indicating that the team members had a high recognition of knowledge transfer within the network. In particular, the average score for Q9 reached 3.99, indicating that the team members had a high degree of recognition of knowledge and benefits within the network. The above results proved that the social network formed among team members had a positive effect on knowledge transfer among construction workers.

Table 6. The reliability analysis of the learning effects within the network.

Items	Cronbach's Alpha	CITC	Cronbach's Alpha If the Item Deleted	Mean Value
Q8	0.829	0.674	0.778	3.79
Q9		0.696	0.754	3.99
Q10		0.696	0.755	3.81

5. Social Network Analysis of Knowledge Transfer among Workers

5.1. Building the Social Network Model of Knowledge Transfer

A representative reinforcement team was selected from the respondents to build the social network model. The reinforcement team is a typical team running through the whole process of project construction, which is the team with the largest number of members and demands out of all the different kinds of teams. The representative team could comprehensively reflect the network relationships and knowledge transfer characteristics of construction workers. In addition, all 22 workers in this reinforcement team were educated, able to understand the content of this survey and make objective answers, and had a positive willingness to participate in this survey. Of the 22 workers in the team, 6 were between 26–35 years old, 9 were between 36–45 years old and 7 were 46 years old or above. The age distribution was relatively balanced, which fully represented the situation of the three generations of construction workers, namely, the young, middle-aged and older workers. There were five workers who had worked for less than 5 years, eight workers who had worked for 6–10 years, eight workers who had worked for 11–20 years and one worker who had worked for more than 20 years. In total, 77.3% of the workers had over 5 years of service and could objectively reflect on the knowledge transfer characteristics of the workers in their network. In addition, in this team, there was a team leader, two technical instructors and nineteen ordinary workers, which was in line with the general structure of construction worker teams. The two technical instructors were assigned by a labor company to provide technical guidance to the workers.

Firstly, all team members were gathered in a conference room at the construction site. With the help of a video, a technician explained the steel bar binding technology of a laminated plate for a prefabricated building, which was new knowledge for all members. Then, they were asked to go to the construction site and carry out the actual operation of steel bar binding a laminated plate. When all members had completed this work, they were asked to return to the conference room and answer the last question, as shown in Table 3. UCINET 6.0 software was used for the data analysis and to obtain a knowledge transfer network diagram of the reinforcement team, as shown in Figure 2.

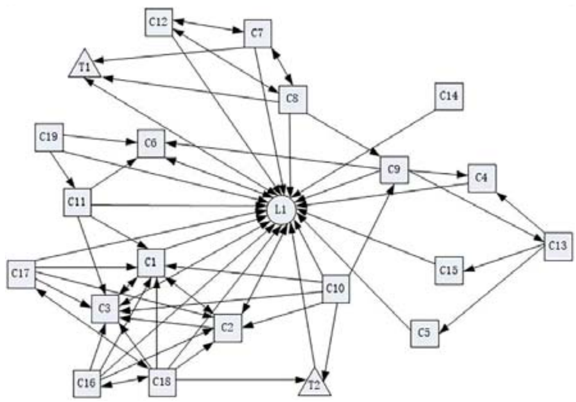

Figure 2. The knowledge transfer network of the reinforcement team.

5.2. Network Density Analysis

The nodes in the network diagram represent the team members and the connecting edges between the nodes represent the knowledge transfer relationships between members [40]. Network density refers to the ratio of the number of connections between nodes within the social network to the number of connections within theoretical networks. The network density determines the degree of knowledge transfer among participants. The value is between 0 and 1, which reflects the connection degree of the whole network. The closer the network density is to 1, the higher the frequency of connections and interactions between the nodes and the more frequent the knowledge transfer. The network density of the team members in this study was 0.1472, indicating that the overall network density of the team was relatively low and that the knowledge transfer connections between members was not close enough.

The network of construction workers had geographical relationships, blood relationships and work relationships, but the density of the knowledge transfer network was very small. According to the survey, most workers did not pay attention to improving their knowledge and skills: they just wanted to complete the task as soon as possible and be paid. They had a weak sense of responsibility over the project quality and project objectives and lacked the motivation to learn new knowledge and skills. This was also related to the fact that there is no clear responsibility for construction workers within the current quality responsibility system.

5.3. Network Centrality Analysis

The network centrality degree (CD) is used to evaluate the position of a node within a network and its influence on other nodes by calculating the number of connections between the node and other nodes. It generally includes three specific indicators: degree centrality (DC), closeness centrality (CC) and between centrality (BC). DC includes out-degree centrality (OC) and in-degree centrality (IC). OC refers to the number of connections that a node sends to the whole network, i.e., the number of direct connections between one member and the other members. IC refers to the number of connections sent from the whole network to a node, i.e., the number of connections that one member receives directly from the other members. The higher the CD of a node, the more connections it has with other nodes and the greater the power and influence it has on other nodes. UCINET 6.0

software was used to calculate the DC, CC and BC of each network node. The calculation results are shown in Table 7.

Table 7. The index values of network centrality.

Node	OC	IC	CC	BC
L1	23.810	95.238	95.455	69.571
T1	4.762	14.286	52.500	0.000
T2	4.762	9.524	52.500	0.095
C1	14.286	33.333	60.000	1.222
C2	14.286	28.571	58.333	0.429
C3	4.762	38.095	60.000	1.222
C4	4.762	9.524	53.846	1.452
C5	4.762	4.762	52.500	1.452
C6	4.762	19.048	55.263	0.667
C7	19.048	9.524	53.846	0.159
C8	23.810	9.524	56.757	1.159
C9	19.048	9.524	58.333	5.167
C10	28.571	0.000	58.333	1.810
C11	19.048	4.762	55.263	0.952
C12	14.286	9.524	52.500	0.000
C13	14.286	4.762	41.176	1.190
C14	4.762	0.000	50.000	0.000
C15	4.762	4.762	52.500	1.452
C16	23.810	4.762	55.263	0.000
C17	23.810	4.762	55.263	0.000
C18	33.333	9.524	58.333	1.048
C19	14.286	0.000	52.500	0.000

The team leader L1 had both a high OC value and a high IC value, which indicated that he was closely connected with other members and had a great influence on others, demonstrating that the team leader disseminated knowledge with reputation and authority among the team. C18, C8, C10 and C19 had high OC values but low IC values, which meant that they often took the initiative to learn from other members but other members seldom learnt from them. Through further investigation, we found that these four members had relatively short periods of work experience, especially C18 with only 2 years of experience. At work, they lacked knowledge and experience, and thus, they needed to constantly seek the help of other members. C1, C2 and C3 had high IC values but low OC values, which meant that these three members often provided knowledge and skills to other members but seldom learnt from other members. Through the investigation, we found that these three members had long working lives and rich experience and skills; thus, they could provide other members with the knowledge and skills that they needed. At the same time, these three members were more enthusiastic and willing to teach others very patiently; therefore, there were more members who sought help from them.

CC was used to measure the distance between a member and other members. When the distance between members is closer, the information transfer speed is faster. The CC value of team leader L1 was the highest at 95.455, indicating that the average path of knowledge transfer between L1 and the other members was the shortest and the speed of knowledge transfer was very fast. The CC value of all other members, except C13, was greater than 50, which indicated that the members of the network did not rely on others when disseminating information and that the knowledge transfer speed of the whole network was fast.

BC refers to the ability of a member to act as an intermediary between other members to help them transmit information and master resources. The higher the BC value of a member, the larger the intermediary role that the member plays and the more information and resources the whole network obtains. Team leader L1 had the highest BC value at 69.571, demonstrating that he was the most important intermediary for the other members in the whole network in terms of knowledge transfer. Compared to that of L1, the BC values of the other members were very low. The main reason for this was the large gaps in knowledge and skills between different workers, which caused some workers to mainly take the role of information input, whereas other workers mainly took the role of information output. Few members could achieve a balance between information input and information output, and thus, it was difficult for the members to play intermediary roles in knowledge transfer.

5.4. Structural Hole Analysis

In a social network, when there is no direct relationship or indirect redundancy relationship between two individuals or groups, then the gap between them is called a structural hole. Structural holes are used to measure the cohesion of a network and the influence of individuals within the network [41]. Freeman (1977) [42] applied BC to describing structural holes. Ronald (2004) [43] proposed to measure structural holes using the indices of constraint (CT), effective size (ES), efficiency (EF) and hierarchy (HI). Han et al. (2016) [44] analyzed different factors that affect seven existing structural hole measurements in social networks and pointed out that BC is relatively more effective among these seven methods and that the measurement results of structural holes are more accurate when multiple indices are used. BC was discussed in Section 5.3; therefore, in this section, ES, EF and CT (which are not related to BC) were used to measure the structural holes in this study.

ES is an index used to measure the overall influence of nodes and can measure the importance of structural holes to a certain extent. EF is usually used to describe the influence degree of a node on other nodes, and the nodes in structural holes are more efficient. CT is used to measure the dependence of a node on other nodes. The larger the value, the stronger the CT and the less likely the node is to cross a structural hole. The calculation results are shown in Table 8.

Table 8. The index values of structural holes.

Node	ES	EF	CT
L1	17.380	0.869	0.152
T1	1.750	0.583	0.575
T2	2.167	0.722	0.422
C1	4.500	0.563	0.383
C2	3.556	0.508	0.420
C3	4.444	0.556	0.378
C4	1.833	0.611	0.487
C5	2.000	1.000	0.500
C6	2.100	0.525	0.484
C7	2.250	0.563	0.639
C8	3.286	0.657	0.525
C9	4.667	0.778	0.304
C10	3.833	0.639	0.343
C11	3.000	0.600	0.440
C12	1.600	0.533	0.671
C13	3.500	0.875	0.321
C14	1.000	1.000	1.000
C15	2.000	1.000	0.500
C16	2.233	0.467	0.462
C17	2.233	0.467	0.462
C18	4.389	0.627	0.390
C19	1.333	0.444	0.637

From the calculation formulae of the indices, it can be seen that ES and EF are linear, whereas CT has a negative correlation with ES and EF. The larger the value of ES and EF and the smaller the value of CT, the greater the overall influence of nodes within a network [44].

The ES of L1 was the largest at 17.380, indicating that L1 had the greatest influence on the whole network and that he was also the most important structural hole member among the team. The EF values of C1, C3, C9 and C18 were also greater than 4.0, indicating that these four members had some influence on the network. At the same time, their CT values were less than 0.4, which indicated that they were not strongly dependent on other members; therefore, these four members could be regarded as the structural holes of the network and played important roles in knowledge transfer among the whole network. The EF value of C13 was very high, but his CT value was very low; thus C13 could be considered as having an important impact on knowledge transfer in this network.

The CT values of C7, C12, C14 and C19 were very high and their BC values were very low, which showed that these four members were highly dependent on the network and found it difficult to cross the structural hole, especially C14 and C19, whose IC and BC values were both 0.0, indicating that their knowledge transfer ability was very weak and that they were at the edges of the network. According to the survey, these workers were all older and were slow to accept new knowledge and skills; thus, their contributions to knowledge transfer were very small.

6. Results and Discussion

Through network analysis, the following results could be obtained:

- Team leaders are the core of the whole team, are closely connected with other members and have a great influence on others in terms of knowledge transfer. At the same time, team leaders are also the most important hubs of knowledge transfer within whole networks. Team leaders are authoritative in knowledge transfer and the transfer paths are short and the transfer speed is fast; therefore, their knowledge and skills are easily spread to whole networks. This means that they play great guiding roles in the promotion of the knowledge and skills of the other members. On the contrary, if the knowledge or skills of team leaders is defective, this has significant negative effects on the whole team. Therefore, the government and enterprises should give full support to the core role of team leaders and provide stable working environments, development spaces and sustainable incomes for them. At the same time, through training from team leaders and the core members of teams, the levels of knowledge and skills of the workers could be improved. This method could not only reduce the costs of training, but also the mobility of workers.
- In this study, C1, C3, C18 and C9 were all structural holes, but their connections were quite different. From Figure 2, it can clearly be seen that the network composed of L1, C1, C2, C3, C16, C17 and C18 was denser than the network composed of the other members and that the connections between these seven members were more frequent, indicating that there were smaller knowledge transfer groups within the team. Due to the large gaps in knowledge and skills among the workers, one-way flows of knowledge occurred easily within the group. Common workers form internal, small groups according to the intimacy of their relationships, which creates barriers to knowledge transfer within networks. Thus, it is necessary to pay attention to the training and guidance of workers who are on the edges of networks and cannot acquire new knowledge and skills in a timely manner. According to the above, managers should pair workers with active personalities who are good at communication and workers who are on the edge of the network so that the former can improve the knowledge and skills of the latter. At the same time, technical instructors should strengthen the help and supervision provided for workers at network edges and find and solve their problems with work processes in a timely manner to ensure their work quality and efficiency.
- In this study, the technical instructors T1 and T2 did not fully participate to in the knowledge transfer within the network. From the results of our network analysis, the OC and IC values of T1 and T2 were low, indicating that they had little knowledge-based interaction with the other workers. The BC values of T1 and T2 were very small,

especially the BC value of T1 at 0.0, which meant that T1 and T2 could hardly play the role of a "bridge" in knowledge transfer. Compared to education and knowledge levels, workers pay more attention to work experience and intimacy; therefore, if highly educated technical instructors lack practical experience and cannot form close relationships with the workers, then they cannot be the "bridge" role in the knowledge transfer among the team, and ultimately, only make few contributions to improvements in the team's knowledge and skills. Technical instructors can only play guiding roles for a few people, but not for the promotion of the overall knowledge and skills of the network. Therefore, when selecting technical instructors, enterprises should not only pay attention to educational background and skill level, but also to close relationships with other workers.

Compared to previous research, the main innovation of this paper is reflected in the following three aspects:

- Most previous studies have focused on the transfer of safety knowledge among construction workers. This research focused on the transfer characteristics and transfer rules of comprehensive, professional knowledge among construction workers and provided targeted suggestions to improve knowledge transfer efficiency and the professional skills of construction workers in order to lessen the learning and efficiency weaknesses of traditional construction workers in the professional and intelligent development of the construction industry.
- Due to the limitations of environments and methods, many research studies on the learning abilities and learning efficiency of construction workers have used volunteers to replace construction workers as experimental objects [45–48]. This study used a construction worker group to conduct research and obtained objective data that could accurately reflect the characteristics of knowledge transfer among construction workers, thereby providing a scientific basis for formulating strategies to improve the knowledge and skills of construction workers.
- From this study, we found that traditional construction workers were still most affected by blood and geographical relationships in terms of knowledge transfer and that different roles within the worker group had different characteristics in the process of knowledge transfer. Therefore, adopting unified training or technical guidance is not an effective way to improve the professional skills of construction workers.

7. Conclusions

By using the SNA method to study knowledge transfer among construction workers, we found that the knowledge transfer network of the workers also had the following characteristics:

- Compared to other groups, the willingness of construction workers to transfer knowledge is very low. Most individuals do not learn from each other well and the exchange of knowledge and skills is not sufficient. They only focus on the current work and lack the motivation to improve their skills and work efficiency.
- Team leaders, based on blood and geographical relationships, are the cores of teams and have greater impacts on knowledge transfer among construction workers than technical instructors without blood and geographical relationships, even if they have a higher level of education.
- It is very difficult for expatriate technical instructors with high education levels but no blood or geographical relationships with workers to establish knowledge authority among the workers.
- Construction worker groups lack internal knowledge transmission networks with close contacts and frequent interactions. There are big gaps between the workers at the center of a networks and those at the edges in terms of knowledge transfer channels and knowledge transfer efficiency, which means that one-way flows of knowledge occur easily within the group.

This study verified that group characteristics, such as regional concentration, group closure and frequent mobility, have important impacts on the transfer of knowledge and skills among construction worker groups. At the same time, the study explored the knowledge sources and knowledge acquisition channels of construction workers and provided a scientific basis for formulating targeted measures to improve the efficiency of construction worker skills. There were some deficiencies in this study. Due to many factors, such as the high mobility and low participation willingness of the construction workers, it was difficult to collect data. Only one representative team was selected for testing, which reduced the comprehensiveness of the research conclusions. In addition, the research object of this study was only workers on construction sites, not industrial construction workers. We will address and improve the above problems in future research.

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Review

Leadership in Construction: A Scientometric Review

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Abstract: Leadership plays an increasingly important role in construction projects, and numerous research studies have been conducted. This study aims to identify the structure evolution development trends of this knowledge domain using visualisation analysis with CiteSpace. A total of 1789 peer-reviewed articles are collected from Scopus and the WoS core collection database to conduct a scientometric analysis. The results indicate that the US dominates this field and that institutions from Australia have made greater contributions. However, international cooperation in this area is not active. A total of eight co-citation clusters were identified, and the research of leadership in construction primarily focused on the topics of transactional leadership, safety leadership, team performance, leadership interaction processes and actual leader behaviour. The keywords co-occurrence evolution analysis was also conducted to provide a holistic knowledge map. Based on the development of this field and its current status, we propose trends and innovative research areas for future research. The findings in this research would help scholars to understand the structure and future trends of this field. Meanwhile, the research results would provide a reference for construction enterprises to formulate project manager competency criteria.

Keywords: construction industry; leadership; research trend; scientometrics; visualisation

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1. Introduction

Research into leadership has a long history. As an extensively explored theory, leadership has gained the attention of scholars worldwide, resulting in a wide variety of qualitative and quantitative approaches. Some scholars conceptualise leadership as a behaviour or personality, while others view it from a social information processing standpoint [1]. For many years, the importance of leadership was ignored in construction project management, as traditional researchers in this field mainly focused on the technology of the project [2,3].

The research paradigm of leadership in the construction industry began to change at the end of the 20th century. Across a broad research scope, early researchers conducted some interesting cross-sectional studies. For example, Sui Pheng and Lee [4] attempted to construct a managerial grid framework with an ancient Chinese strategy to develop the leadership of construction project management, while Weingardt [5] encouraged engineers to become more involved in leadership on all levels and to broaden their impacts on public policy. During this period, scholars realised that construction projects are people-oriented and that effective leadership is inevitably related to project success [6,7].

Since the beginning of the 21st century, leadership has been documented as an important skill of effective project leaders [8] and engineering management students [9] to accompany their technical skills. The behaviours of the project leader were found to be more significant in the prediction of project performance than the other team members' characteristics [10]. Some quantitative and qualitative methods are gradually being introduced in the literature on leadership in construction projects. Liu et al. [11] developed a model to examine the power structures of the leaders of construction projects, while

Fellows et al. [12] determined the leadership style and power relations. Odusami et al. [8] analysed the data from 60 project team leaders and concluded that project performance is significantly affected by the project manager's leadership style. With a rapidly growing body of leadership research in construction projects, a number of studies have been conducted to determine the factors that contribute to an ideal construction project manager's leadership style from a variety of perspectives [13–17]. Since the work of Turner and Müller [17], the study of the leadership of project managers has gained new momentum. Turner and Müller suggested that research should pay particular attention to the project manager's competence and leadership style in relation to project success. For in-depth research, Müller and Turner [18] conducted qualitative and quantitative studies and concluded that the project manager's leadership style influences project success and that different leadership styles are appropriate for different types of projects.

Over the past two decades, leadership has been regarded as a significant cause of project success or failure [19], and the personal and interpersonal factors of project managers that contribute to project performance have been investigated to some extent [20–24]. As shown in Figure 1, since the first literature appeared in 1992, the number of studies has increased every year. Against this background, several studies have reviewed and analysed the existing literature. Toor and Ofori [22] selected 49 studies and summarised the empirical research on leadership in the construction industry. Simmons et al. [23] conducted a critical review that predicted some future trends. In Graham's [24] systematic review study, a computerised technique was used for bibliometric analysis to develop clear criteria to inform a thematic analysis and compare the analyses between multiple authors. Some other studies remain narrow in focus, dealing only with a certain branch of leadership theory in the construction industry [25–27]. Most studies, however, rely on the subjective judgment of experts, which leads to a lack of quantitative bibliometric analysis in this field. Although there are increasing numbers of publications in this field, little is known about the overall structure of the knowledge landscape.

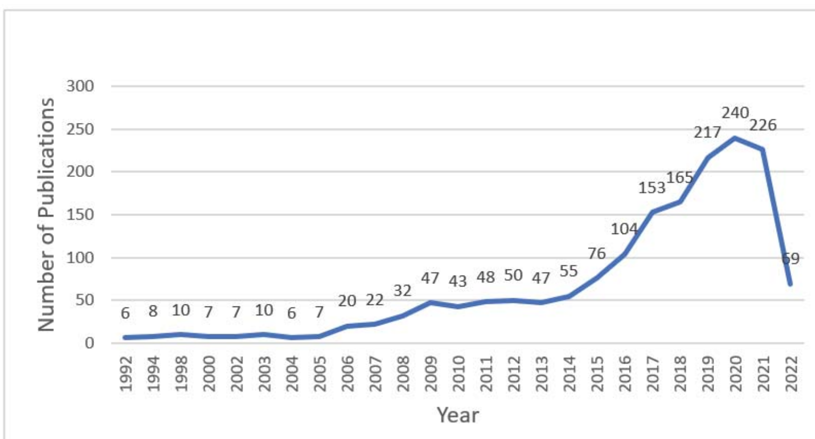

Figure 1. The number of published papers on the topic "leadership in the construction industry" or "leadership in construction projects" (1992–2022). Source: Web of Science.

Scientometrics is a branch of informatics that was defined by Nalimov and Mul'chenko [28] as "the quantitative methods of the research on the development of science as an informational process". It can be considered as the quantitative analysis of patterns in the scientific literature to map knowledge structures and predict emerging trends in a research field. Compared with traditional bibliometrics, scientometrics provides in-depth quantitative analysis of the bibliographic information, such as countries, institutions, authors, keywords, and references [29]. The applications of the scientometrics software reduce the impact of a researcher's subjective opinions on document records' retrieval and screening. By using visualisation tools such as CiteSpace [30], VOSviewer [31] and Histcite [32], the knowledge structure of a scientific research field can be clearly presented. The scientometrics approach is the best way to explore research trends and key areas of study over time [33,34]. Therefore, various visualisation tools have been widely used in the field of technology management analysis [35]. By comparing the features of these software, we found that CiteSpace, which can visualise the networks of cooperation and the development of a research area over time, had the most features and was the most used.

Despite the popularity of visualising the literature, we searched Scopus, WoS and Google Scholar and found that there are still no papers on the current state of leadership research in construction. With the extensive investigation of a field of study, it is necessary to conduct a systematic analysis that provides current conditions and potential future trends. To fill this gap, this study, which attempts to conduct a scientometric review of the scientific literature relating to leadership in construction, is guided by the following key goals: first, to determine the main contributing forces in this research area at the level of countries, institutions and contributing authors; second, to illustrate the intellectual structure and its evolution in the field; third, to identify the disciplines and topics involved in the field; and fourth, to understand emerging trends in the future.

2. Methodology

To make the bibliographic data more comprehensive, we selected two world-leading research databases, Scopus and the Web of Science Core Collection, as this article's data source. Scopus is currently the largest database of peer-reviewed literature, containing over 23,452 peer-reviewed journals from 7000 publishers. In comparison, the Web of Science (WoS) core collection database covers papers from approximately 12,000 leading journals. These two databases have been the traditional sources for most major scientometrics studies [36]. To make the data more concentrated, we used "leadership" in the title as the search condition, limiting the search results to construction projects. Therefore, the approach for bibliographic retrieval is as follows: 'TITLE (leadership) AND ALL (construction project)' in Scopus and "(TI = (leadership)) AND ALL = (construction project)" in WoS. There is no limit to the timespan of the retrieved literature. The retrieval time is 27 August 2022. A total of 2350 document results were found in Scopus, and 228 were found in WoS. Peer-reviewed articles are considered to be more representative [37]. Therefore, the bibliographic search was limited to articles and reviews, and non-English publications were excluded. This process resulted in the removal of 657 records, leaving 1737 records from Scopus and 184 from WoS. The two databases are overlapping. After removing duplicates, a final sample of 1789 records was identified.

The scientometric software CiteSpace was used to analyse the data and generate visualised results. The main purpose of this software is to analyse and illustrate a knowledge domain, which is a broadly defined concept that covers a scientific field, a research area or a scientific discipline and is usually represented by a set of bibliographic records of relevant publications. CiteSpace is a widely used scientometric software that makes it easier for users to identify pivotal points [38]. The pivotal points constitute the basic framework of CiteSpace visualisation graphs, including authors, institutions, countries, terms, keywords, categories, cited authors and cited bibliography. The foundation of CiteSpace is network analysis and visualisation. The intellectual landscape of a knowledge domain, the questions that academics have been focused on and the methods and tools they use to achieve their goals are easy to explore through network analysis models and visualisation.

As shown in Figure 2, after the inclusion of the data, there were three types of bibliometric techniques applied in this study: collaboration analysis, co-citation analysis and keyword co-occurrence analysis. In a knowledge domain, it is essential to understand the process of knowledge diffusion. In the selected dataset, each bibliographic record contains the information of the authors and their addresses. CiteSpace analysed each record and identified the collaboration countries, institutes and authors in the same article. The countries, institutes and authors connected to generate the collaboration network. As shown in this study, the collaboration network can provide a helpful guide for potential cooperation in this research field. Co-citation was first proposed as a new measure of two articles in the early 1970s [39] and has been long considered an effective tool for mapping the intellectual structure of science. Furthermore, cluster analysis was performed based on the co-citation analysis results in this study. The research hotspots in this field in various periods were identified. Co-word analysis was developed in the 1980s. CiteSpace acquires a keyword co-occurrence matrix in the data and detects the citation bursts in the knowledge domain, which is an effective way to trace the research trend and predict future research.

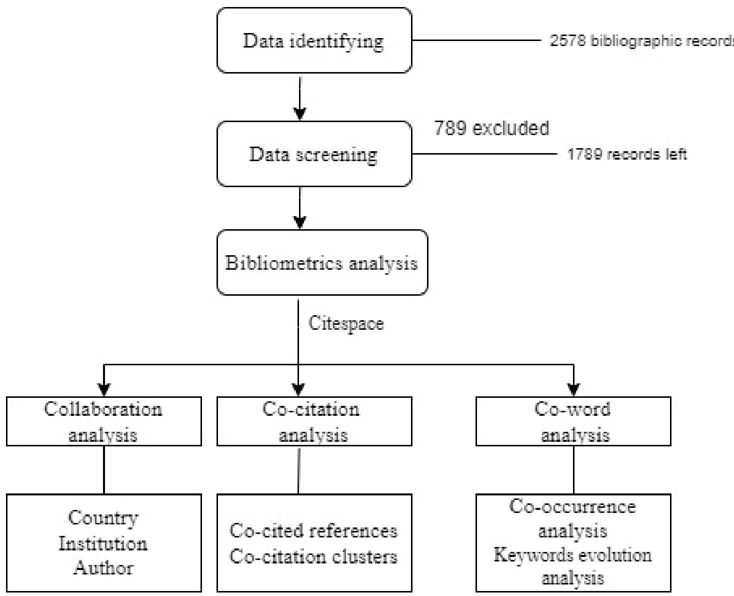

Figure 2. Research framework.

3. Results

3.1. Collaboration Analysis

3.1.1. Country/Region Collaboration Network

As shown in Figures 3 and 4, a country/region collaboration network, which showed the spatial distribution of publications quantitatively, was created based on the number of publications and betweenness centralities. The betweenness centrality refers to the number of times that a node acts as the shortest path between two other nodes. The higher the value, the higher the contribution of a node to make connections with other nodes in a network. The network of collaborating countries contained 118 nodes and 164 links between 1987 to 2022. The country with the highest number of publications is the US, with 418 papers, and the US also contributed the second highest centrality number (0.21), making it the most active country in terms of research in construction leadership, with great contributions to international cooperation (Table 1). The publication records of the UK, China and Australia were 240, 210 and 189, respectively. However, the centrality of China was lower than that of the two other countries. Moreover, the United States and the United Kingdom were the first two countries to start research in this field, nearly ten years earlier than other countries. Research in countries such as Australia, Canada and New Zealand began in the late 1990s. With the continuous development of this research field, scholars from new countries contribute every year. Overall, the United States is leading in this field of research, and the US also has the highest level of burst strength (27.84). Although China has about the same number of publications as Australia and the UK, it is still less influential than these two countries. With the development of the construction industry, increasing numbers of scholars in developing countries have focused on this field.

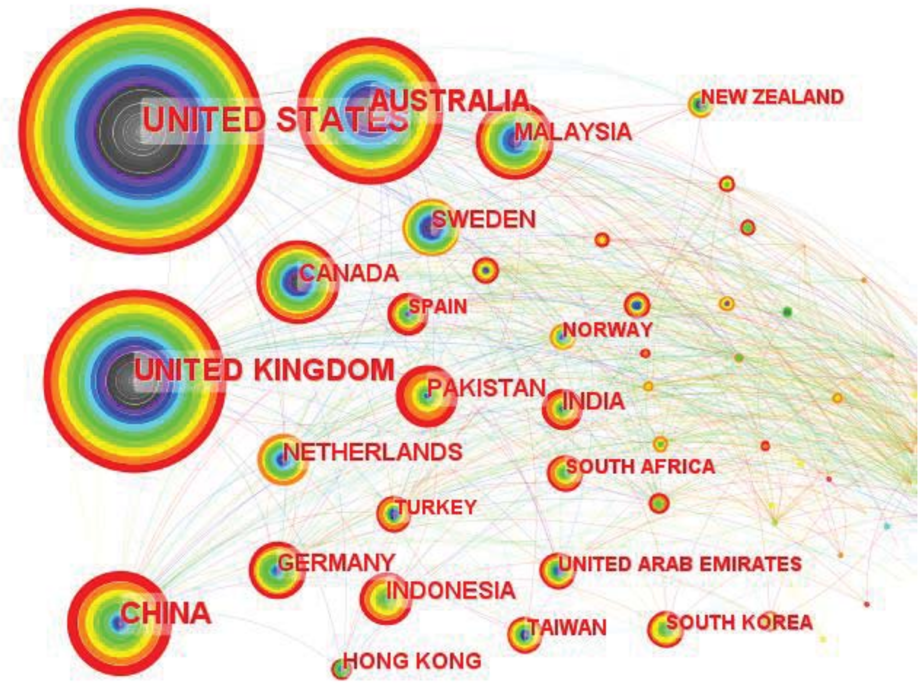

Figure 3. Country/region collaboration network.

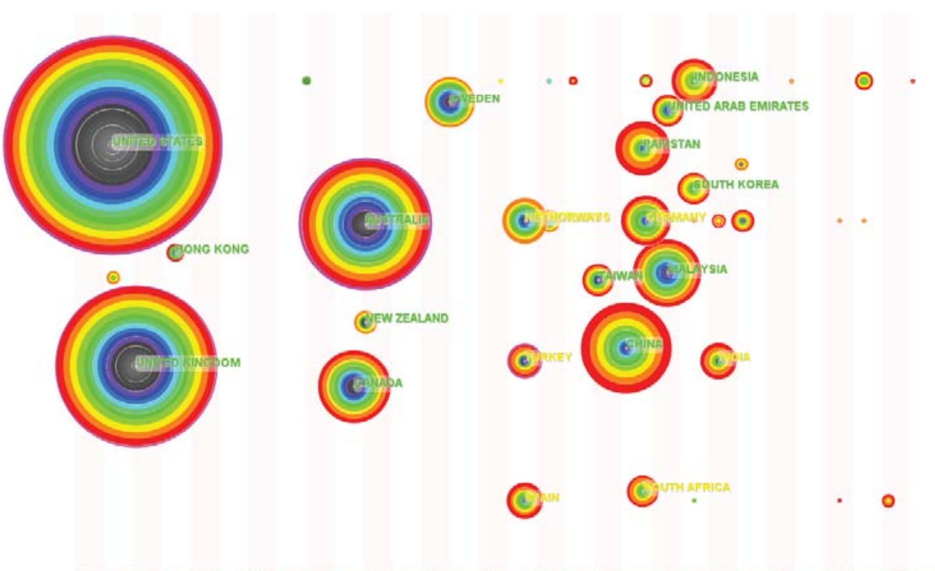

Figure 4. Country/region collaboration network: a timezone view.

Table 1. Top 10 countries/regions based on the number of publications.

Country	Publications	Centrality	Country	Publications	Centrality
US	418	0.21	Pakistan	82	0.03
UK	240	0.18	Canada	73	0.07
China	210	0.09	Germany	59	0.04
Australia	189	0.25	Indonesia	57	0.01
Malaysia	90	0.07	Netherland	51	0.04

3.1.2. Institution Collaboration Network

As shown in Figure 5, the network of collaborating institutions contained 1430 nodes and 1731 links, with a lower density of 0.0017, and the links between the nodes indicate the cooperation between the involved institutions. The relatively loose structure indicated a low level of institutional cooperation in this field of research. Table 2 lists the top 20 institutions that contributed the most publications, such as RMIT University (25 articles), University of Johannesburg (24 articles), Tongji University (21 articles), Curtin University (20 articles), Tsinghua University (20 articles) and The Hong Kong Polytechnic University (18 articles). It is clear that Australian universities are the largest contributors to research on leadership in construction, with six institutions (RMIT University, Curtin University, Queensland University of Technology, Deakin University and The University of Auckland, ranking 1, 4, 7, 16 and 20, respectively). Although a research group is gradually forming, there are still some institutions without external collaboration. Among all the institutions, only RMIT University and Curtin University have a betweenness centrality exceeding 0.05. This indicates a lack of close cooperation between institutions. The red in Figure 5 indicates the citation burst strength. The top-ranked item by bursts is Curtin University, with bursts of 3.57. The second one is RMIT University, with bursts of 3.24. RMIT University has a high number of publications, a high burst strength and a high betweenness centrality, which indicates its significant contribution to this research field.

Figure 5. Institution collaboration network.

Table 2. Top 20 institutions based on the number of publications.

Institution	Publications	Centrality	Country/Region
RMIT University	25	0.06	Australia
University of Johannesburg	24	0.01	South Africa
Tongji University	21	0.05	China
Curtin University	20	0.08	Australia
Tsinghua University	20	0.03	China
The Hong Kong Polytechnic University	18	0.04	Hong Kong
Queensland University of Technology	18	0.04	Australia
City University of Hong Kong	17	0.05	Hong Kong
Chongqing University	17	0.04	China
National University of Singapore	15	0.05	Singapore
University of Science Malaysia	15	0.02	Malaysia
The University of Hong Kong	15	0.02	Hong Kong
Arizona State University	10	0.02	US
Tianjin University	14	0.03	China
Ariel University	13	0.00	Israel
Deakin University	13	0.04	Australia
University of Florida	12	0.04	US
University of Colorado	8	0.02	US
University of Wolverhampton	11	0.00	UK
The University of Auckland	9	0.01	Australia

3.1.3. Author Collaboration Network

The contributions of the authors were also identified. As shown in Figure 6, a loose-structure network of collaborating authors consisted of 4124 nodes and 7884 links. There is a large number of scholars and extensive collaborations in this field. As shown in Table 3, the most productive authors were Shamas-ur-Rehman Toor and Lianying Zhang, who both published 11 articles in this field. However, most authors received a centrality number of 0. The betweenness centrality of a node in the network measures the importance of a node's role as a bridge in the network. Since the system only retains two decimal places, the number 0 means that most of the authors, as nodes, had a centrality of less than 0.01, which indicates that the cooperation in this area is dominated by small teams. Further analysis revealed some communication between the research teams, but there is still a lack of key connecting hubs between different research groups.

Table 3. Top 10 authors based on the number of publications.

Author	Publications	Centrality	Author	Publications	Centrality
Shamas-ur-Rehman Toor	11	0	Ralf Müller	9	0.01
Lianying Zhang	11	0.02	Sadaf Iqbal	9	0.02
Ying Chen	10	0	Junwei Zheng	8	0
Umer Zaman	10	0	George Ofori	8	0
Yanfei Wang	9	0.02	Li H	8	0.02

Figure 6. Author collaboration network.

3.2. Co-Citation Analysis

3.2.1. Author Co-Citation Analysis

As illustrated in Figure 7, the author co-citation network with 1147 nodes and 7737 links was conducted to clarify the essential information of authors and their relationships. There are a few significant nodes in the network, which shows that the leadership research basis in the construction industry is relatively concentrated. The top 10 authors in terms of co-citation frequency, burst strength and centrality are listed in Table 4. Bernard M. Bass has the highest frequency of co-citation and the second-highest centrality. Therefore, it can be said that his research is the foundation of this field. Bernard M. Bass and Bruce Avolio have worked closely together and have contributed significantly to transformational leadership research [40–43]. Both of them are also the authors with the highest centrality values, which shows that transformational leadership has received more attention in construction leadership research. The third most co-cited author is Philip M Podsakoff, whose research interest is the intersection of organisational behaviour and leadership, along with Robert J. House. Among the ten most co-cited authors, Joseph F. Hair and Claes Fornell are interested in multivariate analysis and structural equation models. Moreover, the co-citation of Jörg Henseler, who also focuses on research methods, burst in the year 2019, which indicates the growing use of quantitative methods in construction leadership research.

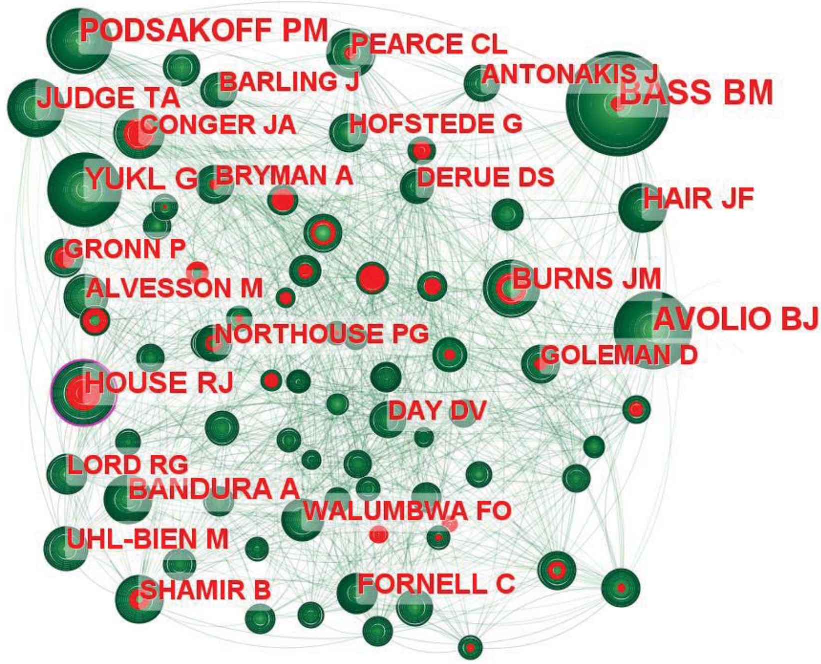

Figure 7. Author co-citation network.

Table 4. Top 10 authors in terms of co-citation frequency, burst strength and centrality.

Top 10 Authors in Co-Citation Frequency	Top 10 Authors in Burst Strength	Top 10 Authors in Centrality
Bernard M. Bass (541)	Jane M. Howell (14.62)	Robert J. House (0.17)
Bruce Avolio (363)	D.A. Aga (13.84)	Bernard M. Bass (0.1)
Philip M Podsakoff (308)	Jörg Henseler (13.79)	Alan Bryman (0.09)
Gary Yukl (283)	Fred E.Fiedler (12.51)	Bruce Avolio (0.07)
Joseph F. Hair (235)	Robert J. House (11.77)	James McGregor Burns (0.07)
Robert J. House (211)	Robert R. Blake (11.56)	Michael Fullan (0.07)
Timothy A. Judge (190)	Jay A. Conger (11.31)	Philip M Podsakoff (0.07)
James McGregor Burns (185)	Lianying Zhang (10.72)	Robert R. Blake (0.06)
Albert Bandura (178)	Daniel Katz (10.22)	Mats Alvesson (0.06)
Claes Fornell (162)	James R. Meindl (9.94)	Paul Hersey (0.06)

According to the research topics of the co-citation authors, the distribution of their subject areas can be roughly divided into three categories: leadership theory (Bernard M. Bass, Bruce Avolio, Philip M Podsakoff, Gary Yukl, Robert J. House, Timothy A. Judge, James McGregor Burns, Jane M. Howell, James R.Meindl and Robert J. House), research methods (Joseph F. Hair, Claes Fornell, Jörg Henseler and Alan Bryman) and management (D.A. Aga, Robert R. Blake, Lianying Zhang and Paul Hersey). Keeping track of the research work of authors in the field of construction project management could facilitate capturing the latest developments in the field, while the studies of authors in the field of leadership theory and research methods could drive researchers to make theoretical and methodological innovations.

3.2.2. Reference Co-Citation Analysis

The reference co-citation network was generated by CiteSpace, using a log-likelihood ratio (LLR.) weighting algorithm to analyse the articles and their references in the data. A total of 102,546 distinct references were analysed in the process, and cluster labels were displayed once the process had been completed. The clusters were numbered in descending order of cluster size, starting from the largest cluster #0, the second-largest cluster #1 and so on. As shown in Figure 6, the intellectual structures of the construction knowledge domain were investigated. The brighter the colour of the area, the more active the field of research. The network of reference co-citations presented in Figure 8 contains 1163 nodes and 2943 links. According to Chen Chaomei, the developer of citespace, high-frequency co-cited articles are often regarded as milestones due to their creative contributions [30]. Therefore, the top 10 cited references listed in Table 5 form the theoretical basis for this knowledge domain.

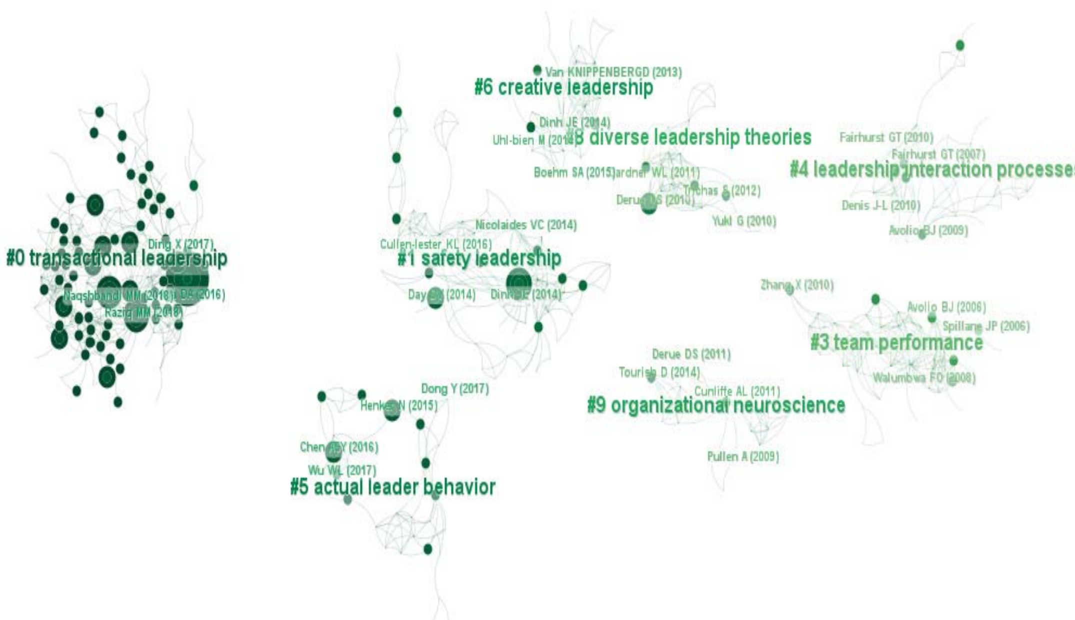

Figure 8. Reference co-citation network.

The network is divided into eight co-citation clusters based on the text analysis using the LLR. algorithm, which usually gives the best result in terms of uniqueness and coverage [44], and the information of the eight clusters is presented in Table 6. The silhouette number measures the average homogeneity of a cluster. All clusters received a high score, which indicated a good consistency of the cluster members. As shown in Table 5, the top terms of the clusters are traditional and long-lasting research topics in the construction project management field, which reflect the knowledge base of construction leadership research. In order to clarify the knowledge structure of this research field, a detailed discussion of the top five clusters is presented below. Clusters 6, 8 and 9 were also excluded due to their small size.

Table 5. Top 10 cited references.

Citation Counts	References	Author	Source Journal/Publisher
24	Transformational leadership and project success: The mediating role of team-building [45]	D.A. Aga	International Journal of Project Management
13	Leadership theory and research in the new millennium: Current theoretical trends and changing perspectives [46]	Jessica E.Dinh	The Leadership Quarterly
13	Leadership styles, goal clarity, and project success: Evidence from project-based organisations in Pakistan [47]	Muhammad Mustafa Raziq	Leadership & Organization Development Journal
11	Knowledge-oriented leadership and open innovation: Role of knowledgemanagement capability in France-based multinationals [48]	M. Muzamil Naqshbandi	International Business Review
10	Linking transformational leadership and work outcomes in temporary organisations: A social identity approach [49]	Xian Ding	International Journal of Project Management
10	A primer on partial least squares structural equation modelling (PLS-SEM) [50]	Joseph F. Hair	Sage publications
10	Advances in leader and leadership development: A review of 25 years of research and theory [51]	Joseph F. Hair	Engineering, Construction and Architectural Management
8	Leadership, organisational culture, and innovative behavior in construction projects: The perspective of behavior-value congruence [52]	David V.Day	The Leadership Quarterly
8	Servant Leadership: A systematic review and call for future research [53]	Nthan Eva	The Leadership Quarterly
8	A meta-analytic review of authentic and transformational leadership: A test for redundancy [54]	George C.Banks	The Leadership Quarterly

Table 6. Top eight co-citation clusters.

Cluster ID	Size	Silhouette	Mean (Year)	Top Terms (Log-Likelihood Ratio)
0	127	0.995	2021	Transactional leadership
1	77	0.927	2016	Safety leadership
3	52	0.938	2010	Team performance
4	37	0.981	2011	Leadership interaction processes
5	31	0.983	2018	Actual leader behaviour
6	29	0.954	2016	Creative leadership
8	22	0.981	2013	Diverse leadership theories
9	18	0.983	2014	Organisational neuroscience

(1) Transactional leadership

The "transactional leadership" cluster had the largest size in the construction leadership field, with a focus on the relationship between the leadership styles of project managers and project success. As a representative type, transactional leadership is used as a cluster label by the LLR algorithm. In the project management field, project success is a major concern and a recurring theme in the literature. Although there is still disagreement on what "project success" is, many leading scholars in the project management field agree with the point of view that the project manager is an important factor leading to project success [55]. Therefore, the factors related to project manager leadership have received the most attention in this field of research. In the two most co-cited papers in cluster 0, D.A. Aga [44] examined the mediating role of team building between transformational leadership and project success based on a field survey of 200 development project managers. At the same time, Muhammad Mustafa Raziq [46] contextualised transactional leadership style and transformational leadership style in the project environment to clarify the impact of leadership style on project success.

Although cluster 0 has the largest size in the construction leadership field, there are still few studies directly exploring the relationship between leadership and program success. Zhang [56] explored the mediation role of leadership styles between project managers' emotional intelligence and other participants' satisfaction. Tabassi [57] proposed that the leadership competency of project managers is a critical factor in project success. Maqbool [58] conducted a quantitative study on the Pakistani construction industry, and the results show that project managers with desired leadership competencies ensure higher project success rates. Some other representative works of literature use leadership as a factor in research models [59–61]. An increased understanding of the factors that influence project success is very important for project-based organisations. Many factors affect the success of a project. The project manager is one of the most important of these factors. Therefore, project success as a criterion can provide a perspective on the leadership of project managers and can help in better understanding the mechanism of the project manager's leadership [44].

(2) Safety leadership

With technological improvements, significant advances have been made to safety levels in the construction industry. The focus on safety has shifted from individual work to organisations. Meanwhile, there has been a significant increase in research on leadership and safety [62]. For example, Hoffmeister [63] explored the links between individual leadership facets and the safety outcomes of the employee. Mullen [64] examined the moderating role of transformational leadership on the relationship between employer safety obligations and employee safety performance based on social exchange theory. Wu [65] identified four dimensions of safety leadership practices to match the types of leaders in construction projects.

Much of the research in this cluster focuses on the safety performance of individual workers [66–68]. However, the two most co-cited papers in this cluster developed multilevel models and introduced other research subjects. Wu [69] proposed that the safety leadership of owners, contractors and subcontractors in construction projects affected each other and clarified the impacting paths. Guo B H W [70] developed an integrative model to predict safety behaviour in the construction industry. Therefore, as the construction industry continues to develop, there is a need to develop a more comprehensive and integrated model exploring the mechanism of safety leadership in the construction industry.

(3) Team performance

Project teams are central to organisations. Due to the temporary nature of project teams, some project teams still cannot reach a stable and mature team when the project is completed, resulting in project failure [71]. Hence, the effective operation of the project team must be highly valued in construction projects [72].

The project team is composed of members with different demands, goals and expectations, and the team leader should motivate members in the early stage to form a team with consistent goals, vision and cohesion [73]. As a temporary organisation, project team members often have different professional backgrounds. Therefore, the project manager's ability to motivate members directly affects team performance [74]. Odusami et al. [8] ranked leadership and motivation as the most important skills for the project leader. Schmid & Adams [71] emphasised that team motivation can be heavily influenced by the project manager, especially during the early stages of the project. Ralf Müller & Turner [75]'s study came to a similar conclusion. Gehring [76] argued that the ability of project managers to perceive the motivations and demands of project team members is the basis of team leadership. Moreover, the competency of project managers in providing task guidance to project team members has been shown in empirical research to impact project performance significantly [75].

(4) Leadership interaction processes

Leadership is constructed and works in the process of practical interaction [77]. Meanwhile, leadership is assumed to positively contribute to most modern organisations' action processes [78]. In practice, different interaction styles of the leaders and followers always imply different group productivity levels [79]. Therefore, Carroll [25] urged leadership research on the "practice turn" in social settings by leaders and followers in interaction. In this cluster, scholars' interests focus on the leadership interaction between different project stakeholders. Chunlin Wu explored the leadership interaction between the key project stakeholders in his two studies [65,69]. Limao Zhang developed a model to clarify the relationships between different stakeholders' leadership and safety performance in a changing construction project environment. Furthermore, the interaction of the individual with the project environment is concerned in this cluster [51]. The study of leadership interaction is interdisciplinary [80], which requires collaborative research between scholars with different disciplinary backgrounds.

(5) Actual leader behaviour

The leader's behaviour can positively impact role clarity and work engagement [81]. Research in this cluster has focused on the impact of the project managers' behaviour on project team members. For example, Naoum [82] developed a model for the stress-coping behaviour of UK construction project managers. NannanWang [83] conducted comparative research to reveal how project managers' conflict-resolving behaviours affect project success. At the same time, Owusu-Manu [84] explored the linkages between the project manager's leadership style and mindset behaviour. The studies in this cluster offered a new, empirical insight into understanding the project manager's leadership.

3.3. Co-Word Analysis

3.3.1. Co-Occurrence Analysis

In order to trace research trends and topics, a timezone view of keywords co-occurrence analysis was conducted, and the result is visualised in Figure 9 below. The keyword co-occurrence network contained 558 nodes and 2679 links. The node size shows the frequency at which a keyword occurred in the data. The top 10 keywords in terms of co-occurrence frequency, burst strength and centrality are listed in Table 7. These keywords connected different research topics and significantly influenced the research of leadership in construction.

Table 7. Top 10 keywords in terms of co-occurrence frequency, burst strength and centrality.

Top 10 Keywords in Co-Occurrence Frequency	Top 10 Keywords in Burst Strength	Top 10 Keywords in Centrality
Leadership (83)	Project management (7.38)	Construction (0.36)
Transformational leadership (73)	Mediating role (6.67)	Leadership (0.34)
Construction (66)	Leadership (5.37)	Construction industry (0.34)
Construction industry (65)	Model (4.62)	Behaviour (0.18)
Performance (63)	Construction project (4)	Construction project (0.13)
Behaviour (38)	Safety climate (4)	Transformational leadership (0.11)
Management (38)	Transactional leadership (3.95)	Management (0.1)
Project management (38)	Professional aspect (3.91)	Performance (0.09)
Model (30)	Construction industry (3.86)	Project management (0.08)
Mediating role (26)	Behaviour (3.8)	Model (0.05)

As shown in Figure 10, the top 10 keywords with the strongest citation bursts were detected to explore the research field in more depth. The number of citations of the keyword "mediating role" has increased dramatically since 2020, with a high strength number of 6.67, indicating the direction of this research field in the next few years. Academics are becoming increasingly concerned with the mediating role between leadership and project success.

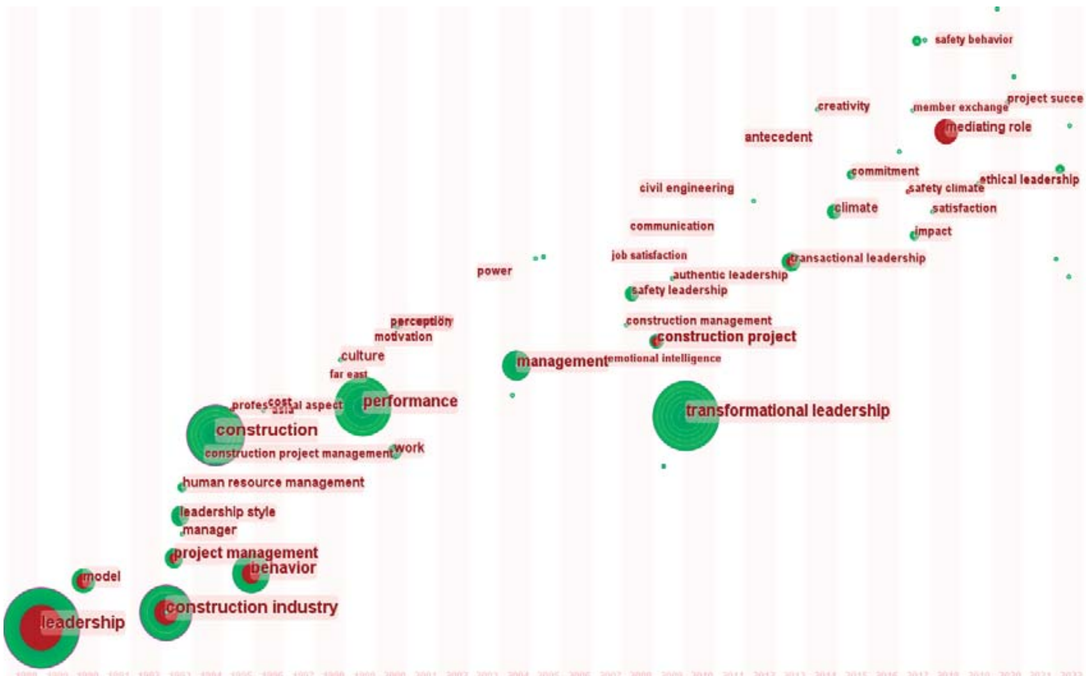

Figure 9. Keywords co-occurrence network from a timezone view.

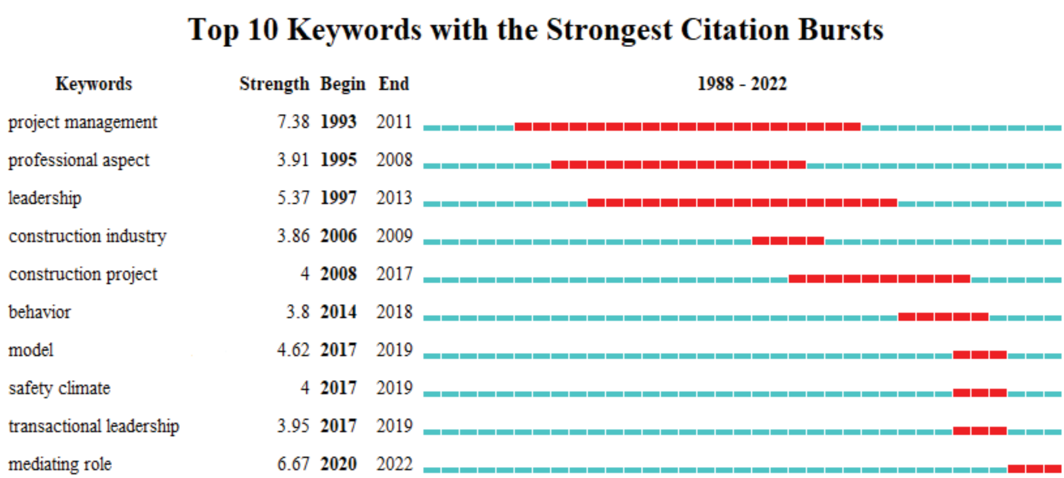

Figure 10. Top 10 keywords with the strongest citation bursts.

3.3.2. Keywords Evolution Analysis

The keywords evolution trend was also shown in the timezone view of co-occurrence analysis. In 1989, the keywords "leadership" and "model" appeared and marked the beginning of this field of study. During 1993–2000, there was a big outbreak of keywords, including "construction", "construction project management", "performance", "leadership style", "behaviour", "culture" and "perception", with a high co-occurrence frequency.

During 2008–2013, the keywords “transformational leadership” and “transactional leadership” appeared and gradually became a research hotspot. There are new co-occurrence keywords, such as “stakeholder management” and “knowledge sharing”, which appeared with no highly frequent one in the last two years due to the short time for accumulation. Furthermore, the appearance of the keyword “PLS-SEM” in 2022 is noteworthy. As a modern multivariate analysis technique, the application of PLS-SEM is relatively new in the construction management field [85].

4. Future Research Prospects

With a large and rapidly growing body of leadership research, the development of related research in construction has led to many achievements. Based on the research results of Section 3, we propose the following trends and innovative research areas for future research.

4.1. Future Reserch Trends

(1) More studies on leadership in different countries. According to the collaboration analysis, it can be seen that new countries and regions enter this research field every year. Due to the variable level of the progress of urbanisation in various countries, the construction industry in developing countries is gradually attracting research attention. Researchers should expand the geographic scope of the countries studied to discover differences in the construction industry between less developed and developed countries. In the process, cross-country academic cooperation should be gradually strengthened. The impact of policy and cultural differences across countries on leadership in the construction industry is worth examining. In practice, these explorations are of great significance for international cooperative construction projects.

(2) More different theoretical perspectives. Leadership theory has practice-focused origins and is designed to address practical challenges for leaders within an organisation [86]. With the development of leadership theory and organisational theory, we argue that researchers should consider the leadership of construction from different theoretical perspectives. We also need to think more broadly about the factors contributing to the improvement of leadership in construction. Therefore, stakeholders outside the project team will gradually be paid attention to by researchers. The emergence of the co-occurrence word, stakeholder management, in 2021 confirms this.

(3) More emphasis on the leadership behaviours of project managers. The growing use of the term “behaviour” shows that scholars are becoming increasingly concerned with how actual leadership behaviour affects the success or failure of a project. In the top eight co-citation clusters, cluster 5 focuses on the impact of the project managers’ behaviour on project team performance. Research on leadership competencies in construction projects largely mirrors the evolution of the broader discourse of behavioural psychology and has attracted scholars’ attention in recent years. It will be valuable for future research to identify the key leadership behaviours of a project manager that lead to project success. In practice, project managers can be quickly and accurately identified based on this criterion.

(4) More quantitative studies using the accurate and effective model. Leadership theory has practice-focused origins. The burst of the keyword “model” in 2017–2019 and the appearance of the keyword “PLS-SEM” in 2022 indicates the continuous emergence of quantitative research in the construction leadership field. Therefore, with in-depth study, the burst of the keyword “mediating role” is logical. Future research should integrate with existing research clusters, such as safety climate [87–89] and knowledge management [90], to conduct more objective empirical research on the mechanism of construction project organisation. The mediating role of project success factors when it comes to different types of leadership will become a research hotspot in the future [91–93].

4.2. Innovative Future Research Areas

Project-based work is booming around the world today. The world itself is constantly changing, and climate change, demographic shifts or pandemic diseases will have a profound impact on the organisation of human society. Therefore, the study of leadership in the project organisation is bound to generate new areas of knowledge with these changes.

(1) Demographic shift and leadership. Research on the relationship between leadership and demographic factors is not uncommon. Previous research has investigated the relationship between demographic traits and leadership from various perspectives, such as gender, nationality and educational background [94]. However, as the demographics have changed, not only have the characteristics of the project manager changed, but the project members are no longer the same. As baby boomers gradually retire, the demographic structure of the project organisation has changed, with practitioners showing the characteristics of youth, a strong personality, high education and a strong desire to learn. How to better manage these new generations of knowledge-based employees is a problem that must be solved in project management today. At the same time, gender issues are increasingly relevant in project management as more women enter the industry. Therefore, the role of leadership in project organisations with changing demographics can be an interesting area of research.

(2) Technology advances and hybrid leadership. As many new technologies, such as Building Information Modeling, big data or virtual teams, are applied to project management, the form of project organisation inevitably changes. Meanwhile, remote work has become the norm in the years since the COVID-19 pandemic. Therefore, as technology advances, a hybrid work environment will become a problem for every project manager. Hybrid environments are hybrid, highly flexible environments that combine traditional face-to-face environments with remote work environments, where employees move in and out of the office flexibly and rely heavily on technology-mediated communications. How do technology and virtual teams affect leadership styles, communication styles and project performance? The answers to this question will become an innovative area of research.

(3) Ethical leadership. Research on ethical leadership and corporate social responsibility has a long history. However, research on project ethics is still in its infancy. Ethical leadership contributes to the effective functioning of an organisation and also affects the attitudes, behaviours and performance of employees [95]. Research on leadership in project-based organisations can not only improve project performance but also drive the development of relevant industry standards.

5. Conclusions

This review sought to explore the current state and trends in leadership research in the field of construction. A large number of publications were considered, from the beginning of the study of construction leadership to the present. A scientometric analysis, based on CiteSpace, of a total of 1789 bibliographic records collected from Scopus and the WoS core collection database was conducted to identify and visualise the intellectual structures of the leadership knowledge domain in the field of construction. In construction leadership research, very few studies have addressed the theoretical changes over time. This review solved this problem by conducting a comprehensive analysis of the development of leadership theory in construction. Meanwhile, further systematic and accurate predictions of changes are provided in this field of study, which could guide scholars in this field and gain insights into future development.

The conclusions that can be drawn from the results are as follows. Since 2006, research on the leadership of the construction industry has gradually deepened, and the number of annual publications has increased significantly. The United States had the earliest start in this field, with a publication frequency and centrality obviously ahead of other countries. The US has also played an essential role in establishing international cooperation for related research. Research in related fields in China and Australia is also developing rapidly, but their performance in terms of international cooperation, which needs to be established gradually over a long time, needs to be strengthened. Scholars from new countries join this research field every year, which has manifested in uneven global economic development. Most of the most prolific institutions and authors come from Asia and Australia, but the cooperation network between them is not well established. Scholars usually focus on the construction industry in their own country. The lack of international cooperation can also be seen from the co-citation analysis, which shows that cross-cultural and international project research has not become a significant cluster. Therefore, we propose that, in future research, scholars should pay more attention to the construction industries in developing countries and carry out more international academic cooperation.

According to the co-occurrence analysis of keywords and the article cluster analysis, it can be seen that transactional leadership, safety leadership, team performance, leadership interaction processes and actual leader behaviour formed related research clusters. Safety and performance are always of concern to researchers. Among the various leadership styles, transformational leadership has received the most attention. The keyword "mediating role" has suddenly appeared in a large number of articles in the past two years. It can be predicted that there will be more empirical studies on the relationship between leadership and project success in future research. At the same time, the mediating role of project success factors on different types of leadership should receive more attention from scholars. Therefore, we proposed following the potential trends: (1) More studies on leadership in different countries; (2) More different theoretical perspectives; (3) More emphasis on the leadership behaviours of project managers; (4) More quantitative studies using the accurate and effective model. At the same time, we also propose three innovative future research areas: (1) Demographic shift and leadership; (2) Technology advances and hybrid leadership; (3) Ethical leadership.

The contribution of this study is in the following two aspects. Theoretically, this article proposes a knowledge map to comprehensively depict the past, present and future of construction leadership research. The collaboration analysis reveals the main contributors in this domain at a micro level. The co-citation analysis identifies the critical research areas, reflecting the knowledge bases and research hotspots. Moreover, the co-word analysis traces the knowledge evolution and presents the historical research hotspots. The results of this study not only point to future research trends but also provide a reference for construction companies to formulate project manager selection criteria at the practical level. Limited by CiteSpace and language, the samples in this study are peer-reviewed articles in English from Scopus and the WoS core collection database. Increasing the range of data sources in future research may result in a more accurate intellectual structure of the leadership knowledge domain in the field of construction. Moreover, the use of other visualisation techniques should be encouraged to enrich the map of this knowledge domain.

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An Empirical Examination of Knowledge Management and Organizational Learning as Mediating Variables between HRM and Sustainable Organizational Performance

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Abstract: Despite increasing competition, the construction industry is still lagging behind other industries in several aspects such as productivity growth, technology adoption, and human resource management. Although the causal link between human resource management (HRM) and organizational performance (OP) is well established and reinforced by several studies, the mediating mechanisms through which HRM practices impact organizational performance remain areas lacking consensus. This article, therefore, aims at examining the mediating roles of knowledge management (KM) and organizational learning (OL) in the established relationship between HRM and the long-term or sustainable peformance of Thai construction firms. Confirmatory factor analysis and partial least square structural equation modeling (PLS-SEM) were employed as the methods of analysis. Based on the dataset of 194 responses, the empirical results of the study strongly supported the three hypotheses that assumed positive relationships between (1) HRM and OP, (2) HRM and knowledge management, and (3) organizational learning and the OP of the firms under study. These findings thus provide empirical evidence for the three relationships. However, empirical results testing the roles of KM or OL or both as mediating variables behind the link between HRM and sustainable OP were not confirmed by the dataset. Therefore, one of the practical implications provided by this study is that Thai construction firms should be better aligned and integrated their HRM practices, knowledge management, and organizational learning to enhance the firms' competitive advantage and to help lead the firms towards a more sustainable pathway of business operations. However, since the fragmented activities of construction make it hard to apply human resource management effectively, such good alignment and integration of HRM, KM, and OL for improving performance may, in practice, be quite challenging for most construction firms.

Keywords: performance; HRM; knowledge management; organizational learning; PLS-SEM

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1. Introduction

The construction industry is an important economic sector that helps contribute significantly to the economic growth and social development of our society. However, the industry and engineers working in this field had long been criticized by philosophers and environmentists for polluting the world with dust, solid waste, greenhouse gases, and so on [1]. For example, some studies have found that the construction industry is probably responsible for the lion's share of the depletion of the world's natural resources [2,3], and it was estimated in 2018 that construction activities contribute to about 35.7% of the total waste in EU countries [4]. In developing countries, the problem could be particularly severe since a considerable amount of government spending through public finance has been allocated for public projects such as economic infrastructure, which are the bedrock and lifeblood of today's modern economies [5]. Currently, alternative infrastructure financing through a program called Public Private Partnership, or PPP, has been increasingly used by governments to provide public services. In PPP, a private entity (i.e., a concessionaire) is contracted in the long-term with a responsible government agency for the funding, design, construction, and operation and maintenance of the project on behalf of the agency. In Thailand, the PPP market is gaining monentum, and it is expected to grow over the next few years. For instance, the State Enterprise Policy Office (SEPO), a public agency overseeing PPP implementation in Thailand, announced the *2020–2027 PPP Plan*, which included 92 projects with total projected investment worth about $26 billion [6].

However, not only are large domestic construction firms interested in the opportunities offered by PPP infrastructure projects but international construction firms also are becoming no less eager to participate in these types of projects. As is the case for Thailand, large domestic construction firms specializing in infrastructure projects, such as CH. Karnchang Plc and Italian-Thai Development Plc, two listed and leading construction firms in Thailand, are currently under increasing pressure to compete with prominent international construction firms, particularly those from China such as China State Construction Engineering Corporation, who is currently the largest construction firm in the world measured by revenues (e.g., in 2021, the company's total revenue was $195,658 million) [7].

Most of the large and medium infrastructure construction firms in Thailand will inevitably have to engage in PPP infrastructure projects, either directly as general contractors (GC) or indirectly as subcontractors. The relationship among parties involved in a PPP setting is especially complex. For example, at the outset of the construction phase, a joint venture (JV) is usually formed either by domestic construction firms or by domestic and international construction firms to bid for the construction work. In addition, equity and debt contributors of the PPP project tend to become closely involved during the construction so as to ensure the completion of project construction. Therefore, under this setting, the ability of construction firms' key personnel to work collaboratively and to acquire, store, share, and transfer new knowledge while working together has become essential to the success of the project and, ultimately, to the growth and survival of the firms [8,9].

Einstein once said that in the middle of difficulty lies opportunity. In fact, difficulty can be a powerful driving force for sustainable performance improvement and adaptation, commonly known as "the Principle of the Hiding Hand" theorized by Hirschman [10]. Accordingly, incidents such as increasing competition and the ongoing impacts of the spread of the COVID-19 and the pandemic may be a catalyst for changes, forcing firms to find efficient ways of doing things.

There is a widely held belief among academics and practitioners in construction that innovative construction methods [11], effective and efficient project management, and prudent business management [12], among all other things, should be excercised by key people such as engineer-managers to help control construction costs. Knowledge, particularly that associated with practical knowledge, plays a large part in how construction work should be done in a more cost-effective way and without compromising specified construction quality. This exercise of innovative construction methods and the business process improvement of firms can be carried out in large part through their employees' knowledge, experience, skills, and expertise, and it requires systematic knowledge management (KM). In addition, in the ever-changing business environment, firms should be able to detect and correct problems to improve performance in the long run, which certainly requires the firms to adopt what is now known as organization learning (OL). As Thai construction firms seek to compete with international firms, especially those from China, their human resources and organizational knowledge embedded in work routines have become an even more important component to the firm's future competitive advantage.

To help conceptualize these ideas about the use of HRM, KM, and OL to manage construction costs and to drive long-term organizational performance (OP), the Casual Loop Diagram (CLD) introduced by Haraldsson [13] is employed to depict the complex interactions among these constructs, as shown in Figure 1.

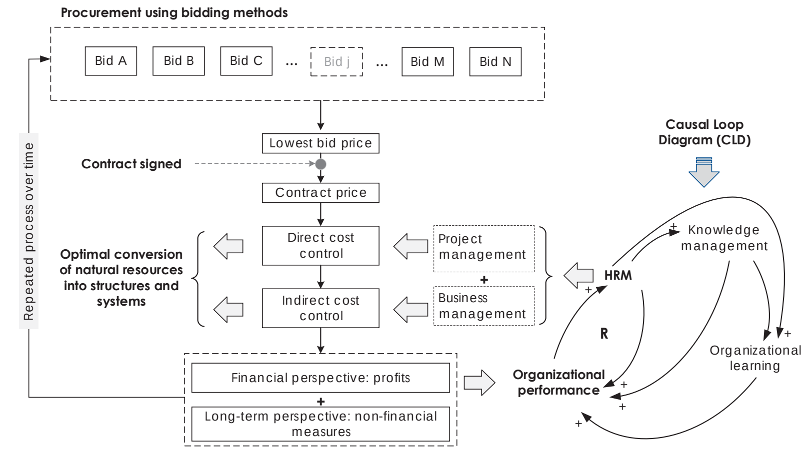

Figure 1. Conceptualized ideas of the study.

Although the positive relationship (denoted by the "+" sign at the near end of the arrow in Figure 1) between HRM and firm-level performance has been well confirmed and reinforced by several studies in the past (denoted by "R" in Figure 1), researchers such as Wright and Ulrich [14] still found it difficult to pinpoint the precise mechanism underlying the link between HRM and the performance outcomes of business operations. Therefore, several studies in the field of HRM emerged to understand a mechanism through which HRM practices may positively affect a firm's performance, and yet they have not come to definitive conclusions on what could be the mediating variables between them.

As for HRM research in the construction industry, which certainly has its own characteristics, several studies also confirmed the casual link between HRM and firm-level performance [15,16]. Some of these studies such as those by Olomolaiye and Egbu [17] and Liao [18] hypothesized that knowledge management of employees was probably a key variable that indirectly links HRM with the performance outcomes of construction firms. A recent study by Kokkaew et al. [19] also confirmed the positive relations between KM and OP in Thai infrastructure construction firms. Some turned their examination to unlocking the link between HRM and performance through organization learning (OL), which they believed could help construction firms better adapt to ever-changing market conditions, thereby increasing the chance of organizational success [20–22].

In summary, although several studies have investigated what a key mediating mechanism could be behind the opaque link between human resource management and organizational performance in the construction industry, to our best knowledge, none have studied the role of KM and OL as two multiple mediating variables in the context of firms specializing in construction.

Therefore, the main objective of this study is to provide an examination of the roles of KM and OL as mediating variables between HRM and sustainable OP (using long-term performance measures as a proxy for sustainable OP) in the setting of the Thai infrastructure construction sector. To explore the relationships between HRM, OL, KM, and sustainable OP of firms under study, a partial least square structural equation model (PLS-SEM) is adopted as a method of analysis in this study. Since most competitors of the Thai infrastructure construction firms are those from China, the results of this study will also be used to compare with those of Zhai et al. [22], whose study also investigated the mediating role of OL in the similar relationship, but of top-grade Chinese construction firms. The contributions of this paper are as follows:

(1). The empirical results of this study could help contribute to the existing body of knowledge of the role of KM and OL in the link between human resource management

(HRM) and long-term or sustainable organizational-level performance (sustainable OP) in the Thai infrastructure construction setting.

(2). The results of this study can be used to compare with those of other studies in similar settings, in which they could become potential competitors to the firms under study. For example, the findings of this study will be used to determine the differences in the levels of employment of KM and OL to enhance OP between Thai and Chinese construction firms.

(3). The proposed conceptual framework and methods of the study can be applied to similar settings in different countries to determine existing performance gaps of construction firms through the use of KM and OL.

The remainder of this paper is organized as follows. In Section 2, we will provide a brief overview of the topics relating to the construction industry, sustainable OP, human resource management, knowledge management, organizational learning, and, more importantly, the studies that tried to unlock the links between these variables. The section ends with past examination of the mediating mechanism behind the link between key constructs. The results of the literature review presented in Section 2 will serve as the basis for hypothesis development in Section 3. Then, Section 4 presents a theorized structural model and a measurement model. In Section 5, a research method is provided in detail. Then, Section 6 provides the information on samples and data collection. Results of structural model assessment and mediation analysis (MA) using PLS-SEM are then presented in Section 7, followed by discussions of the findings and research contributions in Section 8. We then provide the theoretical perspective on the practical implications of the findings for Thai construction firms in Section 9 and the limitations and future research direction in Section 10. The paper closes with a summary and conclusion section.

2. Related Theories and Past Empirical Research

2.1. Challenges of Human Resource Management in the Construction Industry

The construction industry certainly has its own characteristics that set it apart from other industries. For instance, despite adopting new construction technology, such as virtual and augmented reality (VR and AR) and building information modeling (BIM), the industry is still the sector well known for its slow adoption of new technology and its labor intensiveness [23]. Most construction activities still require manual work with close supervision to ensure compliance with quality and safety standards. In addition, construction projects are by nature unique, and they each require different construction methods and techniques, which helps explain the variation in the total construction cost of each project as a result. Construction as a project is a temporary endeavor in which a project team is formed at the inception of the construction and then dissolved when the construction is completed [24]. In addition, the fragmentation of construction processes, composed of several tasks and activities, also makes construction one of the industries where it is difficult to effectively apply human resource management [23]. These are a few examples of the characteristics and uniqueness of construction projects. Some of these characteristics, such as temporary teams and the fragmentation of construction processes, also make it difficult for construction firms in general to manage their human resources effectively, and they in large part account for the persistently low productivity growth of the industry compared with that of other industries [25–28].

Construction firms are currently operating in an ever-increasing business environment, and they could not survive simply by relying on the power of tangible assets, namely, financial, physical resources and labor, but require an increasing role of intangible assets such as innovative construction methods and effective and efficient management techniques [29]. In the industrial age, also known as the Machine Age, organizations treated employees simply as an input of a mechanization production process. Such mechanization of work was carried out to increase productivity by reducing work defects caused by workers. This management idea is known as scientific management, pioneered by Frederick Taylor. Today, the management perception of employees as an input has dramatically changed. Departing from the scientific management and expertize eras to today's management philosophy with a high emphasis on empathy, organizations now place a high value on their employees' knowledge, skills, and abilities (KSAs), a term known as "human capital." This economic view of employees' KSAs as one of the most important intangible assets was pioneered by distinguished economists such as Schultz [30], Becker [31–33], and Pfeffer [34]. However, unlike other assets such as financial assets, human capital is a variable that is difficult to model and measure correctly. They are also difficult and risky to manage in order to obtain the expected results. For this reason, certain researchers such as Youndt and Snell [35] view employees' knowledge, skills, and abilities as the most expensive assets that can be deployed to improve a firm's performance.

Today, the construction industry is facing increased changes and uncertainty and is evolving into what is known as a knowledge-based industry [28]. Many researchers have begun considering not only HRM but also knowledge management and organizational learning as essential management tools that can be exploited to enhance firm-level performance [36,37]. For instance, with the widespread use of communication technologies, construction firms can adopt such technologies to facilitate knowledge sharing among senior and junior employees. This practice may in turn enable organizations to store practical knowledge and know-how in working processes, which could be helpful for continuing work improvements within organizations [38].

2.2. Sustainable Organizational Performance

Like most managers, Rowley [38], for example, advocates that each organization should have its own business strategies, each with direct or indirect implications for human resource management. In a famous book by Porter [39], cost reduction and quality management are the examples of the strategies commonly adopted by most firms in the 1980s. Publicly funded construction work usually requires transparent procurement and fair competition. Competitive bidding is one of the most commonly used methods for selecting construction firms in public procurement. The ability to control the costs of the construction work of a contracted firm is therefore crucial for the performance of construction firms engaging in public construction projects.

In the past, most management experts believed that the ultimate management team's responsibility was to maximize the profits for shareholders. However, by focusing too much on profit maximization, especially in a short-term period, the manager, who is perhaps merely an agent, of a company may do so at the expense of the future profits of the principals or shareholders of the company. In other words, financial performance should not be solely treated as an indicator of the chance of survival of the firms since it is a lagging indicator. Accordingly, Kaplan and Norton [40] proposed a more integrated and sustainable approach called the balanced scorecards (BSC) to the management of a firm's performance by including non-financial performance measures, namely, customer satisfaction, internal business process, and learning and growth, all of which could help lead the firm to a more sustainable path of organizational performance.

These three "non-financial performance measures" may be regarded as sustainable performance of the firms. As for the link between these three non-financial performance measures and sustainability, construction firms with better performance could have a better chance of winning a bid for a construction contract since they are more likely to be cost-effective in performing construction work by, for example, controlling materials to be less wasteful, which is in line with the principle of the optimal conversion of natural resources (see Figure 1 for the depection of this conceptualized idea).

2.3. Human Resource Management

Human resource management has evolved from people management, known in the past as personnel management (PM) [41]. HRM may be broadly defined as "a coherent approach to the management of an organization's most valuable assets, which are the people working there, who individually and collectively contribute to the achievement of its objectives and goals" [42]. The development of a comprehensive HR framework was pioneered by Guest [43], who first outlined the essence of human resource management. He also extended the HR timescale from a short-term to a more long-term, and integrated HR policies into the strategies of an organization.

In addition, Pfeffer [34], one of the leading HR researchers, suggested that some HR practices, if properly used, play a vital role in determining the level of competitive advantage of a firm. Therefore, according to Pfeffer [34], key HR activities that should be included in HR practices are, for example, selective recruiting, employment security, incentive payment, participation and empowerment, training, information sharing, compensation, and promotion from within. In summary, these HR activities must be appropriately designed and implemented with the alignment of organization's core values, objectives, goals, and long-term strategies.

2.4. Knowledge Management and Organizational Learning

Knowledge and knowledge management (KM) may be defined in several different ways based on the context in use. Beesley and Cooper [44], for instance, attempted to find a consensus on how knowledge and KM should be defined. Their investigation on the subject found that the most cited definition used to describe knowledge is given by Polanyi [45] who distinguished two fundamentally different kinds of knowledge. According to Polanyi [45], the first type of knowledge is called explicit knowledge, which is personal/individual. This type of knowledge can be expressed in forms such as written words, pictures, or numbers, and it can be communicated and trasferred quite easily. The second type of knowledge is known as tacit knowledge, which is highly personal and difficult to properly formalize, communicate, and easily share with others. As for the term "knowledge management (KM)," we adopted the defintion by Law [46] who defined it as "the process of acquiring, storing, distributing, and using information within a firm."

In the field of knowledge management, there were several proposed models. However, based on our extensive literature review, the most common used model was the one formulated by Marquardt [47] and Beesley and Cooper [44], whose KM model includes four main components:

(1) knowledge acquisition,
(2) knowledge creation,
(3) knowledge storage and retrieval,
(4) knowledge transfer and utilization.

In this study, we adopted Marquardt's and Beesley and Cooper's KM model.

The engineering and management knowledge of construction firms are of great importance to the sustainability of the world [48], which has limited natural resources to serve the insatiable needs of humankind. This is because, to the bare minimum, "engineering is the application of scientific methods to the optimal conversion of natural resources into structures, machines, products, systems, and processes for the benefits of mankind" [1]. Therefore, if properly employed and implemented, engineering knowlege could help firms tame construction costs by controlling construction materials and labor required for a project to be less wasteful, as depicted in Figure 1.

Another notion related to KM is organizational learning (OL). OL and KM are related-but-different concepts. As dfiiferentiated by Easterby-Smith and Lyles [49], KM focuses on the content (i.e., what is acquired) that can be used in practice, whereas OL goes beyond that and highly emphasizes the process of how learning and knowledge is acquired from a theoretical viewpoint. Perhaps, one of the most lucid descriptions of OL is provided by Argyris [50] who viewed "organizational learning" as a process of detecting an error and then correcting it. This definition of OL given by Argyris [50] was later elaborated by Templeton et al. [51] who defined it elegantly as *the set of actions within the organization that intentionally and unintentionally influence positive organizational changes*.

However, the process and the set of actions indicating organization learning were still unclear to many researchers at the time. In one of several attempts to shed light on how organizations learn, Argyris and Schön [52] proposed a theory on this topic, and their theory expressed two forms of OL: *single and double loop learning*. In single-loop learning, they believed that organizations modify their actions based on the differences between expected and achieved results. Whereas in double-loop learning, organizations correct the underlying causes of problems to achieve better results. In fact, Argyris and Schön [52] insisted that organizations must acquire both forms of OL to help improve the firm-level performance. In essence, as described by Senge [53], OL enables the development of new knowledge, skills, and abilities, thereby increasing the organization's capability to conduct work more effectively by the modification of work processes.

2.5. Previous Empirical Studies

Before a conceptual model and relavant hypotheses can be properly developed, theories and previous studies that investigated and established the direct and indirect causal link between the interested variables in this study will be reviewed and summarized in this section. The detail of the theories and studies on (1) the direct effects of HRM on OP and (2) the mediating role of KM and OL in the connection between HRM and OP are as follows.

2.5.1. Direct Effects of HRM on OP

In the industrial era and the period thereafter, academics and practioners widely shared the belief that the physical assets of a firm played an important role in determining the success of the firm. Later in 1960s, Becker [31] began to question such beliefs. His argument was that, on a country level, an adequate supply of physical assets such as land, capital, and the abundance of natural resources explained only in small parts the success of the economic development in many countries. Like Becker, Pfeffer [34] later viewed HRM very positively by stating that firms need HRM to help improve their performance since right HR policies may help cure a lack of motivation among employees. Highly motivated workers, as we now know, can perform assigned tasks more effectively and efficiently. Becker's and Pfeffer's positive perceptions of the utility of HRM were finally supported by empirical evidence by the work of Huselid [15], who for the first time demonstrated how a significant increase in sales per employee and market value of firms in the US resulted from having good HR practices. In the late 1990s, Drucker [54] started to spread the idea of HRM by stressing the importance of people working within a firm and their valuable knowledge. This is in part because he foresaw that work in the 21st century would require even more knowledge from workers than before, an insight that proved to be true in retrospect.

Following the work of Huselid [15], the direct link between HRM and OP has been widely examined. There are many research articles supporting the perception of the positive impacts of HRM on organizational performance. The causes of such positive impacts were many, and they were all depended on the context too. For instance, performance-based pay and compensation, training and development, and career growth were often found as common HR variables that were positively correlated with OP outcomes [55]. As for the construction industry, the studies on HRM and OP were found to be only a mere handful of them, e.g., Olomolaiye and Egbu [17], Kokkaew et al. [19], and Zhai et al. [22]. Table 1 summarizes the past studies on the relationship between management variables of this study.

2.5.2. Mediating Roles of KM and OL

As for the role of KM as a mediating variable between HRM and OP, there are several studies, such as the articles by Kokkaew et al. [19], Farooq et al. [56], Obeidat et al. [57], and Iqbal et al. [58]. Currently, researchers are also interested in the mediating role of organizational learning in the casual link between HRM and OP. For instance, Zhai et al. [22] confirmed the mediating role of organizational learning (OL) between the relationship of HRM and performance in construction firms in China. In addition, researchers such as Gold et al. [59] and Abbas et al. [21] found that OL acted as a mediating mechanism behind the link between KM and OP. There are several recent research articles investingating the mediating roles of KM or OL as summarized in Table 1. However, despite some of the research investigating the underlying mechanisms behide the link between HRM and OP through KM or OL, none has investigated the multiple mediating roles of KM and OL (see Table 1).

Despite being a key performance measure, financial outcomes of the firms are sometimes omitted for several reasons. One of them is that the "real" impacts of HRM on financial performance may take years. Therefore, using only a cross-sectional dataset may not be appropriate. Examples of researchers who excluded financial performance in the studies include Wattanasupachoke [60], who studied the influence of strategic HRM on the non-financial performance of listed Thai firms. Others [61,62] aimed their study at uncovering the influene of knowledge management on *long-term* performance, which inluded: (1) customer, (2) internal business process, and (3) learning and growth. In this study, we adopted long-term performance measures in part because the study of lagged effects of HRM on firms' performance outcomes requires longitudinal, not cross-sectional, data analysis [63].

Table 1. Studies confirming the relationships between the constructs under this study.

	Authors	Confirmed Relationship between Constructs				
		HRM → OP	**HRM → KM**	**KM → OL**	**HRM → OL**	**OL → OP**
1	Huselid [15]	✓				
2	Arthur [16]	✓				
3	Ahmad and Schroeder [64]	✓				
4	Akhtar et al. [65]	✓				
5	Chow et al. [66]	✓				
6	Dimba [67]	✓				
7	Sun et al. [68]	✓				
8	Takeuchi et al. [69]	✓				
9	Gurbuz and Mert [70]	✓				
10	Lee et al. [71]	✓				
11	Wright et al. [72]	✓				
12	Yahya and Goh [73]		✓			
13	Shih and Chiang [74]		✓			
14	Edvardsson [75]		✓			
15	Filius et al. [76]		✓			
16	Liao [18]	✓	✓		✓	
17	Olomolaiye and Egbu [17]	✓	✓		✓	
18	Zhai et al. [22]	✓			✓	✓
19	Prieto et al. [77]		✓			
20	Al-Hakin and Hassan [78]				✓	
21	Bakar et al. [79]				✓	
22	Zack et al. [80]				✓	
23	Chen et al. [81]				✓	
24	Keyser [82]				✓	
25	Liu and Tsai [83]				✓	
26	Mills and Smith [84]				✓	
27	Wibowo et al. [85]				✓	
28	Lee et al. [61]				✓	
29	Sucahyo et al. [62]				✓	
30	Noruzy et al. [20]			✓		✓
31	Abbas et al. [21]			✓		
32	Garcia-Morales et al. [86]					✓
33	Li et al. [87]	✓	✓			
34	Kokkaew et al. [19]	✓	✓			
	Total	16	9	2	13	3

3. Conceptual Model and Hypothesis Development

Based on theories and previous empirical studies summarized in Section 2.5, we then proposed a conceptual model, and developed hypotheses based on the literature in Section 2.5 and in Table 1. The conceptual model is shown in Figure 2.

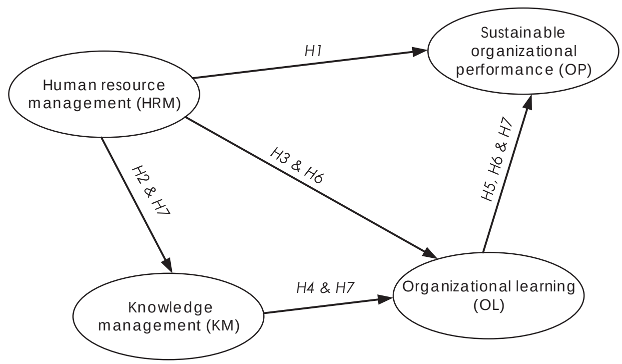

Figure 2. The conceptual model representing the multiple mediating effects of knowledge management and organizational learning on the relationship between HRM and sustainable OP.

As Figure 2 shows, the conceptual model has established the idea of the groundwork of four key variables that include HRM, KM, OL, and sustainable OP. HRM is an independent or exogenous variable in this study. The direct effects of HRM are observed on sustainable OP, which is a dependent or endogenous variable of this study. In addition, the conceptual model draws attention to the multiple mediating roles of KM and OL in the link between HRM and sustainable OP (i.e., Hypotheses 7), which has not yet been explored in the literature. Accordingly, our main hypotheses include (see Figure 2):

H1: *Human resource management has a direct and positive impact on sustainable OP*

H2: *Human resource management has a direct and positive impact on knowledge management*

H3: *Human resource management has a direct and positive impact on organizational learning*

H4: *Knowledge management has a direct and positive impact on organizational learning*

H5: *Organizational learning has a direct and positive impact on sustainable OP*

H6: *Organizational learning mediates the relationship between human resource management and sustainable OP (HRM→ OL→ OP)*

H7: *Knowledge management and organizational learning mediate the relationship between human resource management and sustainable OP (HRM→ KM→ OL→ OP)*

4. Proposed Structural Model

Related theories and empirical studies on HRM, KM, OL, and OP presented in Section 2 were used as a basis for the structural model development of this study, as illustrated in Figure 3. As for the description of reflective indicators to be measured (e.g., indicators HRM1, HRM2, HRM 3, and HRM4 for the construct HRM) and theoretical support for each construct in the measurement models are provided in detail as shown in Table 2.

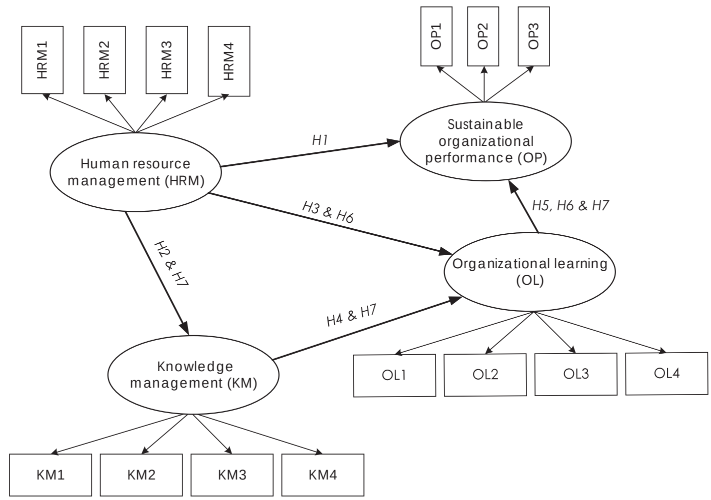

Figure 3. The structural model of the study.

Table 2. Description of constructs, indicators, and theoretical support.

Indicator	Description	References
HRM1	An organization has a recruiting process that focuses on the selection of right candidates objectively.	Bernardin and Russel [88]; Mondy, Noe, and Premeaux [89]; Dessler [90].
HRM2	An organization has a process of improving the current or future performance of its employees.	
HRM3	An organization has attractive and efficient compensation packages so as to attract potential employees without compromising the financial health of the organization.	
HRM4	An organization has a transparent appraisal process, comparing the performance with that of established standards.	
KM1	There is a process of acquiring relevant knowledge that essentially helps improve business operation.	Nonaka and Takeuchi [91]; Marquardt [47].
KM2	There is a process of creating new knowledge by the mobilization and conversion of tacit knowledge.	
KM3	There is a process that helps facilitate the storage and retrieval of the acquired or created knowledge.	
KM4	There is a process that helps facilitate the dissemination and application of the knowledge.	
OL1	An organization has learned or acquired a lot of new and relevant knowledge over the last three years.	Garcia-Morales et al. [86]
OL2	Organizational members have acquired some critical capacities and skills over the last three years.	
OL3	The organization's performance has been influenced by new learning it has acquired over the last three years.	
OL4	This organization is a learning organization.	
OP1	An organization measures its performance related to market share and customer satisfaction.	Kaplan and Norton [40]
OP2	An organization has a process for optimizing to deliver products and services to a client.	
OP3	An organization has a process that facilitates career advancement and learning of employees.	

5. Research Method

This study uses PLS-SEM and the partial disaggregation technique proposed by Bagozzi and Heatherington [92] to examine the relationships among four constructs: (1) human resource management, (2) knowledge management, (3) organizational learning, and (4) the sustainable performance of construction firms in Thailand.

We choose PLS-SEM for the following reasons. First, this method has been used in several studies in the field of construction management [93–95]. Second, PLS-SEM was primarily adopted in the case when the theory is less established. Third, PLS-SEM is a more suitable method of analysis when the sample size is smaller than the requirement of covariance-based SEM [96].

Observed variables measured in this study included four indicators representing HRM, four indicators related to KM, four indicators related to OL, and three indicators related to sustainable OP (See Table 2 for the description of each indicator). Selected multi-item scales for each construct were as follows.

Human resource management (HRM): This construct was measured by the scales used by Zhai et al.'s study [22] and Kokkaew et al. [19]. Included in the scales are 4 questions for the indicator HRM1: recruitment and selection; 4 questions for the indicator HRM2: training and development; 3 questions for the indicator HRM3: compensation; and 3 questions for the indicator HRM4: performance evaluation.

Knowledge management (KM): The KM construct was measured by the scales used in an article by Gold et al. [59]. They include 2 questions concerning the indicator KM1: knowledge acquisition; 2 questions concerning the indicator KM2: knowledge creation; 2 questions concerning the indicator KM3: knowledge storage and retrieval; and 2 questions concerning the indicator KM4: knowledge transfer and utilization.

Organizational learning (OL): This construct was measured by the scales developed by Garcia-Morales et al. [86]. The scales comprise four items/questions measuring OL.

Sustainable organizational performance (OP): This construct was measured by the scales used by Zhai et al. [22]. Included in the scales are 2 questions concerning the indicator OP1: customer satisfaction; 2 questions concerning the indicator OP2: internal process improvement; and 2 questions concerning the indicator OP3: learning and growth.

We certainly acknowledge that there may be different choices of the scales and questions that can be adopted for each construct. However, in this study we decided to adopt the scales used by Zhai et al. [22], Gold et al. [59], Kokkaew et al. [19] and Garcia-Morales et al. [86]. Detail of the questions can be found in the Appendix A of this article. In this study, the measurement models were first evaluated using reliability and validity tests. Then, PLS-SEM was employed to test the seven hypotheses specified in the structural model.

6. Sample and Data Collection

As suggested by Hair et al. [97] and by Schumacker and Lomax [98], the sample size should be at least 10–20 per indicator. Hair et al. [99] also suggested that the minimum sample size for structural equation modeling be at least 150. Accordingly, since there is a set of 15 indicators in this study, the estimated minimum sample is 150. The sample size of this study was 194, which is greater than the minimum criteria suggested by Schumacker and Lomax [98], Hair et al. [99], and Hair et al. [100].

Then, a five-point Likert scale (see the Appendix A) was adopted for the questionaire survey in this study. Quota sampling and a snowball sampling questionnaire survey were conducted, with 250 questionnaires in papers and web-based formats being distributed to middle and top management levels (i.e., from senior site engineers to project directors) of engineers working for construction companies across Thailand. A list of the construction firms in this study can be found in Part 3 in the Appendix A. As for the choice of middle and top management levels of engineers, the reason is that they are more qualified to answer the questions regarding the management policies and practices of the firms. The total number of responses obtained was 194 or about a 78% response rate. The web-based questionaires and the snowball method helped increase the response rate of this study. In addition, before proceeding with the PL-SEM analysis, any potential issues of common method bias and non-response bias were thoroughly checked. In fact, before data collection, Podsakoff et al. [101] suggested that procedural remedies such as notifying participants about the confidentiality of personal data were employed to ensure honesty in answering the questions.

7. Results of Analysis

7.1. Descriptive Data Analysis

The demographic information of questionnaire participants is shown in Table 3.

Table 3. Demographic information of the questionnaire participants.

Characteristic	Description	Frequency	Percentage
Gender	Female	10	5.15%
	Male	184	94.85%
Position	Senior Engineer	29	14.95%
	Project Engineer	137	70.62%
	Project Manager	26	13.40%
	Project Director	2	1.03%
	Total	194	100.00%

As shown in Table 3, participants are mostly male, representing about 94.85%. As for the positions, it was found that most participants are project engineers, representing about about 70.62% of the sample size of 194.

7.2. Measurement Model Evaluation

There are four measurement models in this study: (1) human resource management (HRM), (2) knowledge management (KM), (3) organizational learning (OL), and (4) sustainable organizational performance (OP). Verification of each measurement model was as follows. First, we performed PLS-SEM analysis using the *SmartPLS* on 15 reflective indicators measuring the level of practice of human resource management, knowledge management, organizational learning, and sustainable organizational performance.

Then, according to Hair et al. [100], the reliability of the measurement models should be first verified using Cronbach's alpha or composite reliability (CR) to evaluate the construct measures' internal consistency reliability, followed by the validity assessment of the measurement models. The purpose of measurement model evaluation is to ensure that the constructs are accurately measured and represented [102]. Recently, the discriminant validity of latent variables can also be assessed using a technique called the heterotrait–monotrait ratio of correlations (HTMT), introduced by Henseler, Ringle and Sarstedt [103]. We presented the results of the reliability and validity tests in Table 4. Then, the results of discriminant validity using Fornell–Larcker, and HTMT criterion were presented in Tables 5 and 6, respectively.

Table 4. Reliability and Validity (N = 194).

Construct	Item	Outer Loading	Cronbach's Alpha	CR	AVE
HRM	HRM1	0.833 ***	0.767	0.851	0.590
	HRM2	0.774 ***			
	HRM3	0.677 ***			
	HRM4	0.780 ***			

Table 4. *Cont.*

Construct	Item	Outer Loading	Cronbach's Alpha	CR	AVE
KM	KM1	0.802 ***	0.860	0.905	0.704
	KM2	0.874 ***			
	KM3	0.854 ***			
	KM4	0.826 ***			
OL	OL1	0.896 ***	0.925	0.947	0.816
	OL2	0.901 ***			
	OL3	0.917 ***			
	OL4	0.898 ***			
OP	OP1	0.887 ***	0.843	0.905	0.761
	OP2	0.864 ***			
	OP3	0.865 ***			

Note: *** for significance at $p < 0.001$.

Table 5. Fornell–Larcker Criterion ($N = 194$).

Construct	HRM	KM	OL	OP
HRM	0.768	-	-	-
KM	0.710	0.839	-	-
OL	0.562	0.654	0.903	-
OP	0.692	0.668	0.631	0.872

Note: The diagonal shows the square roots of the AVE.

Table 6. Heterotrait–monotrait ratio (HTMT) ($N = 194$).

Construct	HRM	KM	OL	OP
HRM	-	-	-	-
KM	0.868	-	-	-
OL	0.662	0.730	-	-
OP	0.858	0.783	0.710	-

As shown in Table 4, the Cronbach's alpha and composite reliability (CR) of all constructs were higher than the minimum treshold of 0.70 [102,104]. Then, we proceeded with the validity assessment of indicators by determining both the convergent and discriminant validity of a construct. Hair et al. [101], for example, suggested that each indicator should have a factor loading of 0.5 or greater. The average variance extracted (AVE) of each construct should be greater than 0.50. As can be seen in Table 4, the factor loadings of all indicators in the model are greater than 0.5, and all constructs' AVE are above the minimum value of 0.5, which indicate that the constructs explain more than 50% of the variance of its indicators. The discriminant validity test using Fornell–Larcker criterion is also confirmed since the indicators loaded highly on the construct it measures. Note that the values meet a satisfactory discriminant validity test if the square root of each construct's AVE is higher than its highest correlation with any other construct [95]. Based on the analysis results shown in Table 5, all the square roots of the AVE values exceed the inter-correlation of values between the construct in their corresponding row and column. Thus, the results confirmed that the Fornell–Larcker criterion was met. As for the analysis of heterotrait–monotrait (HTMT) ratio, almost all values are equal or lower than 0.85. Therefore, all constructs were retained in the model since their CR and AVE values were substantial and highly significant.

7.3. Structural Model Evaluation and Hypothese Test

After the reliability and validity evaluation of the measurement models was confirmed, assumed relationships presented in the structural model can be assessed using PLS-SEM technique. The structural model assessment started with the determination of path coefficients (β), coefficients of determination (R^2), and effect size (f^2). The results of the the hypothese tests using PLS-SEM are presented in Table 7 and Figure 4.

Table 7. Structural model assessment.

Hypotheses	Relationship	Anticipated Impact	β	*t*-Value	*p*-Value	Results
H1	HRM → OP	Positive	0.493 ***	15.277	0.000	Supported
H2	HRM → KM	Positive	0.710 ***	0.054	0.000	Supported
H3	HRM → OL	Positive	0.197	6.608	0.957	Not Supported
H4	KM → OL	Positive	0.515	0.314	0.754	Not Supported
H5	OL → OP	Positive	0.353 **	2.244	0.025	Supported

Note: N = 194, *** for significance at $p < 0.001$ level, and ** for significance at $p < 0.05$ level.

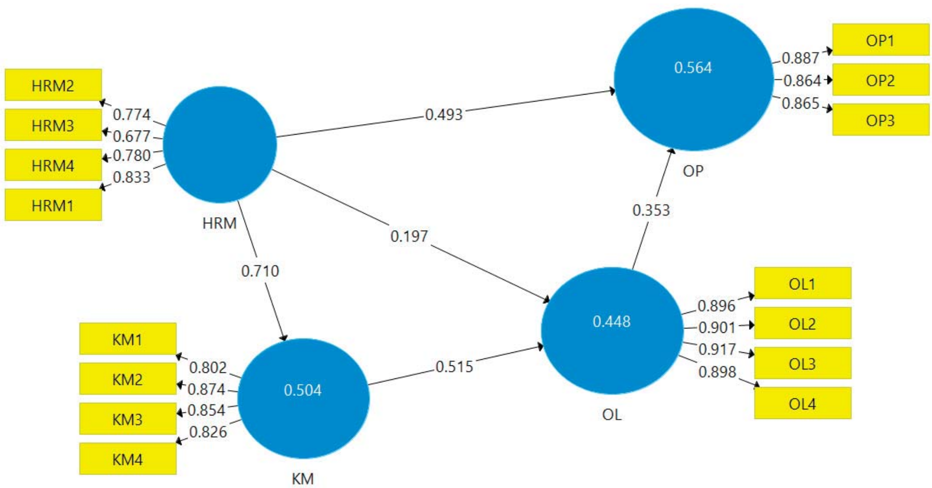

Figure 4. Results of the structural path coefficients.

According to the results shown in Table 7 and in Figure 4, the path coefficient (β) of HRM and KM is 0.710, which is greater than the threshold of 0.250, as recommended by Hair et al. [95]. The relationships between KM and OL and between OL and sustainable OP are also found to be positively correlated, with the path coefficients of 0.515 and 0.353, respectively. As for the direct effect of HRM on sustainable OP, it is confirmed by the results of the study, with the path coefficient of HRM and sustainable OP being 0.493.

Next, the coefficient of determination (R^2) is used to measure the model's predictive accuracy. The suggested values of the R^2 are 0.75, 0.50, and 0.25 for describing substantial, moderate and weak levels of predictive accuracy, respectively [105,106]. In this study, the R^2 values of KM, OL, and sustainable OP are 0.504, 0.448, and 0.564, respectively, suggesting a moderate predictive accuracy of the model.

Finally, the effect size (f^2) is employed to assess whether an exogenous variance has an influence on the endogenous variable. According to Hair et al. [100] and Cohen [107], the f^2 values of 0.35, 0.15, and 0.02 represent large, medium, and small effects, respectively. This study found that the f^2 value of HRM and KM (HRM → KM) is 1.01, indicating the marked effects of HRM on KM. The f^2 values of KM → OL and HRM → OP are 0.24 and 0.17, respectively, suggesting the modest effects of KM on OL and HRM on sustainable OP. Finally, the f^2 values of HRM → OL and OL → OP are 0.04 and 0.10, respectively, suggesting the marginal effects of HRM on OL and OL on sustainable OP in firms under study.

7.3.1. Analysis of Direct Effects

The direct effects between the exogenous variable (i.e., human resource management) and the endogenous variable (i.e., sustainable organizational performance) were described in Figure 4 and Table 7.

In our study, hypothesis 1 (**H1**) claimed that *human resource management has a direct and positive impact on sustainable organizational performance*. According to the results of the structural model assessment of the proposed model, there exists a statistically significant direct and positive relationships between HRM and sustainable OP (β = 0.493, p < 0.001 level).

As for hypotheses 2 and 5 (i.e., **H2** and **H5**), the results supported the claim that there exists a statistically significant and positive impact between human resource and knowledge management (β = 0.710, p < 0.001 level), and between organizational learning and sustainable organizational performance (β = 0.353, p < 0.05 level). However, hypothese **H3** and **H4** (**H3:** *human resource management has a positive impact on organizational learning* and **H4:** *knowledge management has a positive impact on organizational learning*) were not supported by the study.

7.3.2. Analysis of Indirect and Total Effects

Indirect effects can be measured through hypotheses **H6** and **H7**. The results of the mediation analysis are presented in Table 8.

Table 8. Mediation analysis (MA) results.

Hypotheses	Relationship	Anticipated Impact	β	t-Value	p-Value	Results
H6	HRM → OL → OP	Positive	0.070	0.075	0.940	Not Supported
H7	HRM → KM → OL → OP	Positive	0.129	0.371	0.711	Not Supported

Note: N = 194.

The total indirect effect can be computed as the sum of the specific indirect effects, which is 0.199 (i.e., [0.197 × 0.353] + [0.710 × 0.515 × 0.353]), and the direct effect between HRM and non-finanical OP is 0.493. Therefore, the total effect of HRM on sustainable OP is 0.692. (i.e., the sum of the direct effect and the total indirect effects, which can be calculated as 0.493 + [0.197 × 0.353] + [0.710 × 0.515 × 0.353] = 0.692).

7.3.3. Characterization of Analysis Outcomes

Traditionally, according to Baron and Kenny [108], the outcomes of the mediation analysis can be characterized as partial mediation, suppressor effect, and full mediation. However, Hair et al. [109] pointed out that there are conceptual and methodological problems with Baron and Kenny's [108] approach. Accordingly, Hair et al. [109] preferred an approach presented by Zhao et al. [110], who classified the outcomes of the mediation analysis (MA) into two group: (a) mediation and (b) non-mediation. The types of mediation include (1) complementary, (2) competitive, and (3) indirect-only mediation. As for non-mediation, there are (1) direct-only non-mediation and (2) no-effect non-mediation.

The results of our mediation analysis of the role of knowledge management and organizational learning in the established link between human resource management and sustainable performance measured using non-financial indicators are summarized in Table 9.

Table 9. Characterization of mediation analysis (MA) results.

Relationship	Direct Effect	Indirect Effect	Result
HRM → OP	0.493 ***	0.199	Direct-only non-mediation

*** for significance at p < 0.001 level.

As can be seen in Table 9, the direct effect from HRM to OP is 0.493 with significance at p < 0.001 level, whereas the indirect effect from HRM to OP is 0.129 and not significant.

Accordingly, based on Zhao et al. [110], we can characterize the outcome of the mediation analysis of the role of knowledge management and organizational learning on the established link between human resource management and sustainable performance in the Thai infrastructure construction firm setting as "direct-only non-mediation."

8. Discussion of the Findings and Research Contributions

We have tested the seven hypotheses presented in Section 3 using the theorized model presented in Section 4. Based on the results of the analysis, the duscussion of the findings and research contributions can be provided as follows.

First, HRM practices measured in this study include (1) recruitment and selection, (2) training and development, (3) compensation, and (4) performance appraisal. We based our decision about HRM variables solely on the past literature. However, different choices of scales may be employed to measure this construct. Similar to past studies, this study found that HRM practices have a moderate and statistically significant positive impact on sustainable performance of Thai construction firms ($\beta = 0.493$, $p < 0.001$), thereby reinforcing the established relationship between HRM and OP.

In the construction industry, the findings of this study are consistent with the results of the study by Zhai et al. [22] and Olomolaiye and Egbu [17]. In Thailand, Wattanasupachoke [60] found a positive and direct link between HRM and the performance of listed Thai firms. The study by Wattanasupachoke [60] also revealed that the positive inner characteristics of employees, such as politeness and positive attitude toward organizations, played an important role in generating higher non-financial performance of listed Thai firms. In addition, Wattanasupachoke's results [60] indicated that those listed Thai firms that put high emphasis on the recruitment and selection of new employees performed better than those without such emphasis, which is consistent with the results of this study.

Second, this study found that HRM has a significantly high and direct positive impact on KM ($\beta = 0.710$, $p < 0.001$). This relationship was confirmed in previous studies such as Iqbal et al. [58], Filius et al. [76], Edvardsson [75], and Yahya and Goh [73]. In the construction setting, this linkage was also established in previous studies by Olomolaiye and Egbu [17]. Similar to the study by Olomolaiye and Egbu [17], HRM and KM are crucial for organizational performance improvements in construction. Additionally, KM should be well integrated with HRM to facilitate the knowledge sharing process through HR policies and practices. This study confirms that HRM lies at the heart of KM, since the success or failure of KM depends on the organization's capability to manage and motivate its employees.

Third, this study showed that organizational learning has a moderate and significantly positive impact on sustainable OP ($\beta = 0.353$, $p < 0.05$). The positive impact of OL on OP was supported in previous studies by, for example, Noruzy et al. [20], Zhai et al. [22], and Garcia-Morales et al. [86]. In the construction industry, this relationship was established in the studies by Olomolaiye and Egbu [17] and Zhai et al. [22]. Consistent with Zhai et al.'s results [22], this study saw the positive influence of organizational learning on sustainable performance of Thai construction firms. Moreover, this study revealed that the employees of Thai construction companies tend to concentrate on acquiring certain capacities and skills (OL2), and they strongly believe that an organization's performance can be improved through new learning (OL3).

Forth, hypotheses **H3** and **H4** (HRM $\rightarrow$ OL and KM $\rightarrow$ OL) were found to have a positive relationship, but the results are not statistically significant. HRM and KM were found to have a strong positive influence on sustainable organizational performance, but they failed to push Thai construction firms to become learning organizations. The firms used in our study are leading construction firms, and some of them are listed on the stock exchange of Thailand. They recruited engineering students from top-engineering schools in Thailand to ensure that they can be competitive in the market, as indicated in an outer factor loading of HRM1 (i.e., recruitment and selection) on the HRM construct. However, there is a weak link between HRM and OL in Thai construction firms ($\beta = 0.171$), whereas this relationship in Chinese construction firms was highly positive and statistically significant ($\beta = 0.950$, $p < 0.001$) [22].

This phenomenon of the missing link between HRM and OL in Thai construction firms may be explained by Argyris' learning theory [111] who argued that competent people were usually excellent at single loop learning but were not so good at double loop learning, which is necessary for the organization learning [111]. In other words, they were excellent at problem-solving to achieve individual goals or to enhance individual performance, but they became somewhat defensive when their modus operandi (M.O.) was challenged or questioned in which a learning organization should encourage such practices in order to better long-term organizational performance and to increase the chances of business survival. This may also be the case for people working for Thai construction firms as well.

The results of this study also showed that 56.40% of the variance associated with sustainable OP was accounted for by HRM and OL, which was consistent with Zhai et al.'s results [22] showing that 62% of the variance associated with OP was accounted for by HRM and OL. We also found that 45% of the variance associated with OL was explained by HRM and KM, which was consistent with Lopez et al.'s results [112] indicating that 56% of the variance associated with OL (measured by knowledge acquisition, distribution, interpretation, and organizational memory) was explained by HRM (measured by staffing, training, compensation, and participation) in Spanish firms. However, our finding was different to Zhai et al.'s results [22], which showed that 90% of the variance associated with OL in Chinese construction firms was accounted for by HRM.

Finally, our analysis of the direct, the indirect (through multiple mediating variables KM and OL), and the total effects of HRM on OP is 0.493, 0.199 and 0.692, respectively, compared with Zhai et al.'s [22] whose results were 0.260, 0.504, and 0.764, respectively.

In summary, in the setting of Thai infrastructure construction, HRM has a moderate and direct positive impact on sustainable or long-term organizational performance; thus, this empirical examination helps contribute to the growing body of evidence that human resources are keys to the firm's performance [15,16,22,30,31]. Interestingly, this direct effect between HRM and OP of construction companies in Thailand is almost twice that of Chinese construction firms [22]. However, when it comes to OL as a mediating variable between HRM and OP, Chinese construction firms viewed it as an important component of competitive advantage in the current market environment, whereas Thai construction firms viewed it as somewhat less important. In other words, Thai construction firms are still lagging way behind Chinese construction firms when it comes to enhancing HR through the use of OL for organizational performance.

Admittedly, there are some different characters between the Thai and Chinese construction firms. For example, top-grade Chinese construction firms are already international players while a handful of top Thai construction firms are still regional (i.e., Southeast Asia) players. This different characteristic may be one of the factors behind such differing views on how OL can be used to increase the level of long-term competitive advantage.

9. Practical Implications for Firm's Performance Improvement

The findings of this study have some implications for improving long-term performance of Thai construction firms in the following manner.

First, based on the results of the study, it can be concluded that human resource management is the key to performance improvement of Thai construction firms. In practice, we found that aggressive recruitment of key people plays an important role in the HRM practices of Thai construction firms, with the belief that by hiring high potential and competent people, the firms can have a competitive advantage and can compete in the construction market. Additionally, the direct effect of HRM on sustainable OP was found to be limited ($\beta = 0.493$), and, in theory, HRM can be employed as a key input for a pathway to improve sustainable organizational performance through KM and OL.

Currently, the management team of Thai construction firms and their HR departments have integrated KM into HR practices as a way to improve sustainable OP, as indicated in the results of this study (β = 0.710). However, we found that there were the weak links between KM and OL and between HRM and OL, despite the empirical results of this study and other previous studies indicating that OL can help improve the sustainable performance of firms. Chinese construction firms, on the other hand, have already stressed the employment of HRM as a key ingredient of organizational learning to improve the firms' performance, as indicated by Zhai et al. [22].

Based on the findings, to improve the long-term or sustainable performance of Thai construction firms through HRM, KM, and OL, they may have to create a system that supports people and organizations to adapt and learn through difficult times. The presence of Chinese constructoin firms in the Thai infrastructure construction market will surely serve as a catalyst for the change and adaptation of Thai construction firms. Additionally, Thai construction firms should facilitate a work-based learning process so that their employees can perform their tasks more effectively and efficiently. More importantly, Thai construction firms should implement policies and corporate cultures that encourage their employees to challenge or correct the underlying assumptions behind the problems of construction projects and business operations. Finally, creating "trust" among team members and between contracting parties in a construction project could also help mitigate the chornic problems of construction delay and cost overruns. This can be done, for example, by using technology such as blockchain-based contracts [113].

However, as revealed by this study and by Wattanasupachoke [60], during the recruitment phase, Thai firms still put a high emphasis on applicants' conformity with the firm's policies and culture (e.g., politeness and positive attitude about the firms), which could impede the organization becoming a learning organization. Therefore, if Thai construction firms can find a balance between hiring new employees with the right qualifications and a positive attitude toward process improvement, without the attribution of current practices, they can improve sustainable organizational performance through organizational learning. This may be a daunting task for the management team and the HR department of Thai construction firms because the Thai construction industry is still one of the most male-dominated and steep hierarchy sectors.

10. Limitations and Future Research

This section provides some of the limitations of this study and future research direction, which are as follows. First, since the focus of the study is on the direct and indirect relationship between HRM and OP in the sub-sector level of the Thai construction industry, other variables or factors such as the size, ages, employee number of the firms are excluded in the study. Therefore, the results of the analysis represent only the aggregate numbers of the sample, which is the Thai infrastructure construction sector. Accordingly, these variables may be of interest in future studies to help determine internal factors that can have an impact on the levels of direct and indirect influence of HRM, KM, and OL on the OP of infrastructure construction companies. Second, because the level of data analysis in this study is on a sub-sector or sub-industry level, comparison of the results of the study to other studies in construction settings must be made with caution. However, the comparison of the results of this study to those of others' studies, whose focuses are on different types of construction, may provide a bigger picture of the application of management theories such as HRM, KM, and OL in the construction industry. The gaps identified among sub-sectors could provide research opportunity into the search for what could be the determinants in the different uses of these management tools for organizational performance improvements. Third, despite having thoroughly checked for common method bias (CMB) and non-response bias, the reliability of the results certainly depends on the quality of the obtained dataset using the questionnaire, and it can be difficult to eliminate all biased responses. Additionally, our respondents in this study are mostly male, representing about 94.85% of the total respondents, which agrees with the fact that the construction industry is one of the male-dominated industries since construction jobs are quite physically demanding. Therefore, the results of this study should be used with caution, especially in comparison with those of other studies, which may be in the same sub-sector but in other countries.

11. Summary and Conclusions

Engineering is the professional and systematic application of science to the economic use of natural resources for the benefit of humankind. Construction as the art and science is considered an indispensable part of our society. However, to build, something has to be destroyed, and thus, on a global scale, construction depletes a large amount of natural resources, and with it comes pollution and waste. Construction firms are currently under increasing pressure to compete for jobs. Their competitors need not be domestic but international. One of the many things that they can responsibly do to stay afloat in this business climate may depend on their ability to properly manage the people and their organization capability to learn and to adapt accordingly. With this view, we explored the contemporary management concepts such as human resource management, knowledge management, organizational learning, and, more importantly, their interactions and impacts on organizational performance.

This study has investigated both the direct and indirect relationship between HRM and sustainable organizational performance, using KM and OL as mediating variables in the established direct relationship between HRM and sustainable OP. We developed the structural model and the measurement model based on established theories. The measurement model was then assessed using CFA. The results of CFA indicated that the data satisfactorily fitted the model with an acceptable range of fit indices. The structural model was then evaluated using PLS-SEM to test the seven developed hypotheses.

The results confirmed the proposed model, showing that there exists a positive and statistically significant influence of (1) HRM on knowledge management; (2) HRM on sustainable OP; and, (3) OL on sustainable performance in Thai construction firms. These findings help reinforce the empirical evidence on how HRM and OL can have a positive impact on the sustainable OP. However, the proposed model, indicating that there existed a positive influence of (1) HRM on OL and (2) KM on OL, was not supported by the dataset.

As for mediation analysis, we found that the link between HRM and sustainable OP, with knowledge management and organizational learning as multiple mediating variables, can be characterized as "direct-only non-mediation." These findings were quite different from the results by Zhai et al. [22], which showed that Chinese construction firms employed HRM as a strategic way to improve performance through organizational learning (OL). Datasets of Thai construction firms, on the other hand, failed to show the influence between HRM and OL and KM and OL, despite the perception of the firms that OL can be used as a management tool for enhancing organizational performance.

Accordingly, based on the findings of this study, if Thai construction companies want to narrow these performance gaps and improve their productivity, they should create a process or system that essentially helps strengthen the link between KM and OL so that they can better adapt to the ever-changing market conditions and increasing competition in the future. This provides opportunities for future research to explore more deeply the factors responsible for a lack of adoption and utilization of KM and OL in the construction industry. Moreover, Thai construction firms may better embrace policies that encourage employees to challenge the underlying assumptions behind the chronic problems of their day-to-day business operations.

We humbly acknowldge that there are some of the limitations in this study as presented in Section 10. Nevertheless, we hope that the findings of this research will be of use for Thai construction firms and those in others countries in order for them to better grasp the issues and challenges faced by the industry. It is also our hope that the fidings will help promote a pathway to the betterment of the human resource management practices of construction firms and lead them toward a more sustainable pathway of business operations.

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Appendix A. Measurement Scales and a List of Thai Infrastructure Firms

Part 1: Human Resource Management (HRM), Knowledge Management (KM), and Organizational Learning (OL)

Please indicate your opinion on the human resource management (HRM), knowledge management (KM), and organizational learning (OL) employed by your firms, and the perception of your firm's sustainable organizational performance (OP) over the past three years.

Five-point Likert scale: (1) strongly disagree; (2) moderately disagree; (3) neither agree or disagree; (4) moderately agree; (5) stongly agree.

Indicators	Questions	Scales				
HRM1	1. Great effort is taken to select the right person.	1	2	3	4	5
	2. Long-term potential of employee is emphasized.	1	2	3	4	5
	3. The members of the department or project team engage in the selection of candidates.	1	2	3	4	5
	4. Not only are knowledge and experience taken into account, but also the capacity to work in synergy and continuous learning.	1	2	3	4	5
HRM2	1. Training and development programs are provided for employees.	1	2	3	4	5
	2. There are comprehensive training policies and programs in place.	1	2	3	4	5
	3. New staff can attend training programs to improve their skills to perform the job.	1	2	3	4	5
	4. Training for increasing problem-solving ability is given.	1	2	3	4	5
HRM3	1. The organization has a mixed system of rewarding.	1	2	3	4	5
	2. Individuals receive bonuses based on the profit of the organization or the project.	1	2	3	4	5
	3. The company offers incentives to its employees according to their performance.	1	2	3	4	5
HRM4	1. Performance appraisals are based on objective quantifiable results.	1	2	3	4	5
	2. Performance appraisals are based on employee's behaviors.					
	3. Employee appraisals emphasize long-term and group-based achievement.	1	2	3	4	5
KM1	1. An organization has processes for absorbing knowledge from individuals into the organization.	1	2	3	4	5
	2. An organization has processes for acquiring knowledge from outside the organization such as our customers or business partners.	1	2	3	4	5
KM2	1. An organization has a structure that facilitates the discovery of new knowledge.	1	2	3	4	5
	2. An organization has a structure that facilitates the creation of new knowledge.					
KM3	1. An organization has processes for making knowledge accessible to those who need it.	1	2	3	4	5
	2. An organization has processes for organizing knowledge and replacing obsolete knowledge.	1	2	3	4	5
KM4	1. An organization has processes for distributing knowledge throughout the organization.	1	2	3	4	5
	2. An organization has processes for using knowledge to solve new problems and improve efficiency.	1	2	3	4	5

Indicators	Questions	Scales				
OL1	1. An organization has learned or acquired a lot of new and relevant knowledge over the last three years.	1	2	3	4	5
OL2	2. Organizational members have acquired some critical capacities and skills over the last three years.	1	2	3	4	5
OL3	3. The organization's performance has been influenced by new learning it has acquired over the last three years.	1	2	3	4	5
OL4	4. This organization is a learning organization.	1	2	3	4	5

Part 2: Sustainable organizational performance (OP).

Please indicate the perception of your firm's sustainable organizational performance (OP) over the past three years.

Five-point Likert scale: (1) very bad; (2) bad; (3) neutral; (4) good; (5) very good.

Indicators	Questions	Scales				
OP1	1. An organization puts an emphasis on market share.	1	2	3	4	5
	2. An organization puts an emphasis on client satisfaction.	1	2	3	4	5
OP2	1. An organization aims at the optimal use of resources to meet its objectives.	1	2	3	4	5
	2. An organization enhances its capability to meet future challenges and opportunities.	1	2	3	4	5
OP3	1. An organization puts an emphasis on employee satisfaction.	1	2	3	4	5
	2. An organization encorages employees to be innovative in construction methods and management.	1	2	3	4	5

Part 3: A list of Thai infrastructure firms in this study.

No.	Company Name	No.	Company Name
1	15 Union Co., Ltd.	33	Ritta Co., Ltd.
2	A.S. Associated Engineering (1964) Co., Ltd.	34	Rojanachai Construction Co., Ltd.
3	Bouygues-Thai Co., Ltd.	35	Ruang Ruethai Co., Ltd.
4	C.E.C. Construction Co., Ltd.	36	S.K. Water Works and Service Limited Partnership
5	CH Karnchang PCL	37	S.U.A. Contraction Limited Partnership
6	Chec (Thai) Co., Ltd.	38	Sahakarn Co., Ltd.
7	China State Construction Engineering (Thailand) Co., Ltd.	39	Sangfah Construction Co., Ltd.
8	Chotichinda Consultants Co., Ltd.	40	Sermsanguan Construction Co., Ltd.
9	Chotichinda Consultants Co., Ltd.	41	Sino-Thai Engineering and Construction PCL
10	Christiani & Nielsen (Thai) PCL	42	Siphya Construction Co., Ltd.
11	Civil Engineering PCL	43	Soltd Civil Co., Ltd.
12	Engineer 19 Mitrapap Limited Partnership	44	Sraloong Construction Co., Ltd.
13	Green Earth Solution Co., Ltd.	45	S-TEC Civil & Construction Co., Ltd.
14	Green Light International Co., Ltd.	46	Syntech Construction PCL
15	Hatyai Nakarin Co., Ltd.	47	Tana Phaisal Kan Yota Co., Ltd.
16	Hip Hing Construction (Thailand) Co., Ltd.	48	Taw Real Estate Co., Ltd.
17	Inter Expert Construction Co., Ltd.	49	Tawee Solar Co., Ltd.
18	Italian-Thai Development PCL	50	Thai Polycons PCL
19	Jaroensuk 2018 Co., Ltd.	51	Thepnimitrkeha Co., Ltd.
20	JMR Engineering Co., Ltd.	52	Thongkarn Construction Co., Ltd.

No.	Company Name	No.	Company Name
21	JSJ & T Construciton Co., Ltd.	53	Three Sakul Co., Ltd.
22	Kanokpol Construction & Consultant Co., Ltd.	54	Tipakorn Co., Ltd.
23	Krung Thon Engineers Co., Ltd.	55	Tonpo Construction Co., Ltd.
24	Nawarat Patanakarn PCL	56	TRC Construction PCL
25	Palm Con Co., Ltd.	57	TTCL PCL
26	PKT International Co., Ltd.	58	Tuscan Con Co., Ltd.
27	PO. Burapa Co., Ltd.	59	Unique Engineering and Construction PCL
28	Power Line Engineering PCL	60	V. Sathapat Co., Ltd.
29	Pre-Built Public Company Limited	61	Vatanapatana Co., Ltd.
30	Professional Join Network Solution Co., Ltd.	62	Vtec Decor Co., Ltd.
31	PSD Construction 2011 Co., Ltd.	63	Vulcan EPC Co., Ltd.
32	Pyramid Concrete Co., Ltd.	64	World Descon Co., Ltd.

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Critical Success Factors for Competitiveness of Egyptian Construction Companies

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Abstract: Advancing construction company competitiveness is a tremendous challenge. In approaching this challenge, it is useful to identify the critical success factors (CSFs) that impinge upon company competitiveness. This research aims to determine the CSFs for the competitiveness of Egyptian construction companies. The research deployed the relative importance index (RII) and the fuzzy Delphi method (FDM) to determine the importance of and screen out the success factors for company competitiveness. The results of the two methods are demonstrated and discussed, and then the CSFs are obtained by taking the intersection of the results of the two methods. This research finds that a sustainable organization and leadership structure and governance system; stating a mission, vision and values; key types of suppliers and partners; reporting relationships among the different parts of the organization; and using technology as a support to achieve strategies are the five top-ranked CSFs for company competitiveness in the Egyptian construction market. The least important factors that influence company competitiveness include having indicators to assess the image of the organization and having positive trends for indicators measuring societal performance. The identification of the CSFs is useful for helping contractors to utilize their limited resources more efficiently to improve their competitive advantage.

Keywords: competitiveness; critical success factors; relative importance index; fuzzy Delphi method; construction companies; Egypt

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1. Introduction

The construction sector is a comparatively significant sector in both developed and developing economies. In developed economies, the gross domestic product (GDP) contribution of the construction sector amounts to almost 10%, and more than 4% for developing economies [1]. Generally, the construction sector is the vehicle that motivates the growth of a country's economy, especially when the country suffers from stagnation. The construction sector is a major supplier to the Egyptian economy and is considered one of its fastest-growing sectors. Slow economic growth, strong competition, and local and international construction sector restructuring has placed high pressure on construction organizations to constantly improve their productivity and performance to either survive or be more competitive [2].

Competitiveness can be defined as an organization's ability to compete for business in various markets [3]. Competitiveness determines the ability to conquer new markets, to outplay other actors in the market, to attract investment and to grow. Policy makers need to understand how competitive their country is relative to others, and how their competitive position evolves overtime [4].

There are many theories for understanding company competitiveness. The first theory is the competitive advantage [5,6]. In his further works, Porter [6] engaged the value chain to disaggregate a company into many discrete value activities and proposed that the activities for implementing a competitive strategy are ultimately the sources for competitive advantage. The second theory is the resource-based and core-competence theory.

According to Dess et al. [7], strategic management directs the organization toward overall goals and objectives considering the engagement of stakeholders in decision making. The three theories provide the guidelines for identifying the candidate success factors for the competitiveness of a contractor. The success factors for the competitive advantage of an organization should collectively cover the areas of competitive strategies, value activities, and firm-specific resources.

The identification of contractor competitiveness factors has been extensively covered in previous studies. Holt, Olomolaiye [8] classified competitiveness factors under five main groups: the contractor's organization, financial considerations, management resources, past experience, and past performance. Hatush and Skitmore [9] proposed a set of criteria classified under five categories for assessing contractor competitiveness, including financial soundness, technical ability, management capability, health and safety, and reputation. Based on the results of many studies [10–13], Shen and Liu [14] proposed a comprehensive set of contractor competitiveness indicators and a model for calculating a contractor's total competitiveness value. In their research, the contractor competitiveness indicators are grouped into six categories: social influence, technical ability, financing ability and accounting status, marketing ability, management skills, and organizational structure and operations. Hoang [15] and Badawy [16] developed models to assess the competitiveness of Canadian construction companies. However, applications of the competitiveness factors introduced in previous studies are limited as there has been no corresponding relevance of competitiveness factors to different types of environments from one country to another.

The Delphi method is widely applied to filter indicators and factors in many fields, but it requires multiple investigations to achieve the consistency of expert opinions, and experts are required and forced to modify their opinions so as to meet the mean value of all the expert opinions [17]. However, the fuzzy Delphi method (FDM) requires only a small number of samples, and the derived results are objective and reasonable [18]. According to Hsu and Yang [19], the FDM reduces the time and cost required for collecting expert opinions, and the experts' opinions will also be sufficiently expressed without being distorted. The FDM is mostly used for the screening process by employing fuzzy sets to represent opinions from experts. This approach has been employed in various applications, including humanities, management, business, physical science, and engineering. Kuo and Chen [18] applied the FDM to construct key performance appraisal indicators for the mobility of the service industries. Ma, Shao [17] applied two kinds of methods to filter road safety performance indicators, namely the FDM and the grey Delphi method. Tseng, Lim [20] identified the top-ranking features of stakeholders' considerations in sustainable supply-chain management and provided practical suggestions. The study of Elmousalami, Elyamany [21] suggested using fuzzy theory and the Delphi method with the analytic hierarchy process in order to efficiently identify the cost drivers. Bui, Tsai [22] applied the FDM to identify barriers to sustainable solid waste management in practice.

The aim of this paper is to identify CSFs for company competitiveness that are applicable to the Egyptian construction environment. Through the relative importance index (RII) method and the FDM, the importance of factors can be derived and CSFs can be constructed.

The paper is structured as follows. The next section gives a brief overview of competitiveness, its success factors, and models for measuring it. This is followed by a description of the research methodology adopted in carrying out the study. The analysis and discussions of the data collected are then highlighted. Finally, the conclusions of the study are presented.

2. Background

Based on the review of the available literature, the following sections present an overview of competitiveness, success factors for competitiveness of construction organizations in different countries, and models for measuring competitiveness in construction companies.

2.1. Overview of Competitiveness

Competitiveness has become common to describe the economic strength of an entity with respect to its competitors in the global market economy in which goods, services, people, skills, and ideas move freely across geographical borders [23]. Investigations of competitiveness can be conducted at different levels such as nation, industry or enterprise, with each level being significantly different [24].

Scott, Lodge [25] gave the definition of national competitiveness as "a country's ability to create, produce, distribute and/or service products in international trade while earning rising returns on its resources". The national level is considered the highest level where communities such as the World Economic Forum (WEF) and International Institute of Management Development (IMD) publish reports yearly to measure the competitiveness of nations.

The industry level is another level where a detailed analysis of individual industries can be studied. Many studies were conducted to measure the competitiveness performance in construction industries in different countries such as Australia, Finland, Sweden, the UK and the USA [26].

Ivancevich, Lorenzi [27] defined firm competitiveness as "the degree to which a firm can, under free and fair market conditions, produce goods and services that meet the test of international markets while simultaneously maintaining or expanding the real incomes of its employees and owners". The firm or organization level focuses mainly on an individual company's competitiveness. Competitiveness research at the firm level has developed a competitive strategy that helps achieve and sustain competitiveness [6], and has analyzed firms' resources that sustain competitiveness [28,29].

Competitiveness research at the project or product level focuses on the competitiveness of each project such as the bidding strategy for a project [30] and studies factors that affect competitiveness in a project [31].

2.2. Success Factors for Competitiveness of Construction Organizations

The study of competitiveness in the construction industry, including the identification of CSFs for competitiveness, has emerged in many academic journals and technical reports. Researchers in many countries such as the USA, the UK, Chile, and many others have developed CSFs that are, to some degree, suitable for their own national attributes. A summary of the available previous studies on major success factors for company competitiveness is shown in Appendix A, which shows that the CSFs for competitiveness of construction organizations differ from one country to another. Different market situations, policies and strategies, cultures, and competitive environments require different measures [32]. Therefore, a need exists to develop a set of CSFs for company competitiveness that are suitable for the environment in Egypt.

2.3. Models for Measuring Competitiveness in Construction Companies

Evaluating company competitiveness is the first step towards building effective marketing strategies [33]. Shen and Liu [14] developed a decision support system for assessing contractors' total competitiveness value in the context of China's construction industry. In a further study, Shen, Li [34] proposed a model that was adopted to award construction contracts on a multi-criteria basis in China by taking into account both a contractor's competitiveness and the defined project objectives. Tan [35] proposed a competitiveness indicator system for assessing Hong Kong contactors' competitiveness based on six aspects: corporate image, technology and innovation, marketing capability, financing capability, project management skills, and organization and human resources. However, it does not provide criteria to calculate an index or functions to calculate a score.

The research of Elwakil, Ammar [36] proposed nine CSFs that were used in-turn to develop an artificial neural network prediction performance model of construction organizations. The model can be used to predict the performance of a construction organization based on estimated values of its success factors.

Hoang [15] developed a model to assess competitiveness in construction companies in Canada. Later, this study helped to build a model to assess competitiveness in construction at the firm level in Canada using the fuzzy analytic network process and PROMETHEE [16]. The model was generated using 26 factors. The included factors were categorized into three main pillars: external pillar, internal pillar, and financial pillar of the organization and affiliated projects. However, the applications of the competitiveness factors introduced in previous studies are limited as the relevance of competitiveness factors to different types of environments from one country to another do not correspond. There is no research aimed at determining the competitiveness in the Egyptian market.

3. Research Methodology

This study was undertaken through the following major research activities and methods: a literature review, data collection, pilot study, questionnaire survey, reliability of questionnaire, data analysis, results and discussion, and conclusions, as shown in Figure 1.

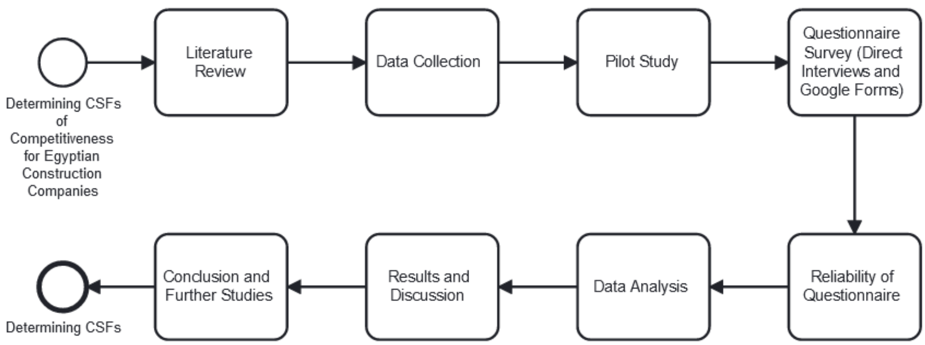

Figure 1. Flow chart of research.

3.1. Data Collection

A list of 83 potential success factors for construction organization competitiveness was derived from an extensive literature review. The 83 factors were divided into three main categories, namely, company profile, enablers, and results. According to Baldrige [37], the company profile sets the context for the company. It serves as the background for all the work it performs. The enablers are the things that the company needs to do to develop and implement its strategy. The results are what the company achieves, in line with its strategic goals.

Because of the large number of factors developed, and more importantly the anticipated overlaps between these factors, a pilot study was conducted. One-on-one interviews with four leading experts and executives working in construction companies in Egypt were conducted. The aim of this first set of interviews was more of a discovery of possible additional factors and a validation of the ones that were developed during the literature reviews. The analysis of the collected data from the pilot study reduced the 83 factors to 49 potential success factors. They were the basis of a questionnaire survey to assess the relative importance of and screen out the success factors. The questionnaire was divided into three main parts. The first part covered the purpose of the questionnaire survey, and the importance of identifying the CSFs for company competitiveness. The second part contained questions about the construction company and the individual filling out the questionnaire, such as the number of years of experience in their current position. In the third part, the respondents were asked to rate each proposed success factor based on their professional experience. A five-point scale on the importance of factor was used to obtain better validity and reliability [38,39]: not important; slightly important, moderately important, important, and very important. The questionnaire was translated into Arabic, the first language of the participants, for their convenience.

The population targeted by the survey was the experts working in construction firms and consulting offices in Egypt. The sample size, which would represent this population, was computed based on the following formula [40]:

$$n = \frac{n'}{\left[1 + \left(\frac{n'}{N}\right)\right]} \tag{1}$$

$$n' = \frac{\left(K^2 \times P \times q\right)}{V^2} \tag{2}$$

where: n = the required sample size, n' = the first estimate of sample size, n = the population size that is considered ∞ in this research, K is the value for the selected 95% confidence level (K = 1.96 for 95% confidence level), P = the proportion of the characteristic being measured in the target population, $q = 1 - p$, and V = the standard error of the sampling population.

To achieve the maximum sample size, the values of p and q were taken as 0.5. The standard error used in determining the sample size was set equal to 10%, which represents the maximum standard error allowed [41]. By substituting the pre-defined variables in Equations (1) and (2), a sample size of $n = 96.04 \approx 96$ is obtained.

3.2. Reliability of Questionnaire

Before conducting the data analysis, testing the reliability of the questionnaire results is very important. According to [42], Cronbach's alpha (α) [43] can be used to test the reliability of the survey based on the five-point scale. The reliability of the questionnaire results measures the internal consistency among the factors. Using the SPSS 23.00 [44], the Cronbach's alpha value of the test was 0.891. According to Santos and Reynaldo [45], a Cronbach's alpha value greater than 0.7 implies that the five-point scale measurement was reliable. Additionally, the results were tested by the Kaiser–Meyer–Olkin (KMO) and Bartlett tests. The results of the KMO and Bartlett tests guarantee that the initial variables are strongly correlated [46]. The KMO index was 0.911, which was higher than the minimum value of 0.8, indicating that the correlation between variables was satisfactory. The Bartlett test (χ^2 = 4161.783, sig. = 0.00) suggested that the data were appropriate for the results.

3.3. Data Analysis

3.3.1. RII Technique

A relative importance index (RII) can be used for ranking purpose. Ref. [47] explained that many researchers in construction management prefer the RII because of the relative comparison of variables whose indices are lower. A relative importance index (RII) and a mean value can be used for ranking the purpose. This research adopted the RII technique because it is suitable for ranking purposes and recommended for inferential statistical analysis.

The participating respondents shared numerical scores from 1 to 5 (Likert scale), stating their opinions on the degree of importance of each success factor. The relative importance of the success factors was determined using the RII shown in Equation (3) [8].

$$\mathrm{RII} = \frac{\sum_{i=1}^{5} W_i X_i}{A \times n} \tag{3}$$

where: W_i is the weight of the ith response (i = 1, 2, 3), X_i is the frequency of the ith response, A is the highest weight (5 in this study), and n is the number of respondents.

3.3.2. FDM

Ishikawa, Amagasa [48] proposed the FDM, which was extracted from the traditional Delphi method and fuzzy theory. The FDM has many advantages over the traditional Delphi method. It takes into account the uncertainty among the participants' opinions. Moreover, instead of gathering the experts' opinions as deterministic values, the FDM converts the experts' linguistic preferences into fuzzy numbers based on human preferences, allowing high uncertainty and retaining qualitative characteristics [22]. According to Habibi, Jahantigh [49], only one round can be used for summarizing and obtaining critical factors instead of repetitive surveys to allow forecasting values to converge, which requires much more time and cost. Accordingly, the efficiency and quality of the questionnaires will be improved [50]. Recently, many researchers have used the FDM in the construction management field for such tasks as project risk management [51–54] and procurement [55–57]. These papers suggest that a mixed use of Delphi and fuzzy sets are more appropriate for research topics related to the construction management areas. This study applied the FDM to screen the success factors for company competitiveness. As for the selection of fuzzy membership functions, previous studies were usually based on the triangular fuzzy number, trapezoidal fuzzy number and Gaussian fuzzy number [58]. This study applied the triangular membership functions and fuzzy theory to solve the group decision. The linguistic preferences were converted into triangular fuzzy numbers as illustrated in Table 1 and Figure 2.

Table 1. Transformation table of linguistic terms [22].

Linguistic Terms (Performance/Importance)	Corresponding Triangular Fuzzy Numbers		
	a	b	c
Not important	0	0	0.25
Slightly important	0	0.25	0.5
Moderately important	0.25	0.5	0.75
Important	0.5	0.75	1
Very important	0.75	1	1

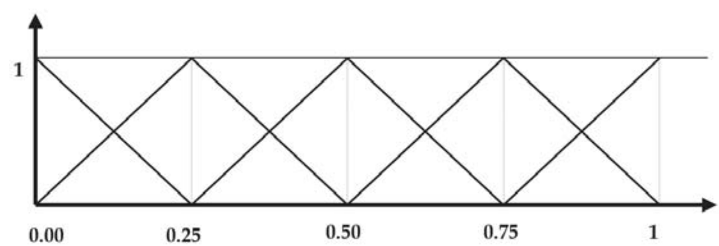

Figure 2. Membership function of the five levels of linguistic variables.

The FDM steps are as follows [58]:

1. Collecting opinions of experts to find the evaluation score of each success factor's significance given by each expert by using linguistic variables in questionnaires.
2. Calculating the evaluation value of the triangular fuzzy number of each success factor given by experts. The computing formula is illustrated as follows:

Assuming the evaluation value of the significance of the no. j factor given by the no. i expert of n experts is $W_{ij} = (a_{ij}, b_{ij}, c_{ij})$, $I = 1, 2, \ldots, n$, $j = 1, 2, \ldots, m$, then the fuzzy weighting w_j of the no. j factor is $w_j = (a_j, b_j, c_j)$, $j = 1, 2, \ldots, m$. Among which

$$a_j = \underset{i}{\mathrm{Min}}\{a_{ij}\},\ b_j = \frac{1}{n}\sum_{i=1}^{n} b_{ij}, c_j = \underset{i}{\mathrm{Max}}\{c_{ij}\} \quad (4)$$

where:

a_{ij}: the minimum of the respondents' common consensuses; b_{ij}: the average of the respondents' common consensuses; c_{ij}: the maximum of the respondents' common consensuses; a_j: mean opinion of the minimum of the respondents' common consensuses (a_{ij}); b_j: mean opinion of the average of the respondents' common consensuses (b_{ij}); c_j: mean opinion of the maximum of the respondents' common consensuses (c_{ij}); W_{ij}: the fuzzy number of all the respondents' opinions.

3. Using a simple center-of-gravity method to defuzzify the fuzzy weight w_j of each factor to develop the value S_j, the following are obtained:

$$S_j = \frac{a_j + b_j + c_j}{3}, \; j = 1, 2 \ldots m \tag{5}$$

where: S_j is the crisp number after defuzzification where is $0 < S_j < 1$.

4. Screening out factors by setting the threshold α that varies based on the researcher's opinion in different studies [49]. The principle of screening is as follows:

If $S_j \geq \alpha$, then the no. j factor should be selected.

If $S_j < \alpha$, then the no. j factor should be deleted.

4. Results and Discussion

The results and discussion will be presented in four sections. The first section presents the background information of the respondents. The second and third sections handle the ranking of success factors for company competitiveness using the RII and the screening of the factors using the FDM, respectively. The fourth section presents the intersection of the results of the two methods and the discussion of the results.

4.1. Respondent's Profile

As stated earlier, a pilot study was conducted with four leading experts in the construction industry in Egypt in order to discover possible additional factors, validate the ones that were developed during the literature reviews, and reduce the large number of factors. The backgrounds of the experts are shown in Table 2. Based on the experts' recommendations, the factors were reduced to 49 factors. The factors chosen gained the agreement of at least three of the four experts.

Table 2. Backgrounds of the four experts.

No.	Expert's Position	Relevant Work Experience
1	Former Chairman of the Board of Directors of the Arab Contractors Company	38 years
2	Chief Executive Officer	33 years
3	Cost Control Director	32 years
4	Cost Control Director	27 years

The 49 potential success factors were the basis of the questionnaire survey to collect the opinions of construction experts working in construction firms and consulting offices about the importance of the factors for company competitiveness. A total of 150 questionnaires were distributed to engineers working in construction companies and consulting offices, along with a cover letter explaining the objective of the study and assuring them of anonymity. A total of 30 questionnaires were paper-based, and the rest were computer-based in the form of an online survey. A total of 89 surveys were completed and returned; most of them were based on the online form. Out of these 89 participants, 67 were contractors, which is a percentage of about 75%. About 30% of the participants had more than 10 years of experience. Table 3 illustrates the characteristics of the respondents.

Table 3. Backgrounds of respondents.

Respondents' Category	Years of Experiences				Total	Percentage
	5–9	10–15	16–20	>20		
Contractors	45	13	3	6	67	75.28%
Consultants	18	1	1	2	22	24.72%
Total	63	14	4	8	89	100%
Percentage	71%	16%	4%	9%	100%	

4.2. Ranking of Success Factors for Company Competitiveness Using RII

The participating respondents shared their numerical scores, stating their opinions on the degree of importance of each success factor for company competitiveness. The values of the RII for the 49 factors were calculated for each group (consultant and contractor) and for engineers that had more than ten years of experience. Then, the success factors were ranked according to each party's own point of view as shown in Table 4.

Table 4. Ranking of the success factors for company competitiveness using RII.

Category	Proposed Success Factor	RII %	Standard Deviation	Overall Rank	Rank According to Contractors	Rank According to Consultants	Rank According to Respondents with ≥10 Years of Experience
Company Profile	Sustainable organization and leadership structure, and governance system	83.37	1.14	1	1	2	2
Company Profile	Stating mission, vision, and values of the organization	80.00	0.15	2	3	15	13
Company Profile	Key types of suppliers, partners, and collaborators	80.00	0.98	3	2	20	11
Company Profile	Reporting relationships among the governance board, senior leaders, and parent organization	79.55	1.09	4	7	1	8
Enablers	Using technology as a support to achieve strategies	79.10	1.12	5	4	7	9
Company Profile	Relative size and growth of the organization	78.43	1.14	6	10	3	27
Company Profile	Workforce groups and segments, educational requirements for different employee groups and segments, and the key drivers that engage them in achieving the organization's mission and vision	77.98	1.11	7	9	4	4
Company Profile	Key strategic challenges and advantages in the areas of construction services, operations, societal responsibilities, and workforce	77.53	0.95	8	8	16	14
Results	Having indicators measuring financial health, market and sales performance, productivity, overall operational, and innovation performance	77.53	1.12	9	6	21	18
Company Profile	Assets of the organization	77.53	1.19	10	5	34	5
Company Profile	Key elements of organizational performance-improvement system	77.30	1.04	11	11	8	21
Company Profile	Regulatory environment under which the organization operates	77.30	1.17	12	12	9	3
Enablers	Producing, delivering and developing products and services in order to create optimum value for customers	76.85	0.98	13	14	12	15
Enablers	Monitoring, reviewing and promoting internal performance and improvements throughout the organization	76.85	1.00	14	19	5	16
Company Profile	Quantity and types of competitors and key collaborators	76.85	1.09	15	15	13	19
Enablers	Taking care of the health and safety of workforce and providing good working conditions	76.85	1.21	16	13	17	17
Enablers	Identifying external stakeholders and thorough an understanding of their needs and expectations based on the strategy, and managing relationships with them accordingly	76.40	1.09	17	16	22	20
Enablers	Developing and sharing a mission, vision, set of values, and a code of ethics for the organization	76.18	1.06	18	18	23	6
Company Profile	Key market segments, customer groups, and stakeholder groups	75.96	1.09	19	20	24	12
Enablers	Managing and enhancing customer relationships	75.96	1.10	20	21	25	1
Enablers	Designing and managing processes by taking into account stakeholders' needs	75.96	1.10	21	22	10	10
Enablers	Developing workforce knowledge and skills	75.28	1.28	22	26	6	25

Table 4. *Cont.*

Category	Proposed Success Factor	RII %	Standard Deviation	Overall Rank	Rank According to Contractors	Rank According to Consultants	Rank According to Respondents with ≥10 Years of Experience
Company Profile	Key mechanisms for two-way communication with suppliers, partners, and collaborators, and the role they play in contributing and implementing innovations in the organization	75.06	1.05	23	17	38	22
Company Profile	Suppliers' and partners' role in organizational work systems	75.06	1.14	24	27	11	32
Results	Having positive trends over the past three years for the indicators measuring its business results	74.83	0.99	25	25	18	23
Enablers	Assuring that the organization is agile and flexible enough to face changes effectively and create a sustainable organization	73.93	1.09	26	24	35	28
Enablers	Assuring that the workforce understands the mission, vision, values and strategy, and that their evaluation is based on those	73.93	1.14	27	29	26	26
Enablers	Addressing opportunities for innovation in products, operations, and the organizational business model	73.71	1.08	28	30	27	29
Enablers	Managing the organization's finance, buildings, equipment, materials and natural resources in a sustainable way, and continually reducing their impact on the environment	73.48	1.20	29	31	28	33
Results	Defining current levels and indicators of operational performance of key work systems and processes	73.26	1.04	30	23	46	35
Enablers	Sharing and understanding all necessary data and information to optimize decision making	73.26	1.21	31	32	31	24
Results	Holding a regular customer survey, with indicators monitoring their satisfaction, complaints and performance perception	73.03	1.29	32	33	32	34
Enablers	Having a system of rewards and recognition to honor and motivate the workforce via policies, services, and benefits	72.81	1.37	33	28	43	7
Company Profile	Organization's special health and safety requirements	72.58	1.30	34	38	14	36
Enablers	Including a plan on the workforce needs for the future and having a workforce change management	72.36	1.17	35	34	39	37
Company Profile	Key requirements and expectations for services, customer support services, and operations	71.91	0.95	36	37	33	38
Company Profile	Available key sources of comparative and competitive data from within the construction industry	71.46	1.08	37	36	44	45
Enablers	Balancing short- and long-term challenges and opportunities	71.46	1.17	38	44	19	30
Company Profile	Differences in requirements and expectations among market segments, customer groups, and stakeholder groups	71.01	0.87	39	35	47	31
Results	Comparing organization's performance with benchmarks for the indicators measuring business, workforce, customers, and society results	71.01	1.10	40	39	36	40
Enablers	Using market research, customer surveys and other forms of feedback to identify improvements, and effectively promote and market the organization's products and services	70.56	1.07	41	45	29	47
Results	Having and developing indicators to monitor the workforce performance and satisfaction, how they understand the strategy, the quality of internal communication, and the adequacy of individual competitors to the needs of the organization	70.56	1.09	42	41	37	44
Results	Having positive trends over the past three years for the indicators concerning the workforce	70.34	1.11	43	46	30	41

Table 4. *Cont.*

Category	Proposed Success Factor	RII %	Standard Deviation	Overall Rank	Rank According to Contractors	Rank According to Consultants	Rank According to Respondents with ≥10 Years of Experience
Enablers	Leadership communication with the workforce for achieving their strategy	70.11	1.12	44	42	41	46
Company Profile	Key applicable occupational health and safety regulations; accreditation, certification, or registration requirements; industry standards; and environmental, financial, and product regulation	69.89	1.22	45	43	45	43
Results	Having positive trends over the past three years for the indicators in the customer survey	69.66	1.13	46	40	48	42
Results	Understanding the rationale behind the evolution of the indicators concerning its workforce	68.54	1.12	47	47	42	39
Results	Having indicators to assess the image of the organization as being concerned about the environment, the environmental impact of the organization, and employees' social commitment	67.64	1.13	48	49	40	48
Results	Having positive trends over the past three years for the indicators measuring societal performance	66.74	1.11	49	48	49	49

Because too many CSFs may be unmanageable, management must prioritize the appropriate success factors. According to Swan and Kyng [59], the appropriate number of CSFs have to be 8–12. Participant-wise, for the contractor, the most highly rated factor for company competitiveness are sustainable organization and leadership structure, and governance system; key types of suppliers, partners, and collaborators; stating the mission, vision, and values of the organization; using technology as a support to achieve strategies; and the assets of the organization.

Likewise for the consultants, the five top-rated success factors for company competitiveness are reporting relationships among the governance board, senior leaders, and parent organization; sustainable organization and leadership structure, and governance system; relative size and growth of the organization; workforce groups and segments, educational requirements for different employee groups and segments, and key drivers that engage them in achieving the organization's mission and vision; and monitoring, reviewing and promoting internal performance and improvements throughout the organization.

According to respondents with at least ten years of experience, the most highly rated factors for competitiveness are managing and enhancing customer relationships; sustainable organization and leadership structure, and governance system; regulatory environment; workforce groups and segments, educational requirements for different employee groups and segments, and key drivers that engage them in achieving the organization's mission and vision; and the assets of the organization.

All the respondents agreed that the most significant factors for company competitiveness are sustainable organization and leadership structure, and governance system; stating the mission, vision, and values of the organization; key types of suppliers, partners, and collaborators; reporting relationships among the governance board, senior leaders, and parent organization; using technology as a support to achieve strategies. It is interesting to note that factors such as understanding the rationale behind the evolution of the indicators concerning its workforce, having indicators to assess the image of the organization as being concerned about the environment, the environmental impact of the organization and the employees' social commitment, and having positive trends over the past three years for the indicators measuring societal performance are the least important for helping to improve a contractor's competitiveness in the current Egyptian construction market conditions.

4.3. Screening of Success Factors for Company Competitiveness Using FDM

This study intends to screen the success factors for company competitiveness by applying the FDM. This section handles the results of application of the FDM. The opinions of the experts in the questionnaires are converted to triangular fuzzy numbers (Table 5), and the defuzzified values can be determined after the calculation. In this study the threshold of factors was set as $\alpha = 0.55$.

Table 5. Success factors for company competitiveness after FDM screening.

Category	Success Factor	Triangular Fuzzy Number	Crisp Value (Sj)	Result
Company Profile	Sustainable organization and leadership structure, and governance system	(0.00, 0.79, 1.00)	0.597	Select
Company Profile	Stating mission, vision, and values of the organization	(0.50, 0.75, 1.00)	0.75	Select
Company Profile	Key types of suppliers, partners, and collaborators	(0.00, 0.75, 1.00)	0.583	Select
Company Profile	Reporting relationships among the governance board, senior leaders, and parent organization	(0.00, 0.74, 1.00)	0.581	Select
Enablers	Using technology as a support to achieve strategies	(0.00, 0.74, 1.00)	0.556	Select
Company Profile	Relative size and growth of the organization	(0.00, 0.73, 1.00)	0.577	Select
Company Profile	Workforce groups and segments, educational requirements for different employee groups and segments, and the key drivers that engage them in achieving the organization's mission and vision	(0.00, 0.72, 1.00)	0.575	Select
Company Profile	Key strategic challenges and advantages in the areas of construction services, operations, societal responsibilities, and workforce	(0.00, 0.72, 1.00)	0.573	Select
Results	Having indicators measuring financial health, market and sales performance, productivity, overall operational, and innovation performance	(0.00, 0.72, 1.00)	0.573	Select
Company Profile	Assets of the organization	(0.00, 0.72, 1.00)	0.573	Select
Company Profile	Key elements of organizational performance-improvement system	(0.00, 0.72, 1.00)	0.573	Select
Company Profile	Regulatory environment under which the organization operates	(0.00, 0.72, 1.00)	0.573	Select
Enablers	Producing, delivering and developing products and services in order to create optimum value for customers	(0.00, 0.71, 1.00)	0.57	Select
Enablers	Monitoring, reviewing and promoting internal performance and improvements throughout the organization	(0.00, 0.71, 1.00)	0.57	Select
Company Profile	Quantity and types of competitors and key collaborators	(0.00, 0.71, 1.00)	0.57	Select
Enablers	Taking care of the health and safety of workforce and providing good working conditions	(0.00, 0.71, 1.00)	0.57	Select
Enablers	Identifying external stakeholders and thorough an understanding of their needs and expectations based on the strategy, and managing relationships with them accordingly	(0.00, 0.71, 1.00)	0.568	Select
Enablers	Developing and sharing mission, vision, set of values and a code of ethics for the organization	(0.00, 0.70, 1.00)	0.567	Select

Table 5. *Cont.*

Category	Success Factor	Triangular Fuzzy Number	Crisp Value (Sj)	Result
Company Profile	Key market segments, customer groups, and stakeholder groups	(0.00, 0.70, 1.00)	0.566	Select
Enablers	Managing and enhancing customer relationships	(0.00, 0.70, 1.00)	0.566	Select
Enablers	Designing and managing processes taking into account stakeholders' needs	(0.00, 0.70, 1.00)	0.566	Select
Enablers	Developing workforce knowledge and skills	(0.00, 0.69, 1.00)	0.564	Select
Company Profile	Key mechanisms for two-way communication with suppliers, partners, and collaborators, and the role they play in contributing and implementing innovations in the organization	(0.00, 0.69, 1.00)	0.563	Select
Company Profile	Suppliers' and partners' role in organizational work systems	(0.00, 0.69, 1.00)	0.563	Select
Results	Having positive trends over the past three years for the indicators measuring its business results	(0.00, 0.69, 1.00)	0.563	Select
Enablers	Assuring that the organization is agile and flexible enough to face changes effectively and create a sustainable organization	(0.00, 0.67, 1.00)	0.558	Select
Enablers	Assuring that workforce understands the mission, vision, values and strategy, and that their evaluation is based on those	(0.00, 0.67, 1.00)	0.558	Select
Enablers	Addressing opportunities for innovation in products, operations, and the organizational business model	(0.00, 0.67, 1.00)	0.557	Select
Enablers	Managing the organization's finance, buildings, equipment, materials and natural resources in a sustainable way, and continually reducing their impact on the environment	(0.00, 0.67, 1.00)	0.555	Select
Results	Defining current levels and indicators of operational performance of key work systems and processes	(0.00, 0.67, 1.00)	0.562	Select
Enablers	Sharing and understanding all necessary data and information to optimize decision making	(0.00, 0.67, 1.00)	0.563	Select
Results	Holding a regular customer survey, with indicators monitoring their satisfaction, complaints and performance perception	(0.00, 0.66, 1.00)	0.553	Select
Enablers	Having a system of rewards and recognition to honor and motivate the workforce via policies, services, and benefits	(0.00, 0.66, 1.00)	0.553	Select
Company Profile	Organization's special health and safety requirements	(0.00, 0.66, 1.00)	0.552	Select
Enablers	Including a plan on the workforce needs for the future and having a workforce change management	(0.00, 0.65, 1.00)	0.551	Select
Company Profile	Key requirements and expectations for services, customer support services, and operations	(0.00, 0.65, 1.00)	0.549	Delete
Company Profile	Available key sources of comparative and competitive data from within the construction industry	(0.00, 0.64, 1.00)	0.546	Delete
Enablers	Balancing short- and long-term challenges and opportunities	(0.00, 0.64, 1.00)	0.546	Delete

Table 5. *Cont.*

Category	Success Factor	Triangular Fuzzy Number	Crisp Value (*Sj*)	Result
Company Profile	Differences in requirements and expectations among market segments, customer groups, and stakeholder groups	(0.00, 0.64, 1.00)	0.546	Delete
Results	Comparing organization's performance with benchmarks for the indicators measuring business, workforce, customers, and society results	(0.00, 0.64, 1.00)	0.544	Delete
Enablers	Using market research, customer surveys and other forms of feedback to identify improvements, and effectively promote and market the organization's products and services	(0.00, 0.63, 1.00)	0.543	Delete
Results	Having and developing indicators to monitor the workforce performance and satisfaction, how they understand the strategy, the quality of internal communication, and the adequacy of individual competitors to the needs of the organization	(0.00, 0.63, 1.00)	0.543	Delete
Results	Having positive trends over the past three years for the indicators concerning the workforce	(0.00, 0.63, 1.00)	0.543	Delete
Enablers	Leadership communication with the workforce for achieving their strategy	(0.00, 0.63, 1.00)	0.542	Delete
Company Profile	Key applicable occupational health and safety regulations; accreditation, certification, or registration requirements; industry standards; and environmental, financial, and product regulation	(0.00, 0.62, 1.00)	0.541	Delete
Results	Having positive trends over the past three years for the indicators in the customer survey	(0.00, 0.62, 1.00)	0.541	Delete
Results	Understanding the rationale behind the evolution of the indicators concerning its workforce	(0.00, 0.61, 1.00)	0.536	Delete
Results	Having indicators to assess the image of the organization as being concerned about the environment, the environmental impact of the organization, and employees' social commitment	(0.00, 0.60, 1.00)	0.533	Delete
Results	Having positive trends over the past three years for the indicators measuring societal performance	(0.00, 0.58, 1.00)	0.532	Delete

If $S_j \geq 0.55$, then the no. j factor should be selected.
If $S_j < 0.55$, then the no. j factor should be deleted.

The success factors after screening are listed in Table 5. It can be seen from Table 5 that 35 factors were selected, and 14 factors were deleted. Fifteen of the selected factors are attributed to the company profile category, which contains 19 factors, while sixteen of the selected factors are attributed to the enablers category, which contains 19 factors. The other four selected factors are attributed to the results category (11 factors).

4.4. CSFs of Company's Competitiveness

In this paper, the RII method was applied to rank the success factors of the company's competitiveness, while the FDM was used to screen out the factors. As mentioned earlier, the number of factors selected using the FDM is 35. Therefore, the CSFs for the competitiveness of the company must be obtained by taking the intersection of the results of two methods, that is, the CSFs for the competitiveness of the company must satisfy two requirements. The first is that it should be one of the factors with the highest rankings using the RII method, and the second is that it should be selected using the FDM method. The results are shown in Table 6 for only the ten top-ranked success factors. Although it is not practical to discuss the full implications of all the factors, the five top-rated factors will be discussed in-depth.

Table 6. Critical success factors for company competitiveness.

Rank	CSFs Using RII	Success Factor After FDM Screening	Final Results
1	Sustainable organization and leadership structure, and governance system	Selected	Organization and leadership structure, and governance system
2	Stating the mission, vision, and values of the organization	Selected	Stating mission, vision, and values of the organization
3	Key types of suppliers, partners, and collaborators	Selected	Key types of suppliers, partners, and collaborators
4	Reporting relationships among the governance board, senior leaders, and parent organization	Selected	Reporting relationships among the governance board, senior leaders, and parent organization
5	Using technology as a support to achieve strategies	Selected	Using technology as a support to achieve strategies
6	Relative size and growth of the organization	Selected	Relative size and growth of the organization
7	Workforce groups and segments, educational requirements for different employee groups and segments, and the key drivers that engage them in achieving the organization's mission and vision	Selected	Workforce groups and segments, educational requirements for different employee groups and segments, and the key drivers that engage them in achieving the organization's mission and vision
8	Key strategic challenges and advantages in the areas of construction services, operations, societal responsibilities, and workforce	Selected	Key strategic challenges and advantages in the areas of construction services, operations, societal responsibilities, and workforce
9	Having indicators measuring financial health, market and sales performance, productivity, overall operational, and innovation performance	Selected	Having indicators measuring financial health, market and sales performance, productivity, overall operational, and innovation performance
10	Assets of the organization	Selected	Assets of the organization

A sustainable organization and leadership structure, and effective governance system is ranked as the most important CSF for indicating a contractor's competitiveness. The organization structure provides the framework in which a business can operate and strategies can be developed and implemented. The key elements in formulating an organization include making the structure suitable and clearly defined with allocated functions for different departments, and the collaboration and communication between departments [60]. This factor also handles how leaders' personal actions guide and sustain the organization, and how the organization fulfills its legal, ethical, and societal responsibilities [37]. The sustainable organization and leadership structure factor was ranked as one of the important factors in many past studies from countries such as Canada, China, and Hong Kong [33,60,61]. For example, it was ranked sixth in the Canadian market [33] and fourteenth in the Chinese market [60].

Stating the mission, vision, and values of the organization is ranked the second CSF for company competitiveness. Senior leaders set the organization's vision and values and deploy them, through the leadership system, to the workforce, to key suppliers and partners, and to customers and other stakeholders, as appropriate. Moreover, senior leaders' personal actions should reflect a commitment to those values [37]. This factor was ranked as one of the most important factors in past studies in Canada and Switzerland [33,37]. For example, it was ranked the ninth factor in the Canadian market [33]; however, it was not ranked as one of the important factors in the Chinese Market [60].

The key types of suppliers, partners, and collaborators is ranked as the third important CSF. The types of suppliers, partners, and collaborators are very important for the company to succeed. This result is in line with the findings of previous studies in Canada, Chile and Hong Kong [33,61,62], suggesting that selecting qualified suppliers and partners is vital for contractors in enhancing their competitiveness in an increasingly dynamic construction industry. This factor was ranked as the eighth factor in the Canadian market [33], and was ranked as the twenty-eighth factor in the Chinese market [60].

Reporting relationships among the governance board, senior leaders, and parent organization is ranked as the fourth CSF from the survey. It seems that managers of Egyptian construction companies are fully aware of the importance of the effective implementation of communication and a feedback system in improving competitiveness. Reporting relationships might include relationships with external stakeholders such as a government agency and funding sources. This factor was ranked as the third factor in the Chinese market [60]. In addition, it was ranked as the tenth factor in the Canadian Market [33].

Using technology as a support to achieve strategies is ranked as the fifth CSF. Using technology is a strategic management process that aims to maximize value by achieving a complete integration of a company's IT practices with its structures, processes, decision making, and evolving strategic goals [63]. Technology management is necessary to achieve the strategy required for the company. This factor is ranked as one of the most important factors in previous studies in countries such as Chile and Hong Kong [61,62]. However, technology management was ranked as the least factor of significance to company competitiveness in the Canadian market [33], and was ranked as the nineteenth in the Chinese market [60].

Briefly, the factors in the higher ranks are more critical to a contractor's competitiveness. Those factors should be given priority by the company. The identification of the CSFs provides a vehicle for guiding contractors in utilizing their competitive resources more efficiently to improve their competitive advantage.

5. Conclusions, and Further Work

To advance their competitiveness, increase their productivity, and enhance their performance, it is important for contractors to identify the success factors that have a bearing on their competitiveness in local markets. The main goal of this paper was to identify the CSFs for company competitiveness as perceived by contractors and consultants working in Egypt. In this paper, depending on a review of the national and international literature, there were 83 preliminary factors classified under three main categories that were listed for the identification of competitiveness in construction firms. A pilot study was performed with four experts to reduce the large number of factors to 49 critical factors. A questionnaire form was then designed to collect the opinions of experts working in construction companies and consultant offices in Egypt. A total of 89 surveys were completed and returned. Two kinds of methods were used to rank and screen the success factors for company competitiveness, which were the RII and FDM, respectively. The CSFs for the competitiveness of Egyptian construction companies included a sustainable organization and leadership structure, and governance system; stating the mission, vision, and values of the organization; key types of suppliers, partners, and collaborators; using technology as a support to achieve strategies; relative size and growth of the organization; workforce groups and segments, educational requirements for different employee groups and segments, and key drivers that engage them in achieving the organization's mission and vision; key strategic challenges and advantages in the areas of construction services, operations, societal responsibilities, and workforce; having indicators measuring financial health, market and sales performance, productivity, overall operational, and innovation performance; and the assets of the organization. Understanding the rationale behind the evolution of the indicators concerning its workforce; using indicators to assess the image of the organization as being concerned about the environment; and having positive trends over the past three years for the indicators measuring societal performance are the lowest-ranked factors for the perception of competitiveness of construction companies.

The results showed that the ranking of the CSFs is different compared to the Canadian and Chinese markets, which emphasizes the importance of this research. The CSFs should be given priority by the company. The identification of the CSFs provides a vehicle for guiding contractors in utilizing their competitive resources more efficiently to improve their competitive advantage. This study was focused on the Egyptian construction market. Therefore, the findings of this research are not applicable to other countries as each market has its own characteristics, but the research methodology can be applied to other countries.

In future studies, the fuzzy analytic hierarchy process (FAHP) can be used as a basis to build a model for measuring/evaluating the competitiveness of the Egyptian construction industry. This model will serve both the contractor and the owner in Egypt.

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Appendix A

Table A1. Success factors for company competitiveness summarized in the literature review. The Dot (●) indicates that the factor was used in the selected study.

No.	Success Factors	Reference (Country)										
		El-Diraby, Costa [33] (Canada)	Tan, Shen [62] (Hong Kong)	FIDIC [64] (Switzerland)	Lu, Shen [60] (China)	Elwakil, Ammar [36] (Canada)	Hoang [15] (Canada and other countries)	Orozco, Serpell [61] (Chile)	Ercan and Koksal [65] (USA and Middle East)	EFQM [66] (Europe)	Badawy [16] (Canada)	Baldrige [37] (USA)
1	Company vision, mission, value and ethics	●		●		●	●		●	●		●
2	Leadership communication and performance improvement			●			●		●	●		●
3	Sustainability of organization structure	●	●	●	●	●	●		●	●	●	●
4	Organization and leadership structure			●					●			●
5	Governance system			●					●			●

Table A1. *Cont.*

No.	Success Factors	Reference (Country)										
		El-Diraby, Costa [33] (Canada)	Tan, Shen [62] (Hong Kong)	FIDIC [64] (Switzerland)	Lu, Shen [60] (China)	Elwakil, Ammar [36] (Canada)	Hoang [15] (Canada and other countries)	Orozco, Serpell [61] (Chile)	Ercan and Koksal [65] (USA and Middle East)	EFQM [66] (Europe)	Badawy [16] (Canada)	Baldrige [37] (USA)
6	Organization culture	•		•	•		•	•	•			
7	Image and reputation							•				
8	Litigation and attribution history			•								
9	Organization's credibility	•	•		•							
10	Leaders' personality and capability	•	•		•		•	•				
11	Recognized grade of the company		•									
12	Banking credibility rating		•									
13	Promoting legal and ethical behavior									•	•	•
14	Societal responsibilities and support of key communities											•
15	Communication and coordination among functional departments	•			•			•		•		•
16	Interaction between management and general staff				•							
17	Assets of organization (Major facilities, technologies, and equipment)					•			•			•
18	Company experience	•		•		•	•	•				
19	Relative size and growth of company				•				•		•	
20	Strategy development, implementation, and improvement				•	•	•	•		•	•	•
21	Availability and efficient utilization of company resources	•	•	•	•		•		•	•	•	
22	Healthy and stable financial status		•	•	•			•	•			
23	Financing capacity				•			•	•			
24	Price competitiveness							•	•		•	
25	Capability of gathering and processing information of new projects/contracts				•		•					
26	Value of projects completed in the past three years		•	•			•					
27	Credibility grade certified by relevant financial bodies		•									
28	Capability of loan repayment		•									
29	IT application and Technology management	•	•		•	•	•	•	•		•	•
30	Availability of R&D	•			•	•	•	•			•	
31	Project management knowledge area: integration, scope, schedule, cost, quality, contract, communications, risk, procurement, and stakeholder management	•	•	•	•	•	•	•	•		•	

Table A1. *Cont.*

No.	Success Factors	Reference (Country)										
		El-Diraby, Costa [33] (Canada)	Tan, Shen [62] (Hong Kong)	FIDIC [64] (Switzerland)	Lu, Shen [60] (China)	Elwakil, Ammar [36] (Canada)	Hoang [15] (Canada and other countries)	Orozco, Serpell [61] (Chile)	Ercan and Koksal [65] (USA and Middle East)	EFQM [66] (Europe)	Badawy [16] (Canada)	Baldrige [37] (USA)
32	Proportion of advanced construction equipment and plant		•									
33	Work system management and improvement (design and manage processes)								•	•		
34	Improvement system											•
35	Customer groups and types	•										•
36	Customer relationship and satisfaction	•		•	•		•	•		•	•	•
37	Customer culture challenges			•		•	•					
38	Product offerings and customer support									•		•
39	On the tender list for governmental works		•									
40	Key types of suppliers, partners, and collaborators											•
41	Organization's client and supplier awareness	•					•					
42	Relationship with government departments & with public		•		•		•			•	•	
43	Relationship with partners, subcontractors or suppliers & designers and consultants	•	•		•		•	•	•	•	•	
44	Payment to subcontractors/suppliers on time		•									
45	Supplier environment						•					
46	Effectiveness of co-ordination with subcontractors		•									
47	Logistic and supply-chain management				•							
48	Number and kind of competitors							•				•
49	Workforce capability and capacity	•	•		•	•	•	•		•	•	•
50	Workforce communication and engagement									•		•
51	Workforce satisfaction and motivation	•			•	•	•	•		•		•
52	Workforce union relations	•										
53	Workforce salary						•					
54	Workforce performance						•					•
55	Workforce change management						•	•		•		•
56	Effectiveness of workforce enhancements, training, and education		•		•	•	•	•		•		
57	Retention of core staff		•									
58	Effectiveness of group-working and problem solving		•					•		•		
59	Availability and management of data, information, and knowledge					•						•

Table A1. *Cont.*

No.	Success Factors	Reference (Country)										
		El-Diraby, Costa [33] (Canada)	Tan, Shen [62] (Hong Kong)	FIDIC [64] (Switzerland)	Lu, Shen [60] (China)	Elwakil, Ammar [36] (Canada)	Hoang [15] (Canada and other countries)	Orozco, Serpell [61] (Chile)	Ercan and Koksal [65] (USA and Middle East)	EFQM [66] (Europe)	Badawy [16] (Canada)	Baldrige [37] (USA)
60	Emergency readiness											•
61	Society satisfaction and social conditions	•					•	•				
62	Legal and regulatory environment	•	•		•			•				•
63	Political conditions	•		•		•					•	
64	Construction industry conditions			•			•	•	•		•	
65	Environmental issues	•						•			•	
66	Product maintenance					•						
67	Having indicators measuring financial health, market and sales performance, productivity, overall operational, and innovation performance									•		•
68	Having positive trends over the past three years for the indicators measuring its business results									•		
69	Defining current levels and indicators of operational performance of key work systems and processes									•		
70	Holding a regular customer survey, with indicators monitoring their satisfaction, complaints, and their perception of organization's performance									•		•
71	Comparing organization's performance with benchmarks for the indicators measuring business, workforce, customers, and society results									•		•
72	Having and developing indicators to monitor the workforce performance and satisfaction, how they understand the strategy, the quality of internal communication, and the adequacy of individual competitors to the needs of the organization									•		•
73	Having positive trends over the past three years for the indicators concerning the workforce									•		•
74	Having positive trends over the past three years for the indicators in the customer survey									•		•
75	Understanding the rationale behind the evolution of the indicators concerning its workforce									•		•
76	Having positive trends over the past three years for the indicators in the customer survey									•		•
77	Having indicators measuring market and sales performance and other performance indicators									•		•
78	Having positive trends over the past three years for the indicators measuring its business results									•		•

Table A1. *Cont.*

No.	Success Factors	Reference (Country)										
		El-Diraby, Costa [33] (Canada)	Tan, Shen [62] (Hong Kong)	FIDIC [64] (Switzerland)	Lu, Shen [60] (China)	Elwakil, Ammar [36] (Canada)	Hoang [15] (Canada and other countries)	Orozco, Serpell [61] (Chile)	Ercan and Koksal [65] (USA and Middle East)	EFQM [66] (Europe)	Badawy [16] (Canada)	Baldrige [37] (USA)
79	Defining current levels and indicators of operational performance of key work systems and processes									•		•
80	Having indicators to assess the image of the organization as being concerned about the environment, the environmental impact of the organization, and employees' social commitment									•		•
81	Having positive trends over the past three years for the indicators measuring societal performance									•		•
82	Having indicators measuring sustainable management of building, equipment, material, and rational resources									•		•
83	Having indicators measuring leadership and governance outcomes									•		•

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Article

Assessing Construction Constraint Factors on Project Performance in the Construction Industry

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Abstract: A construction constraint is a condition that impedes progress toward meeting construction project goals. This paper seeks to assess the constraint factors affecting project performance in the South African construction industry. The study adopted a quantitative research design, and a questionnaire was designed to retrieve data from the target populations. The target population were construction professionals within the South African construction industry. One hundred and eighty questionnaires were administered to construction professionals within the study area through the purposive quota sampling technique. Retrieved data were analysed using descriptive and exploratory factor analysis. In order to determine the data reliability and the interrelatedness of the variables, Cronbach's alpha test was carried out on each component. The results of the exploratory factor analysis show that stakeholders' inappropriate project scheduling and coordination factors, organisation and government policies factors, and organisation and government policies factors were the leading constraints affecting construction project performance in the South African construction industry. Due to time and distance constraints, this study was limited to construction professionals in South Africa's Free State province. The paper concluded that to reduce the construction constraints affecting construction project performance, construction professionals must improve their project scheduling, coordination, organisational policies, and managerial capacity. The paper's findings will assist stakeholders in identifying and overcoming construction constraints in construction projects' execution and delivery.

Keywords: constraints; construction projects; construction industry; free state; South Africa

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1. Introduction

The construction industry is one of the major sectors responsible for the economic growth of nations due to its importance and contributions to Gross Domestic Product [1,2]. The diversity of the construction industry includes the nature of its operations, involvement of different stakeholders, different construction phases, applicable codes, bylaws, and regulations in ensuring successful project planning, designing, construction, and delivery [3–5]. Similarly, refs. [6–9] point out that the success of a construction project is determined by appropriate timing and budgeting for construction projects in line with the quality specified. Refs. [10,11] argue that stakeholders' involvement and how the project is scheduled in terms of cost, quality, and time determine its success or failure. Refs. [12,13] opine that the construction industry encounters numerous constraints during the project life cycle ranging from overruns of time, cost, project scope, conflicts, and low-quality performance.

Construction constraints, as defined by refs. [14,15], are conditions or forces that obstruct the progress of construction operations toward achieving the triple project's objectives or goals of cost, time, and quality, which is considered the criterion for project success. Ref. [16] defines a constraint in project management as a point where the project fails to perform as expected. Ref. [17] asserts that the construction industry's paradigm shift due to the sites' complex nature, duration performance, imbalanced cash flows, and complex contractual agreements pose several constraints that usually prevent construction projects from being completed on time and within the cost budgets. Refs. [14,18] posit that stakeholders must have studied the possibility of project constraints at the outset by understanding the dynamics of the project and how different constraints are interrelated. Thus, identifying these constraints will provide the practical steps for making effective organisational decisions that will reduce the impact of these constraints in the construction process [19].

However, refs. [20,21] posit that construction project execution is risky and prone to certain constraints and circumstances threatening successful project delivery. Ref. [16] argues that controlling such constraints is a precondition for the astonishing performance of the construction project. Ref. [22] sustains that the consequence of construction constraints are drawbacks to project success leading to disputes or litigations among the stakeholders, which can affect the project performance. In their study, ref. [23] noticed that constraints could involve all the parties to a contract. If not well-managed, it will affect the contractual relations among the stakeholders. Therefore, the negative impacts of constraints on construction projects' operation include time and cost overruns, a decline in profit and productivity, and damage to contractual relations [24]. Refs. [25,26] state that constraints must be identified and managed at the early stage of the project because ignoring them could lead to conflicts, disputes, and sabotage of stakeholders' relationships. As such, constraints not identified and managed may produce controversies among stakeholders and directly or indirectly cost the clients and contractors, compromising project quality and scope during the design and implementation ref. [27].

Conversely, ref. [28] posits that insufficient previous research focuses on the construction industry's emergence of conflicts and project constraints. The factors causing construction constraints and their relative impacts on construction operations are rarely known or fully explored. Thus, the rapid rate of development and construction operations in the construction industry demands a research study focusing on identifying factors causing constraints and how they affect project goals' performance and delivery. Hence, this study aims to bridge the knowledge gap by assessing factors causing constraints in construction project performance in the construction industry, using construction projects in South Africa as a case study.

Although a previous study of ref. [29] aimed to assess the criticality of the factors that influence the performance of highway projects, the study cannot be generalised for general construction work because it focuses more on highway projects. Highway projects cannot be entirely compared with other construction projects, given the technicality involved in highway projects. Hence, this study is carried out to focus more on general construction projects. Further, the previous study of ref. [29] was carried out in another developing country, whereas what is applicable in their construction project process might not be applicable in the South African context. These submissions necessitate carrying out this study.

This study precisely focused on assessing factors causing constraints to construction project performance in the construction industry. The motivation for conducting this study in the South African construction industry is that previous studies (refs. [16,23]) on construction constraints only focused on consultants and contractors within construction projects. This study will fill this gap by assessing factors causing constraints in construction project performance among construction professionals within their different professional bodies in the South African construction industry.

The study is important for construction industry professionals in identifying construction constraints early toward achieving a more effective construction project performance. The review of prior literature, theoretical background, methodology, results, discussion of findings, conclusion, and recommendations are among the sections of the article that aid in reaching the stated purpose.

2. Literature Review

2.1. Findings from Extant Literature on Factors Causing Construction Constraints

Construction projects succeed when the deliverable objectives are attained within the time, budget, quality, and safety progress of construction operations [30]. The study of constraints on resources, risk, and management practices in construction projects cannot be ignored because of its influence on project deliverables [28]. The paradigm shift in construction project management emphasises the importance of identifying major constraint factors against the traditional concept of the triple constraints of time, cost, and quality [31]. The construction project objectives (time, cost, and quality) are limiting factors that can impact project delivery, quality, and overall project success if not well-managed [30]. Hence, in Pakistan, ref. [32] identified "natural disaster", "financial and payment difficulties", "poor planning", "poor site management", "insufficient stakeholders experience", and "shortage of materials and equipment" as the major factors causing construction constraints in project execution. Additionally, ref. [28] investigated the effect of stakeholders' conflicts on projects constraints and attributes of the factors causing constraints to "lack of communication", "poor quality delivery", "change in design and rework", "safety regulations", "workers productivity", and "protection of the environment".

Ref. [33] posited the six factors particular to Thailand's construction industry as constraints relating to owners' problems, designers, construction management related issues, contractors, and resources suppliers. The findings of ref. [34] on the Iranian construction operatives' productivity present factors causing project constraints as "lack of material", "design deficiency and/or change order", "lack of proper tool and equipment", "equipment breakdown", and "weather and site condition". Ref. [35] conducted a study on stakeholders' assessment of constraints to project delivery. The study aimed to identify and assess the constraints to construction project delivery and identified fifty factors causing constraints, mostly in developing countries. Thus, the study attributed the most frequent constraints on project delivery to "poor communication", "lack of coordination and conflicts between stakeholders", "weather/climate conditions", "ineffective or improper planning", "material shortages", "financial problems", "payment delays", "equipment/plant shortage", "lack of qualified stakeholders", "labour shortages", and "poor site management".

Similarly, the study of ref. [16] showed that constraint factors that have high impacts on construction project performance include "improper allocation of funds to parties", "land acquisition", "building regulation", "safety regulation", "dispute in the contractual agreement", "government labour laws", "delay in solving design issues", "inappropriate project cost estimate", and "flawed drawing and details". In Nigeria, ref. [36] identified four external environmental factors causing constraints and affecting project performance: land acquisition tussles, weather conditions, economic situation, and government policies. Further, ref. [37] grouped the factors under political, legal, construction techniques and resources, economic and financial, sociocultural, and physical. Ref. [38] identified a shortage of cash flow, clients' financial difficulties, and poor procurement. Ref. [39] argued that project constraints that influence productivity include a lack of incentives system, poor health conditions of workers, material delay, inadequate site amenities, and an aging workforce.

Ref. [40] attributed factors causing constraints in the Congolese construction industry to client and management, production scheduling and contract, shortages of experience stakeholders and skilful design team, and client/owner payment delay. Similarly, ref. [41] identified delays in assessing changes in the scope of work by the consultant, contractor financial misappropriation, shortage of contractor's experience, design errors, and inadequate site investigation. In South Africa, ref. [42] posited disputes related to contractual documents, undocumented changes in design, financial difficulties, unbalanced cost of materials, high cost of equipment, poor communication between design and construction team, economic instability, and forex exchange rate as the factors causing construction constraints. Ref. [43] posited that constraints in the South African construction industry always lead to variations, overrun costs, and times due to changing project scope, financial difficulties, government policies and regulations, and inappropriate project cost estimation.

Refs. [42,43] aimed to investigate the causes of cost overruns and management of cost constraints, which is just one of the key elements of the traditional concept of triple constraints in construction projects. Findings from both studies were based on contractors' and consultants' perspectives using descriptive statistical procedures. However, the contributions of this study differ from both studies because they assess the factors causing constraints in construction project performance from the angle of the traditional concept of triple constraints in construction projects based on construction professionals' perspectives. Further, retrieved data in this study are analysed using descriptive and exploratory factor analysis.

2.2. Theoretical Background

In explaining the factors causing constraints affecting the project performance, the theory of constraints (TOC) model [44] was engaged. The theory of constraints (TOC) explains five steps to identify and eliminate organisation constraints. The theory of constraints provides the organisation with a logical philosophy of continuous improvement, identifying factors limiting the organisation from attaining goals. Ref. [44]'s theory of constraints' first steps involves identification in the organisation system, harnessing the system constraints, subordinate strategic and tactical approach to the above decision, elevating the system constraints, and reapplying the procedures for continuous improvement. Ref. [45] detailed the evolution of TOC and its application in five different eras citing ref. [44], namely, the first era focused on optimisation production technology 1979–1984; followed by the second era, named the goal era, 1984–1990; the third era was named haystack syndrome 1990–1994; the fourth era was tagged it's not locked era 1994–1997; and the fifth era is called critical chain era 1997–2000. According to refs. [46–48], TOC has grown interested in different fields over the years. Its application has cut across the fields of accounting, marketing, logistic, construction project management, and many industries that desire system change.

Refs. [49,50] posited that the theory of constraints applies to construction project management. Ref. [49] explained that the TOC deals with the fundamental aspects of construction project management, including exercising control, monitoring the project's input and output, and evaluating and selecting the best alternatives to ensure client satisfaction. Ref. [48] posited that constraints limit an organisation's performance; identifying and eliminating constraints is the focus of TOC because of its continuous search for improving the organisation system by dealing with the constraints. Similarly, ref. [51] suggested that the theory of constraints applies to construction project management because its operations are similar to the manufacturing production process in which productivity is affected by various constraints.

Thus, ref. [51] combined the factors causing construction project management constraints under five categories: environmental, economic, legal, technical, and social. With this understanding, this study is underpinned by the theory of constraints and its application in assessing factors causing construction constraints in the project performance using construction projects in Free states province, South Africa, as a case study.

Subsequently, as shown in Table 1 above, a synthesis in the current study of the views developed by various authors provides a more holistic outline to guide this study. Thus, detailed in Table 1 are the factors causing constraints on construction projects that guide this study as extracted from relevant literature. As seen in the literature reviewed, the factors represented the views different studies have advocated primarily on constraints in construction projects.

Table 1. Factors causing constraints on construction projects.

Codes	Factors Causing Constraints (FCA)	Authors
FCA 1	Climate change resilience	Refs. [21,23,28,31,34]
FCA 2	Inappropriate project cost estimation	Refs. [16,20,26,33]
FCA3	Traditional beliefs of people	Refs. [27,30,33,36]
FCA4	Lack of supervision onsite	Refs. [16,20,28,39]
FCA5	Delay in materials supply	Refs. [28,31,32,34,40]
FCA6	Poor coordination stakeholders	Refs. [16,28,34,37]
FCA7	Construction workers strikes	Refs. [21,27,33,38]
FCA8	Poor communication	Refs. [28,31,34,36,41]
FCA9	Ownership financial problems	Refs. [3,27,32,37]
FCA10	Poor provision of equipment	Refs. [20,31,32,34]
FCA11	Not completing the project as planned	Refs. [26,28,37]
FCA12	Building regulations	Refs. [16,29,37,40]
FCA13	Safety regulations	Refs. [21,28,33,38]
FCA14	Changes in drawings/design	Refs. [20,23,28,30]
FCA15	Design for deconstruction and disposal	Refs. [20,26,28,39]
FCA16	Waste, water management, dust, vibration, and noise	Refs. [23,26,31,38]
FCA17	Poor planning and scheduling	Refs. [24,31,33,34]
FCA18	Difficulties in obtaining work permits	Refs. [22,28,31,42]
FCA19	Land acquisition	Refs. [27,35,38,39]
FCA20	Availability of local workforce	Refs. [8,16,20,26]
FCA21	Work laws (of the current government)	Refs. [15,25,35,39]
FCA22	Dispute related to contractual documents	Refs. [12,18,26,28,33]
FCA23	Use of inexperienced workers	Refs. [8,23,31,34,38]
FCA24	Delay in solving design problems	Refs. [20,28,31,34]
FCA 25	Difficulties in obtaining loans from financiers	Refs. [8,26,31,38]
FCA 26	Air, water, or ground pollution	Refs. [16,28,31,34]
FCA 27	Usage of sustainable materials	Refs. [21,28,31,32,34]
FCA 28	Preservation of ecology and transportation	Refs. [23,32,37,40]
FCA 29	Improper allocation of money to contractors	Refs. [20,31,34,38,39]

Source: Author's compilation (2022) as reviewed from the literature.

3. Methodology

As indicated in Figure 1, a quantitative research method was adopted to investigate factors causing constraints in construction project performance in the South African construction industry. The respondents targeted construction professionals in the built environment: architects, construction managers, consultants, engineers, project managers, site agents, quality coordinators, and quantity surveyors. The choice of using these construction professionals was based on their involvement in building construction projects from planning, designing, construction delivery, and administration in the study area. Hence, a closed-ended questionnaire was designed in line with variables from the extant literature reviewed in Table 1.

The survey requested respondents to indicate their level of agreement with each identified factor causing constraints in the construction projects in Free state, South Africa. Free-State province was chosen for the study because of different construction projects (government and private) sited within the province with a high rate of abandonment [52]. A five-point Likert scale was used: 1 = Strongly disagree (SD), 2 = Disagree (D), 3 = Neutral (N), 4 = Agree (A), 5 = Strongly agree (SA). Through the purposive quota sampling technique, one hundred and eighty (180) questionnaires were administered to construction professionals within the study area. Retrieved data were analysed using descriptive and exploratory factor analysis (EFA). Out of the administered questionnaires, a total of one hundred and fifty (150) copies were retrieved from the respondents for the analysis. This represents 83.33% of the total questionnaires administered. As postulated by ref. [53], a total of 27,000 construction professionals worked within the Free-State province construction industry of South Africa. Ref. [54]'s equation, as cited by [55], was used to calculate a sample size that can represent the total population of 27,000 construction professionals in the Free-State province construction industry of South Africa. Equation (2) below is used to calculate the sample size for this research.

$$n = N/[1 + N(e)^2] \quad (1)$$

where n = the random sample size, N = the population size, and e = the level of precision.

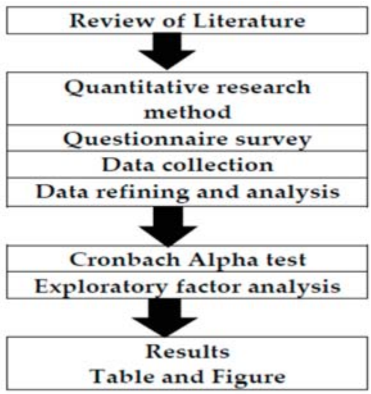

Figure 1. Research methodology adopted for the study.

According to ref. [54], the level of precision is the 95% confidence level and is equivalent to $p = 0.05$, and it was adopted for this equation in this research. Therefore, the sample size n for this research is

$$n = 27{,}000/[1 + (27{,}000) \times (0.05)^2] = 68.5 \quad (2)$$

From Equation (1), the sample size required for this study is 68.5 respondents. However, the number of respondents used for the study is 150, representing 18.5% of the total population of 27,000. This is an acceptable value required for using exploratory factor analysis (EFA), as [56] suggested, which recommended a sample size of at least 100 respondents for effect analysis. Ref. [56] stated further that it is trusted that the bigger the sample size, the lower the probability of blunder in summing up the populace. This study's sample size of 150 respondents is also adequate based on the recommendations of [57]. Statistical package for the social sciences (SPSS) version 21 was used to analyse the data obtained from the field survey. This was followed by descriptive analysis using percentage, frequency, standard deviation, and ranking. The data adequacy for exploratory factor analysis (EFA) was determined through Kaiser–Meyer–Olkin (KMO) and Bartlett's sphericity test. Ref. [58] posited that EFA helps researchers reduce large data to smaller numbers by exploring their level of relationship. Cronbach's alpha test was conducted to determine the data reliability and the interrelatedness of the variables in each component. Ref. [59] opined that Cronbach's alpha test explores the scale reliability of data via their internal consistency. In addition, ref. [60] stated that for data reliability, the coefficient of Cronbach's alpha scale must return a 0.7 value minimum, justifying the reliability of the data collection instrument; the results of the analysis were presented in figures and tables. The EFA method used in this study to address the factors causing constraints in construction project performance is distinctive. The benefit of using EFA for this study was that it aided in identifying groups of interrelated variables (constraint factors) to see how they are related to each other.

4. Results and Discussion of Findings

4.1. Demographic Information of the Respondents

Figure 2 shows the years of working experience of the respondents. Six percent of the total respondents had less than two years of work experience, followed by 20% with less than five years of work experience. However, 22% of the respondents had years of working experience ranging from six to ten years, and 22% had years of working experience ranging from eleven to fifteen years, respectively. Nineteen percent had an experience that ranged from sixteen to twenty years, and 8% had an experience that ranged from twenty-one to twenty-five years. Lastly, 3% of the respondents had more than 25 years of industry working experience. The data analyses of the respondents' years of experience justified that the respondents were experienced enough to respond to survey questions that will be asked in the subsequent sections of the questionnaire data analyses.

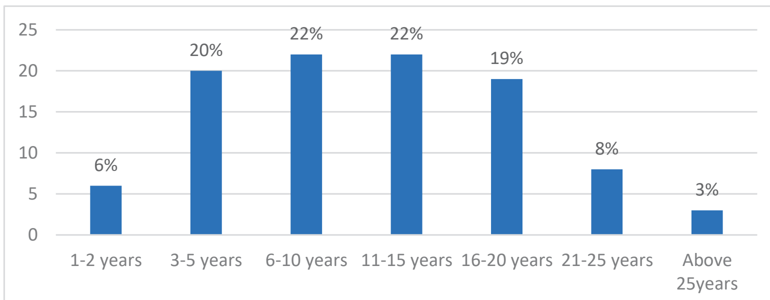

Figure 2. Respondents' years of experience.

Figure 3 shows findings relating to respondents' professions, which revealed that 7% were project management, 3% consultants, followed by 37% contract managers, 23% engineers, 5% architects, 18% quantity surveyors, 4% site agents, and 3% quality coordinators.

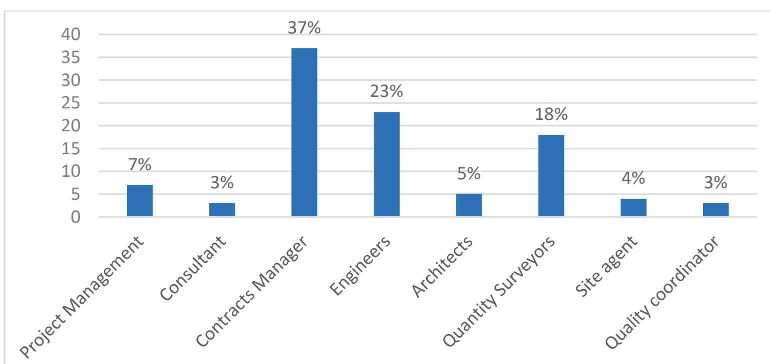

Figure 3. Respondents' professional qualification.

Figure 4 presents the educational qualification of the respondents. Three percent of the respondents had a national diploma, 5% had a doctoral degree, 17% had a professional degree, 19% had an honour degree, 24% had a bachelor's degree, and 32% had a master's degree. These ratios justify that the respondents involved in this study had the required levels of education for this study.

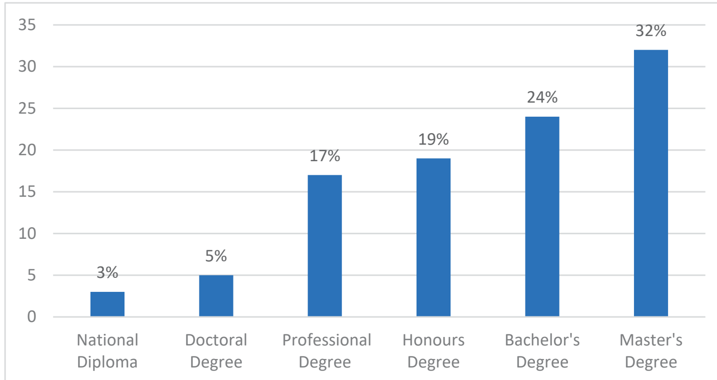

Figure 4. Respondents' educational qualification.

4.2. Results from the Exploratory Factor Analysis

4.2.1. KMO and Bartlett's Test

Table 2 presents the result of EFA measures of data sample adequacy using Kaiser–Meyer–Olkin (KMO) and Bartlett's test of sphericity. The KMO returned a value of 0.826 more than the 0.6 set as minimum criteria, and Bartlett's test returned a significant value of 0.000 below 0.5 as benchmarked data suitability for factor analysis [59].

Table 2. KMO and Bartlett's Test.

KMO and Bartlett's Test		
Kaiser–Meyer–Olkin Measure of Sampling Adequacy		0.826
Bartlett's Test of Sphericity	Approx. Chi-Square	2713.031
	Df	406
	Sig.	0.000

4.2.2. Scree Plot

Similarly, Figure 5 shows the scree plot for the data set, highlighting the eigenvalues for all the 29 variables of factors causing constraints (FCA) analysed. The scree plot shows that only six factors are above 1 on the eigenvalue axis [57,58]. Further inspection of the scree plot reveals that the last significant break on the plot was on the sixth factor, which confirms the extraction of six factors. The steeper portion of the slope shows the large factors, while the gradual trailing off shows the rest of the factors that have an eigenvalue lower than 1.

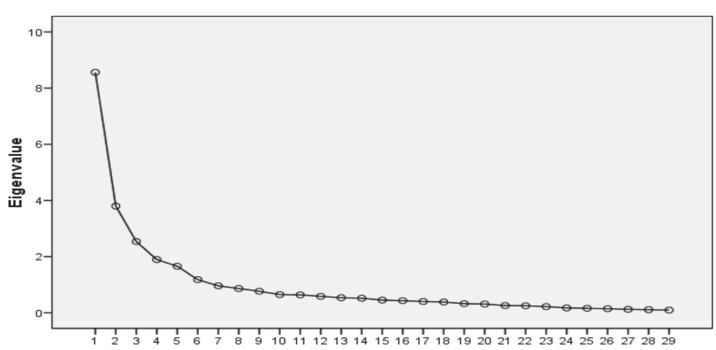

Figure 5. Scree plot.

4.2.3. Communalities

Table 3 shows the various FCA items after extraction, which should contain values above 0.1. The values as seen in the table show that all the FCA variables have extraction values greater than 0.1 and are, therefore, suitable for factor analysis.

Table 3. Communalities for FCA variables.

FCA Variables	Initial	Extraction
Delay in solving design problems	1.000	0.630
Inappropriate project cost estimation	1.000	0.658
Poor communication	1.000	0.537
Poor planning and scheduling	1.000	0.514
Poor coordination between different agencies	1.000	0.633
Not completing the project in a given duration	1.000	0.732
Difficulties in obtaining loans from financiers	1.000	0.709
Improper allocation of money to related parties	1.000	0.713
Availability of local workforce	1.000	0.627
Land acquisition	1.000	0.823
Safety regulations	1.000	0.790
Building regulations	1.000	0.836
Difficulties in obtaining work permits	1.000	0.796
Dispute related to contractual documents	1.000	0.611
Changes in drawings/design	1.000	0.597
Work laws (of the current government)	1.000	0.621
Air, water, or ground pollution	1.000	0.744
Usage of hazardous or sustainable materials	1.000	0.810
Use of inexperienced workers	1.000	0.646
Waste and water management, dust, vibration, and noise	1.000	0.649
Preservation of ecology, traffic, and transportation	1.000	0.629
Climate change resilience	1.000	0.626
Design for deconstruction and disposal	1.000	0.581
Traditional beliefs of people	1.000	0.598
Ownership financial problems	1.000	0.698
Construction workers strikes	1.000	0.668
Delay in materials supply	1.000	0.766
Poor provision of equipment	1.000	0.721
Lack of supervision on site	1.000	0.666

Extraction Method: Principal Component Analysis.

4.2.4. Total Variance Explained

Table 4 shows the eigenvalues of the variables in the data set. The Kaiser's criterion, which entails retaining factors with eigenvalues that are above 1.0, was employed. Hence, six factors with eigenvalues greater than 1 were retained. The eigenvalues of the retained factors are 8.561, 3.800, 2.536, 1.896, 1.656, and 1.180, which explains 11.063%, 9.078%, 8.001%, 6.751%, 6.470%, 6.127%, 5.633%, and 5.396% of the variances, respectively. These six clusters of factors represent 67.691% of the total variance, which highlights the importance of all 29 variables measured.

4.2.5. Pattern Matrix[(a)]

Table 5 presents the pattern matrix, highlighting how the factors have been clustered together. The table shows that the exploratory factor analysis returned six components of factors causing constraints in construction project performance. The table also revealed the arrangement of the variable under each returned component according to their significance. After a critical study of Table 5, a common name for each clustered component was decided [55,56]. Factor 1 is named "stakeholders' inappropriate project scheduling and coordination"; factor 2, "organisation and government policies"; factor 3, "ownership financial and contractual irregularity"; factor 4, "external factors"; factor 5, "Project peculiarity factors"; factor 6, "managerial factor".

Table 4. Total variance explained.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings [a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
FCA 1	8.561	29.521	29.521	8.561	29.521	29.521	6.927
FCA 2	3.800	13.105	42.625	3.800	13.105	42.625	4.848
FCA 3	2.536	8.746	51.371	2.536	8.746	51.371	3.325
FCA 4	1.896	6.538	57.909	1.896	6.538	57.909	4.632
FCA 5	1.656	5.712	63.621	1.656	5.712	63.621	3.457
FCA 6	1.180	4.070	67.691	1.180	4.070	67.691	1.625
FCA 7	0.960	3.312	71.003				
FCA 8	0.864	2.979	73.982				
FCA 9	0.766	2.641	76.623				
FCA 10	0.650	2.242	78.866				
FCA 11	0.637	2.197	81.063				
FCA 12	0.587	2.025	83.088				
FCA 13	0.537	1.851	84.939				
FCA 14	0.519	1.790	86.730				
FCA 15	0.452	1.559	88.289				
FCA 16	0.431	1.487	89.776				
FCA 17	0.402	1.388	91.164				
FCA 18	0.384	1.323	92.487				
FCA 19	0.325	1.121	93.608				
FCA 20	0.312	1.077	94.685				
FCA 21	0.259	0.892	95.577				
FCA 22	0.250	0.863	96.440				
FCA 23	0.221	0.763	97.203				
FCA 24	0.174	0.602	97.804				
FCA 25	0.159	0.549	98.353				
FCA 26	0.146	0.504	98.857				
FCA 27	0.124	0.428	99.285				
FCA 28	0.111	0.382	99.667				
FCA 29	0.096	0.333	100.000				

Extraction Method: Principal Axis Factoring. [a] When factors are correlated, sums of squared loadings cannot be added to obtain a total variance.

Table 5. Pattern matrix[(a)].

Variables	Pattern Matrix[(a)] Component					
	1	2	3	4	5	6
Not completing the project in each duration	0.903					
Difficulties in obtaining loans from financiers	0.812					
Availability of local workforce	0.802					
Improper allocation of money to related parties	0.771					
Poor communication	0.732					
Inappropriate project cost estimation	0.704					
Delay in solving design problems	0.682					
Poor coordination between different agencies	0.593					
Poor planning and scheduling	0.453					
Safety regulations		0.912				
Building regulations		0.913				
Land acquisition		0.892				
Difficulties in obtaining work permits		0.873				
Dispute related to contractual documents		0.774				

Table 5. *Cont.*

Variables	Pattern Matrix[(a)] Component					
	1	2	3	4	5	6
Traditional beliefs of people			0.754			
Changes in drawings/design			0.672			
Ownership financial problems			0.663			
Construction workers strikes			0.654			
Poor provision of equipment			0.543			
Delay in materials supply			0.534			
Climate change resilience				0.711		
Use of inexperienced workers				0.684		
Design for deconstruction and disposal				0.662		
Preservation of ecology, traffic, and transportation				0.606		
Work laws (of the current government)				0.554		
Usage of hazardous or sustainable materials					0.873	
Air, water, or ground pollution permit					0.782	
Waste and water management, dust, vibration, and noise permit					0.732	
Lack of supervision on site						0.823

Extraction Method: Principal Axis Factoring. Rotation Method: Oblimin with Kaiser Normalisation. [(a)] Rotation converged in 15 iterations.

Component one: stakeholders' inappropriate project scheduling and coordination.

As shown in Table 5, the first component had nine variables loaded into the component: "not completing the project in each duration (90%)", "difficulties in obtaining loans from financiers (81%)", "availability of local workforce (80%)", "improper allocation of money to related parties (77%)", "poor communication (73%)", "inappropriate project cost estimation (70%)", "delay in solving design problems (68%)", "poor coordination between different agencies (59%)", and "poor planning and scheduling (45%)". Thus, this cluster gathered 29.521% of the total variance. The factors loaded in the first component emphasised the stakeholder's inappropriate project scheduling and coordination, which directly impact the overall performance of construction projects. The findings are in line with refs. [20,28,32,34,35], which opine that inappropriate project cost estimation, improper allocation of money to related parties, and delay in solving design changes cause constraints to stakeholders in construction project management. This makes the factors loaded in the first component important in determining successful project performance and delivery.

Component two: Organisation and government policies.

As shown in Table 5, the second cluster had five variables loaded into the component: "Safety regulations (91%)", "building regulations (91%)", "land acquisition (89%)", "difficulties in obtaining work permits (87%)", and "dispute related to contractual documents (77%)". Thus, this cluster gathered 13.105% of the total variance. These factors address the external and internal policies that govern the construction industry operations. The findings confirm the studies of refs. [16,30,36,39] that lack of adherence to government regulations regarding safety, land acquisition, and contractual dispute-related issues are factors causing construction constraints that affect project performance in the construction industry.

Component three: Ownership financial and contractual delays.

As shown in Table 5, the third cluster had six variables loaded into the component: "traditional beliefs of people (75%)", "changes in drawings/design (67%)", "ownership financial problems (66%)", "construction workers strike (65%)", "poor provision of equipment (54%)", and "delay in materials supply (53%)". The factors loaded in the third component show that clients' decisions contribute to factors that cause construction constraints that affect projects' performance in the construction industry. The cluster gathered 8.746% of the total variance. The finding agrees with [12,38,43] studies that financial problems of the client, poor equipment provisions, delays in material supply, worker strikes, and traditional beliefs are key factors causing construction constraints affecting project performance in the construction industry.

Component four: External factors.

As shown in Table 5, the fourth cluster had five variables loaded into the component: "climate change resilience (71%)", "use of inexperienced workers (68%)", "design for deconstruction and disposal (66%)", "preservation of ecology, traffic, and transportation (61%)", and "work laws of the current government (55%)". Hence, this cluster gathered 6.538% of the total variance. The findings align with those of refs. [8,23,32,35,39] that external factors such as climate change resilience, preservation of ecology, and poor transportation system are factors causing construction constraints leading to poor project performance within the construction industry.

Component five: Project peculiarity factors.

As shown in Table 5, the fifth cluster had three variables loaded into the component: "permit on the usage of hazardous or sustainable materials (87%)", "air, water, or ground pollution permit (78%)", and "waste and water management, dust, vibration, and noise permit (73%)". The three factors refer to the requirement of local enforcement agencies to control the use of natural resources, hazardous materials, and the management of construction pollution. Thus, the cluster gathered 5.712% of the total variance. The findings agree with refs. [22,28,32,35] that factors such as the use of hazardous materials, poor waste management, and delay in the issuance of permits cause construction constraints that affect project performance in the construction industry.

Component six: Managerial factors.

As shown in Table 5, the sixth component had one variable loaded into the component: "lack of supervision onsite (82%)". The cluster gathered 4.070% of the total variance. The finding is in line with refs. [28,32,35] that poor supervision is a factor causing construction constraints affecting construction performance in the construction industry.

4.2.6. Component Correlation Matrix and Reliability of the Factors

From Table 6, the relationship between the cluster groups is shown in the component correlation matrix in that some of the clusters have values around 0.300. This is an indication that there is a relationship between these clusters. Moreover, the variables of the components within the factors highly correlate with each other. It also shows a relationship and dependence among the variables [59,60]. Additionally, the Cronbach alpha coefficient test conducted on each variable in Table 5 shows a value of between 0.711–0.917. The result indicates that the variables measured are reliable and valid and that the data collection instrument used is reliable in collecting information [59,60].

Table 6. Component Correlation Matrix and Reliability of the factors.

Factor	1	2	3	4	5	6	Cronbach's Alpha Coefficient
Component 1	1	−0.29	0.182	0.374	0.2	0.141	0.913
Component 2	−0.29	1	−0.06	−0.24	0.03	−0.11	0.917
Component 3	0.182	−0.06	1	0.122	0.22	0.08	0.789
Component 4	0.374	−0.24	0.122	1	0.06	−0.03	0.802
Component 5	0.202	0.028	0.22	0.06	1	0.092	0.711
Component 6	0.141	−0.11	0.08	−0.03	0.09	1	0.854

Extraction Method: Principal Axis Factoring. Rotation Method: Oblimin with Kaiser Normalisation.

5. Conclusions and Recommendations

This study assessed factors causing construction constraints in project performance in the construction industry. The study adopts EFA to explore the significance of the twenty-nine factors identified from the review of the literature. The EFA returned six components of constraint factors: "stakeholders' inappropriate project scheduling and coordination factors", "organisation and government policies factors", "ownership financial and contractual irregularity factors", "external factors", "project peculiarity factors", and "managerial factors".

The factors included in the components explain the construction constraints causing constraints on project performance and delivery in the construction industry. The study's findings identify the underlying relationship between measured constraints' variables from literature. Thus, the theoretical assessment is consistent with the research's empirical outcomes. Further, the feedback corresponds with the literature on factors causing constraints in construction project performance based on the traditional concept of triple constraints in construction projects. The study concludes that the identified factors causing constraints on construction projects in the six components directly influence project goals, performance, and delivery.

The study findings add to the knowledge gap by identifying particular factors causing constraints on project performance in the construction industry. Moreover, due to the difference in location and scope of work, the grouping of the factors causing constraints ends up in six components, compared with a grouping of four components by an earlier study. The implications of the study's findings show that constraints in construction projects as identified in the six components will result in costs and time overruns, delays, disputes, and litigations, which can affect overall project performance in the construction industry.

The practical application of the findings is relevant to construction professionals, construction stakeholders, and government agencies on decision-making and strategies to improve construction projects through the early identification of pertinent construction constraints that might affect construction project performance. It will also expand stakeholders' knowledge and understanding of the impact of constraints' determinants such as cost, time, risk, scope, quality, and resources on projects' success. It will assist stakeholders in identifying and overcoming construction project execution constraints. This study is limited by the inability of the authors to explore more case studies involving a large sample.

The study also recommends that the six components of construction constraints identified in this study should guide professionals in the construction industry in effectively improving the performance of construction projects. However, due to time constraints, the study was limited to construction professionals within Free-State province, South Africa, showing that the findings cannot be generalised for the South African construction industry. Nonetheless, it is important to note that construction professionals in Free-State Province used for this study account for the substantial professional activities in the South African construction industry. Equally, future studies can be conducted to test the six components identified in this study as they affect the traditional concept of triple constraints (time, cost, and quality) in construction project performance. This can be done by incorporating all built environment professionals with first-hand experience in construction project planning, execution, and management.

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Article

Correlation of Construction Performance Indicators and Project Success in a Portfolio of Building Projects

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Abstract: Construction management is a highly competitive project-based field of complex specialized services, creating or altering the built environment for a client. For construction projects to be successful, and in turn, for construction firms to be successful, understanding the relationship of performance statistics as indicators of project outcomes, such as cost, time, and profitability, is essential. There have been a number of efforts made to identify key performance indicators related to construction project success. However, due to lack of available data, many questions remain. There lies an opportunity to analyze project statistics as indicators of project success, similar to the way analytics have been used to predict success in sports. Construction firm project data for a portfolio of building projects were analyzed, and this study identifies correlated factors for completed building construction projects. A highlight of this correlation analysis identified profit differential as demonstrating a strong relationship with the number of requests for information and architects supplemental instructions on a project.

Keywords: correlation; performance indicators; construction management

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1. Introduction

Construction management is a highly competitive project-based field of complex specialized services, creating or altering the built environment for a client. For construction projects to be successful, and in turn, for construction firms to be successful, understanding the relationship of performance statistics as indicators of project outcomes, such as cost, time, and profitability, is essential. Historically, these evaluations have been performed internally by the firm, and limited literature is available based on actual internal project statistics for commercial construction building projects. There lies an opportunity in the industry to analyze project statistics as indicators of project success in much the same way that analytics have been used to predict success in sports, as popularized by the book and subsequent movie *Moneyball* [1]. An ENR top 400-ranked construction firm requested analysis of project data for a portfolio of commercial building projects, in search of factors that can be closely managed to improve the opportunity for project success. The analysis presented here searches for patterns, related project statistics, or related factors in the project portfolio data. This study identifies correlated factors in the completed construction project data. Then, the correlations are analyzed for contributing factors that may indicate project success and to attain recommendations for further analysis.

2. Background

Project management research generally deals with solving practical problems and identifying the factors that influence projects and that are relevant to managerial implications [2]. The exploration of success in construction projects, along with efforts to better understand what constitutes a successful outcome, and what factors contribute to success, have been ongoing for decades. Pace [3] recognized that project success factors are important to the overall successful outcome of a project, examining a number of studies in an attempt to correlate reported project success with the chosen project management methodology, but recognizing only a weak correlation at best. Determining project success is dependent on the stakeholder's role in the project [4–16]. Pinto and Slevin [10] discussed the criteria for a project consisting of the following characteristics: a specified time for completion (schedule), a limited or defined budget (budget), performance expectations and a series of activities (performance), and issues dealing with the client (client satisfaction). The defined characteristics of a project become the criteria evaluated to determine success, and if the characteristics are incomplete, a determination of project success may be incomplete or inaccurate. Critical success factors (CSFs) can help quantify the success of a project, but which CSFs contribute the most to performance and if they apply equally to all stakeholders continues to be an ongoing debate [12]. Atkinson [5] goes on to state that success must be defined beyond the simplistic "iron triangle" of cost, schedule, and quality, and should include the criteria of the information system, organizational benefits, and stakeholder community benefits. Shenhar et al. [9] identified four project success dimensions: project efficiency, impact on the customer, organizational success, and preparation for the future. Cooke-Davies [6] identified 12 critical success factors in three distinct categories: project management success (time, cost, quality, performance), project success (overall project objectives), and consistently successful projects (repeated performance).

For contractors, overall project success may be out of their hands if the goals of the project do not align with the client's organizational need, investment strategy, or changing market conditions, regardless of project management success or consistently successful organizational operations practices [7,14]. The complexity of construction projects can impact project success from the perspective of the contractor; however, the investigation of those elements and the quantifying of their impacts on project success is limited [16]. Rämö [17] discusses the concept of performing project processes (doing things right) in efficient project time, but notes that the success of the project may require taking the correct action at the key appropriate progression of the project (doing the right thing), and the contractor may not have the knowledge or authority to do so. As a business, construction managers and contractors acting as project delivery organizations invest time and resources to complete a project, with the expectation that the project will recoup the investment and earn a profit. In that case, strategic project selection and allocation of resources at the firm level can play a role in client satisfaction and project success, independent of project management success [2]. Determining when a project is successful requires the appropriate scale for the appropriate stakeholder, such as project management success, project ownership success, and project investment success [8].

Construction managers and contractors, as project delivery organizations, should focus on understanding what project factors, statistics, or attributes contribute to project management success such as profit and are essential in directing project effort to achieve project success from their perspective [8]. The Project Management Institute identifies the knowledge areas essential in meeting construction project requirements as: integration; scope; schedule; cost; quality; resource; communication; risk; procurement; stakeholder; health, safety, security, and environment; and financial management [18]. Self-assessing performance is crucial for a contractor to drive individual performance improvement [13]. Gunasekara et al. [13] found that the key areas of performance included the categories of health and safety, quality, experience, financial, environmental, human resources, and productivity. Although construction managers and contractors may define project success by a number of factors for their organization, including keeping their workforce employed, developing a new client or market, strengthening reputation or capabilities, and growing experience, in the financial category, project success can be quantified in terms of return on investment, realized profit, and debt ratio [8,11,13].

Earned value management (EVM) considers scope, time, and cost to monitor performance over time to drive project success [15]. EVM should motivate project teams to monitor costs and progress to make timely decisions to achieve project success. EVM, however, may not account for the implications of all factors regarding the project. Construction managers and contractors, in determining project success from their perspective, should seek to understand the implications of the documented occurrences on a project, such as project factors, statistics, or attributes, and how they relate or contribute to project success, such as through realized profit or profit margin. If the factors related to project success can be identified, improving the performance of those factors can improve performance on a project or a portfolio of projects. Cooke-Davies [6] found that cost escalation was not strongly correlated to schedule delay for individual projects. In that study, self-reported and inferred project management practices among 23 organizations were ranked by their developed process maturity on a scale of "not at all adequate" (1), to "fully adequate" (4). Analyses of these processes resulted in a correlation between schedule and cost performance against the schedule and budget, respectively. The projects evaluated averaged USD 16 million and 3 years, with a median of USD 2 million and 18 months, and ranging up to USD 300 million and 10 years. Cooke-Davies [6] further found that the presence of a few of the project management processes, rated by maturity and adequacy, correlated to on-time or on-cost performance. However, quantifying factors such as the adequacy of company-wide education on the concepts of risk management or the maturity of an organization's process for assigning ownership of risk to an outcome is very difficult. Whether or not a company participates in these practices and the qualitative maturity or adequacy of a practice does not indicate correlation to an outcome of success on a given project, or any factor of the project. Further, Shahandashti et al. found that considerable research consistently highlights the importance of risk management to success, but found that schedule, cost, cash flow, change management, and safety were the top five areas of key results [11].

Construction performance management involves the monitoring of past performance, improvement of individuals and teams, and evaluation and improvement of processes [19]. Key performance indicators (KPIs) in construction performance management play a critical role in the success of construction projects [20–24]. The benchmarking of KPIs could improve project management performance [11,25]. Suk et al. [26] and Alvarado et al. [27] proposed performance dashboards for benchmarking project performance and the performance of a portfolio of projects. These dashboards proposed the use of performance scores based on KPIs, weighted schedule performance, or budget performance. However, weighted performance scores and several of the KPIs suggested are qualitative and difficult to correlate with quantitative project factors.

According to Habibi et al. [28], " ... success of construction projects can be attributed to the effective time/cost performance of project ... " Many studies have attempted to identify the leading performance indicators (LPIs) of engineering, procurement, and construction (EPC) projects, but inconsistency between indicators identified in the studies and their ability to indicate success have resulted in no universal method. Habibi et al. [28] concluded that design change is the principal cause of delay and cost overruns on projects, but the study does not provide a means for correlating design change, or other contributing factors, to project success, primarily due to limited project data factors.

There is very limited literature indicating the relationship between key attributes of construction projects and profit margin [29]. Construction projects collect a large amount of data concerning project factors, the process, and the outcomes. Often, that information is held internally by the contractor and not released or readily available for analysis outside of the company. As such, limited methods are available in the literature to analyze construction project data to indicate success. Big data approaches have been proposed to demonstrate project analysis, but have limited applications for indicating success for any given construction company on a given project [29]. With enough data, the Pearson correlation can be calculated to determine connections between project factors, including success [30]; however, there is typically not enough historical data to determine correlation [31].

Data analytics from sports offer a parallel to analyzing project success from performance factors. Recognized in the book *Moneyball* [1], statistical analysis of various in-game occurrences in baseball could indicate successful outcomes, such as games won, and be further used to build a more successful team. These types of analyses have been used in sports beyond baseball. Performance indicators (PI) can be analyzed with match outcomes, such as win-loss or score margin, in Australian (Rules) Football (AF) [32]. PIs can be classified as two types: (1) those gathered directly, and (2) those created from original PIs. Further collinearity, or the Pearson correlation, can be checked using a correlation matrix. In tennis, it appears that individual performance factors are correlated to overall performance regarding the win rate among tennis players [33].

This research targets the gap in the literature, analyzing construction company project data from actual projects to determine factors that indicate project success. The intent is to use a similar sports analytics approach to analyze the project data. The implication is that if PIs parallel project factors and match outcomes parallel successful projects, the key project performance factors can be identified. Similar correlation analysis could be performed for construction projects, where instead of win-loss or score margin, profit margin or projected project profit achievement could be used as project success indicators, and correlated project factors could be identified for a group of projects. A correlation matrix of project factors and outcomes can be created in an attempt to identify correlated factors of project outcomes that can be used as indicators of project success. This analysis could be the first step to further analysis in predicting project success based on project performance factors.

3. Methodology

This research targets the analysis of construction project performance data using a correlation matrix of project factors and outcomes to identify correlated factors that can be used as indicators of project success.

Correlations between price and duration have been studied in construction projects encompassing various sectors. There is a lack of studies on the correlation of performance indicators regarding a portfolio of construction projects related to project success, including profit and duration. This analysis investigates the correlation of performance indicator data in a portfolio of construction projects. This analysis will investigate the correlations among key performance indicators to determine if relationships exist between the duration, cost, and profit to other variables with the methodology shown in Figure 1.

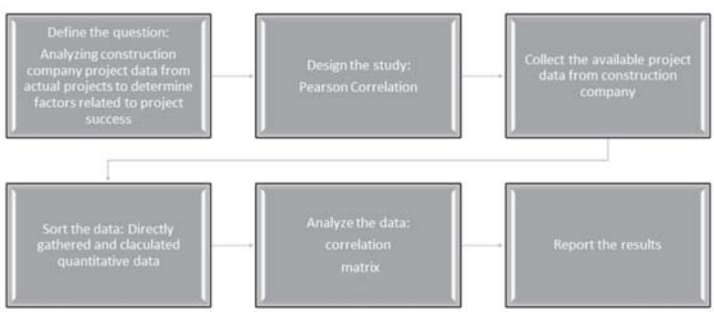

Figure 1. Overview of the methodology.

Correlation has been investigated between individual factors and overall performance in sports. These types of analyses have been used in sports, as outlined by Lewis [1] for baseball, and beyond baseball, including the correlation of individual factors to predict overall success in tennis [25], and PI can be analyzed with match outcomes, such as win-loss or score margin in AF [32].

3.1. Population and Sample/Data Collection

Data for 108 current commercial construction projects was provided for analysis to better understand project success and the factors leading to discrepancies in duration, project cost, and profit differential from those planned. The company data provided was separated into projects completed between May and September 2020 (including complete data). This resulted in 23 projects. Only projects with completed data were used in this analysis because it would not be possible to determine project success prior to project completion, which could artificially skew results. Additional data were requested twice, after an initial review and after the subsequent review, with the aim of providing a more complete analysis. The additional data was provided in December 2020 and March 2021. The 23 projects were then analyzed with the additional factors. The data factors were identified by category as nominal, qualitative, and quantitative. The quantitative data was used for this analysis. Certain factors, such as the contract price and contract days, are predicted data, where the actual final price and actual days are recorded data. Some of the predicted data comes from various stages of project preparation, from the estimate phase leading up to the proposal or bid, the contractual obligation, or the management planning following the award.

Young et al. [32] identified performance indicators (PI) as represented by two types: (1) gathered directly, and (2) created from original PIs. In addition to the recorded data gathered directly, some differential calculations created from the recorded data were included in the analysis, as advised by the expertise of the contractor. In the analysis, six schedule differential calculations were included. These calculations produced the difference between schedule days at different documented points in the project progression. In addition, the analysis included one profit differential calculation showing the difference between actual profit less budgeted profit, in that order, so that a positive number represented a more profitable project than budgeted. All the data factors by category used are shown in Table 1.

Table 1. Project data factors sorted by categories.

Nominal Data	Qualitative Data	Directly Gathered Quantitative Data	Calculated Quantitative Data
Job Number	SILO	Building square footage	Estimated days–Actual days
	PM	Number of floors	Scheduled days–actual days
	Market	Site acreage	Estimated days–scheduled days
	Project type	Estimated days duration	Contract days–actual days
	Contract execution date	Contract days Duration	Estimated days–contract days
	3 Week Look-Ahead Schedule software used for project	Schedule days duration, ops team	Contract days–scheduled days
	Overall scope description	Actual days duration at completion	Actual profit–budgeted profit
		Contract price	
		Approved change order price	
		Final project price	
		Number of addendums and owner incorporated changes	
		Request for information and architect supplemental instructions	
		Number of punch list items	
		Overhead and general conditions Cost for the project	
		Budgeted profit	
		Actual profit	

3.2. Data Analysis

The data was compiled to include only quantitative data, with abbreviated column headings to be analyzed to find the Pearson correlation. The abbreviated column headings and the data factors are shown in Table 2. The analysis was performed using R Studio statistics software. A Pearson correlation analysis was performed to identify any significant correlations between data factors. In addition, a correlation matrix was produced to visualize the data. Correlation indicates the relative strength of a relationship between factors, but is not necessarily an indication of causation. Dancey and Reidy [25] identified correlation coefficients of +1 and −1 as perfect, and 0.9 to 0.7 and −0.7 to −0.9 as strong correlations.

Table 2. Project data factor abbreviations.

Abbreviation	Data Category
Job	Job Number
Bldgsf	Building square footage
Floors	Number of floors
Site.acre	Site acreage
Est	Estimated days duration
Cont	Contract days Duration
Sched	Schedule days duration ops team
Act	Actual days duration at completion
Est.act	Estimated days–Actual days
Sched.act	Scheduled days–actual days
Est.sched	Estimated days–scheduled days
Cont.act	Contract days–actual days
Est.cont	Estimated days–contract days
Cont.sched	Contract days–scheduled days
Price	Contract price
Co	Approved change order price
Fin.price	Final project price
Add.oic	Number of addendums and owner incorporated changes
Rfi.asi	Requests for information and architects' supplemental instructions
Punch	Number of punch list items
Oh.gc	Overhead and general conditions cost for the project
Bud.prof	Budgeted profit
Act.prof	Actual profit
Prof.dif	Actual profit–budgeted profit

4. Findings

The data mean, median, and range maximum for the project data for each data factor were calculated and are included in Table 3 below.

Table 3. Data factor statistical analysis for project group.

Data Factor	Mean	Median	Range Max
Building square footage	136,357	76,005	605,000
Number of floors	0	0	1
Site acreage	4	0	45
Estimated days duration	79	50	217
Contract days duration	95	64	227
Schedule days duration, ops team	86	58	240
Actual days duration at completion	78	55	205
Estimated days–actual days	1	−5	118
Scheduled days–actual days	8	6	38
Estimated days–scheduled days	−6	−12	109
Contract days–actual days	18	12	115
Estimated days–contract days	16	10	65
Contract days–scheduled days	10	5	106
Contract price	4,436,338	617,766	25,752,359
Approved change order price	131,441	0	2,041,377
Final project price	4,567,779	672,564	25,869,752
Number of addendums and owner incorporated changes	5	1	22
Requests for information and architects' supplemental instructions	23	7	136
Number of punch list items	64	23	359
Overhead and general conditions cost for the project	41,266	12,636	196,315
Budgeted profit	160,601	31,369	750,069
Actual profit	187,380	65,472	946,745
Actual profit–budgeted profit	26,779	4575	232,773

Analysis resulted in the correlation matrix, shown in Figure 2, displaying the correlation coefficients for each relationship. As the legend on the right side of the figure indicates, the coefficients range from +1, indicated with a dark blue color, to −1, indicated with a dark red color, with zero as white, and increasingly lighter shades of blue and red, respectively, as the coefficient approaches zero. Figure 3 shows the correlation coefficients graphically in black and white. As the legend on the right side of the figure indicates, the coefficients range from +1, with positive coefficients indicated with a black circle, to −1, with negative coefficients indicated with a white circle, with the size of the circle decreasing as the coefficient approaches zero.

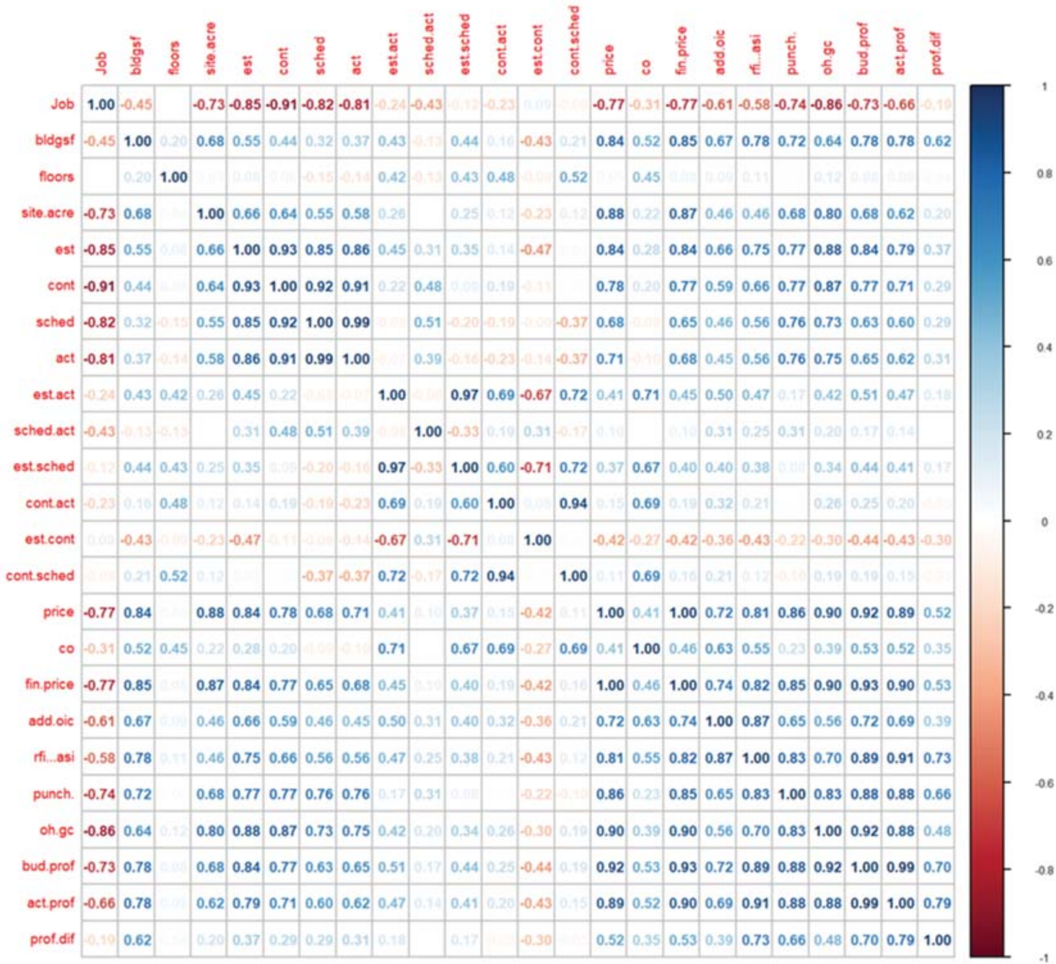

Figure 2. Correlation matrix of project data factors.

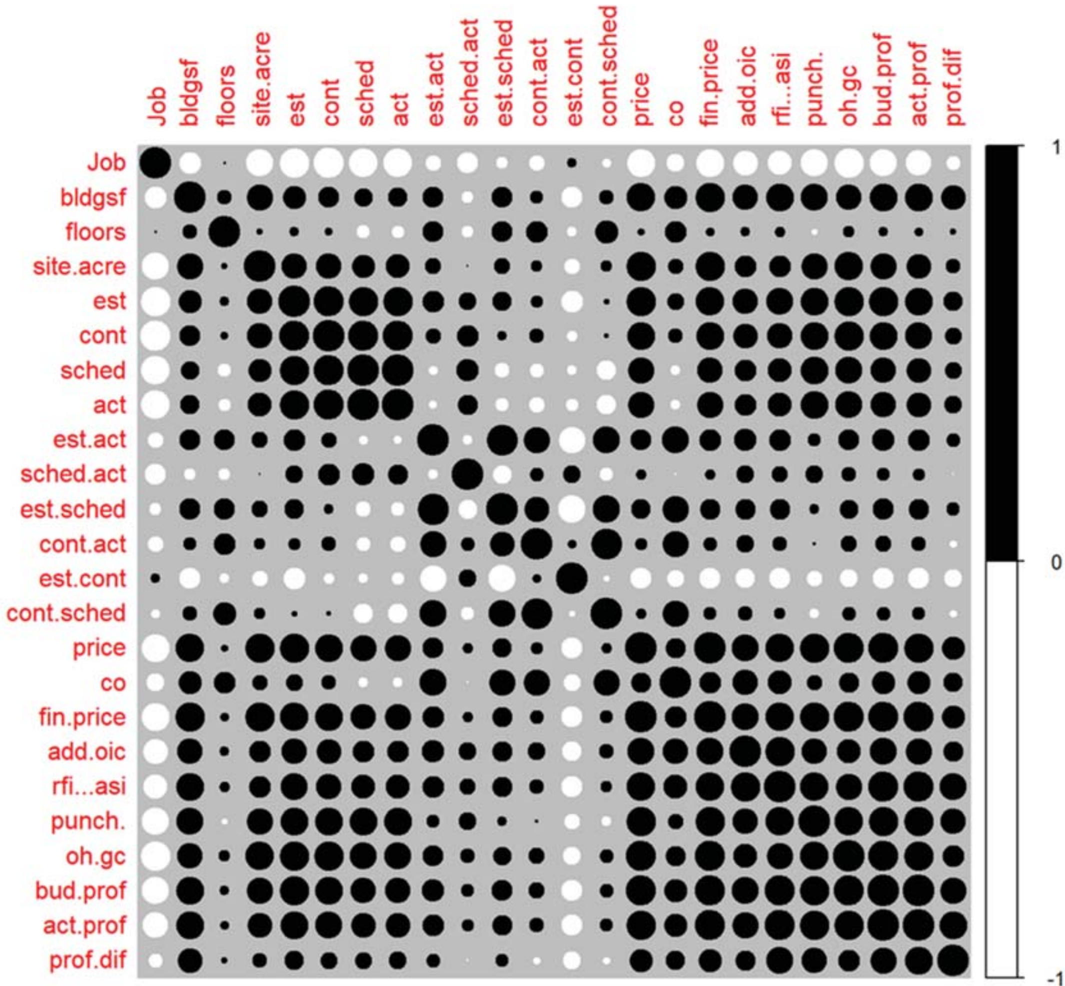

Figure 3. Correlation matrix of project data factors, shown graphically.

There were 23 factors tested for correlation. Each factor has a correlation of 1 with itself, resulting in a total of 253 possible relationships between factors. The threshold of |0.7|+ indicates a strong correlation [34] and is considered significant for this analysis. The statistical analysis of the data factors from this project group resulted in 66 significant correlations among all factors, and these are shown in Table 4.

Table 4. Project group dataset significant correlation factors |0.7|+.

Correlation	Factor 1	Factor 2
1	Price	Final Price
0.99	Scheduled days	Actual Days
0.98	Budgeted profit	Actual Profit
0.97	Estimated days–actual days (dif)	Estimated days–scheduled days (dif)
0.96	Estimate days	Actual days
0.94	Contract days–actual days (dif)	Contract days–scheduled days (dif)
0.93	Estimate days	Contract days
0.92	Contract days	Scheduled days
0.92	Overhead/General conditions	Budgeted profit
0.92	Budgeted profit	Final price
0.91	Contract days	Actual days
0.91	Budgeted profit	Price
0.91	Actual profit	RFI ASI
0.9	Actual profit	Final price
0.89	Overhead/General conditions	Price
0.89	Overhead/General conditions	Final price
0.89	Budgeted profit	RFI ASI
0.89	Actual profit	Price
0.88	Site acre	Price
0.88	Overhead/General conditions	Estimated Days
0.88	Budgeted profit	Punch list
0.88	Actual profit	Punch list
0.87	Site acre	Final price
0.87	Addendums/OIC	RFI ASI
0.87	Overhead/General conditions	Actual profit
0.86	Punch list	Price
0.86	Overhead/General conditions	Contract days
0.85	Building square footage	Final price
0.85	Estimate days	Scheduled days
0.85	Punch list	Final price
0.84	Building square footage	Price
0.84	Estimate days	Price
0.84	Estimate days	Final price
0.84	Budgeted profit	Estimated days
0.83	RFI ASI	Punch list
0.83	Overhead/General conditions	Punch list
0.82	RFI ASI	Final price
0.81	RFI ASI	Price
0.8	Overhead/General conditions	Site Acres
0.79	Actual profit	Estimated days
0.79	Actual profit	Profit Differential
0.78	Contract days	Price
0.78	RFI ASI	Building square footage
0.78	Budgeted profit	Building square footage
0.78	Actual profit	Building square footage
0.77	Contract days	Final price
0.77	Punch list	Estimated days
0.77	Punch list	Contract days
0.76	Punch list	Scheduled days
0.76	Punch list	Actual days
0.75	RFI ASI	Estimate Days
0.74	Addendums/OIC	Final Price
0.74	Overhead/General conditions	Actual days
0.73	Profit Differential	RFI ASI
0.72	Estimated days–actual days (dif)	Contract days–scheduled days (dif)

Table 4. *Cont.*

Correlation	Factor 1	Factor 2
0.72	Estimated days–scheduled days (dif)	Contract days–scheduled days (dif)
0.72	Addendums/OIC	Price
0.72	Punch list	Building square footage
0.72	Overhead/General conditions	Scheduled days
0.72	Budgeted profit	Addendums OIC
0.71	Actual days	Price
0.71	Estimated days–actual days (dif)	Change orders
0.71	Actual profit	Contract days
0.7	Overhead/General conditions	RFI ASI
0.7	Budgeted profit	Profit differential
−0.71	Estimated days–scheduled days (dif)	Estimated days–Contract days (dif)

4.1. Directly Gathered Quantitative Data

Final project price, actual construction days, and actual profit are the three outcomes identified to indicate project success, to some degree [4–12,14–16]. All 22 correlations were shown for the final price in Table 5, the actual construction days in Table 6, and the actual profit in Table 7 for further analysis of the factors, with or without strong correlations. None of the analyzed projects were in litigation or dispute, or headed to litigation or dispute. The final price is the actual price agreed upon by both parties and paid to the contractor from the client upon satisfactory completion of the contracted scope of work. Actual construction days equal the duration from notice to proceed to project acceptance by the client through the provisions of the contract, indicating completion of the scope of work, acceptance by the municipality of jurisdiction (certificate of occupancy), and within the specified and agreed upon tolerances (appropriate quality). Additionally, regarding a completed, accepted, and payment received project, actual profit is a good indication of project management success for a project from the contractor's perspective, and in this case, success across a portfolio of projects.

Table 5. Correlations for final price.

	Final Price
Price	1
Budgeted profit	0.93
Overhead/General conditions	0.9
Actual profit	0.9
Site acres	0.87
Building square footage	0.85
Punch list items	0.85
Estimated days	0.84
RFIs and ASIs	0.82
Contract days	0.77
Addendums and OIC	0.74
Actual days	0.68
Scheduled days	0.65
Profit differential	0.53
Change order price	0.46
Estimated days—actual days (dif)	0.45
Estimated days—scheduled days (dif)	0.4
Contract days—actual days (dif)	0.19
Contract days—scheduled days (dif)	0.16
Scheduled days—actual days (dif)	0.1
Floors	0.08
Estimated days—contract days (dif)	−0.42

For the final price, eleven factors with strong correlations were identified: price, budgeted profit, overhead/general conditions, actual profit, site acres, building square footage, punch list items, estimated days, RFIs and ASIs, contract days, and addendums and OIC. In addition, two factors, actual days and scheduled days, are included in the significant threshold at 0.68 and 0.65, respectively, if rounded to one significant digit. Since there is often a strong relationship between the schedule and the cost [5], we could include them in future analysis. Most expected factors show a strong positive relationship with the final price, and that is expected. Change order price does not show a strong correlation to final price, indicating that the value of change orders is different for each project and changes the final contract price at a different rate per project, depending on a number of factors, which could be evaluated in future research. In addition, actual profit and budgeted profit both show strong correlation to the final price; however, profit differential does not show a strong correlation to the final price, indicating that the factors responsible for the difference between the budgeted and actual profit are not captured in this analysis and should be investigated further.

Table 6. Correlations for actual construction days.

	Actual Days
Scheduled days	0.99
Contract days	0.91
Estimated days	0.86
Punch list items	0.76
Overhead/General conditions	0.75
Price	0.71
Final price	0.68
Budgeted profit	0.65
Actual profit	0.62
Site acres	0.58
RFIs and ASIs	0.56
Addendums and OIC	0.45
Scheduled days—actual days (dif)	0.39
Building square footage	0.37
Profit differential	0.31
Estimated days—actual days (dif)	−0.07
Change order price	−0.1
Floors	−0.14
Estimated days—contract days (dif)	−0.14
Estimated days—scheduled days (dif)	−0.16
Contract days—actual days (dif)	−0.23
Contract days—scheduled days (dif)	−0.37

For actual construction days, six factors with strong correlations were identified: scheduled days, contract days, estimated days, punch list items, overhead/general conditions, and price. In addition, final price is included in the significant threshold at 0.68 and budgeted profit at 0.65, if rounded to one significant digit, and these could be included in future analysis, as they should have a strong relationship with actual construction days. Different variations of the schedule, such as scheduled days, estimated days, and contract days, have a strong positive relationship to actual construction days. Price and final price should also have a strong positive relationship to actual days, although the relationship for final price is slightly less than for price, and this could indicate another influencing factor. The strong positive relationship between actual construction days and the number of punch list items is of note and warrants further investigation. Of note, but not completely surprising, the actual days to complete the project do not show a strong correlation to the size of the building in square footage, the number of floors, or the size of the site in acres. This could indicate a number of factors influencing the actual duration of the project, not the least of which is building complexity, from either the interior or exterior finishes or mechanical systems, or a number of other potential factors.

Table 7. Correlations for actual profit.

	Actual Profit
Budgeted profit	0.99
RFI and ASIs	0.91
Final price	0.9
Price	0.89
Punch list items	0.88
Overhead/General conditions	0.88
Estimated days	0.79
Profit differential	0.79
Building square footage	0.78
Contract days	0.71
Addendums and OIC	0.69
Site acres	0.62
Actual days	0.62
Scheduled days	0.6
Change order price	0.52
Estimated days—actual days (dif)	0.47
Estimated days—scheduled days (dif)	0.41
Contract days—actual days (dif)	0.2
Contract days—scheduled days (dif)	0.15
Scheduled days—actual days (dif)	0.14
Floors	0.08
Estimated days—contract days (dif)	−0.43

For actual profit, ten factors with strong correlations were identified: budgeted profit, RFIs and ASIs, final price, price, punch list items, overhead/general conditions, estimated days, profit differential, building square footage, and contract days. In addition, addendums and OIC is included in the significant threshold at 0.69, if rounded to one significant digit, and should be included in future analysis.

In this analysis, building square footage is strongly correlated to actual profit, at 0.78, and is consistent, as budgeted profit also strongly correlated, at 0.78, to building square footage. Actual profit and budgeted profit are very strongly correlated, at 0.99, with actual profit and profit differential strongly correlated at 0.79. Actual profit is also strongly correlated with the price, at 0.89, and final price, at 0.9. Overhead/general conditions is strongly correlated to actual profit, at 0.88; however, overhead/general conditions are more strongly correlated to budgeted profit, at 0.92.

Actual profit is not strongly correlated to actual days, at 0.62, but is more strongly correlated to estimated days, at 0.79 and contract days, at 0.71. This may indicate that there is another influencing factor in the relationship of actual profit and actual days.

RFIs and ASIs at 0.91, addendums and OICs at 0.88, and punch list items at 0.69 are all strongly correlated to actual profit. Budgeted profit is also strongly correlated to RFIs and ASIs, at 0.89, addendums and OICs, at 0.72, and punch list items, at 0.88. Further analysis should look at the relationship between these items, as these items are likely unpredictable prior to their occurrence on a project, and thus, are beyond the control of the contractor.

4.2. Calculated Quantitative Data

Following analysis of the quantitative calculated data, several schedule version differentials demonstrated a significant relationship with another schedule differential. All of the schedule day data factors are strongly correlated, so it follows that differentials calculated from the same factors would show strong correlation. Ultimately, estimated days, contract days, and scheduled days are all predictions for actual days.

Only one schedule differential showed a significant correlation to a recorded data factor. That was estimated days–actual days (dif) and approved change order price (r = 0.71). A total of 18 of the 23 projects (78%) in this group had at least one change order. This relationship represents that an increase in approved change order price is strongly related to the difference between the estimated days and actual days for the project. That factor should be investigated in any additional project group analyses to see if it is consistent or an anomaly within this set of projects. Since there is no data point to capture the increase in contract time associated with an approved change order, only a change in contract value, that additional data point should be included in future studies to better understand this relationship.

Profit differential was the calculation of actual profit less budgeted profit. Only three significant correlations were found, as shown in Table 8. As could be expected, actual profit and budgeted profit are two of the three significant correlations for the calculated differential. The third correlation is interesting, as RFIs and ASIs is found to be strongly correlated to profit differential. There are many possible reasons that could account for this, such as the pricing and clarification of quantified risk. The relationship between RFIs and ASIs and profit differential is of note and should be explored in greater detail.

Table 8. Significant correlations for profit differential.

	Profit Differential
Actual Profit	0.79
RFIs and ASIs	0.73
Budgeted Profit	0.70

5. Discussion

Project success is attributed to several factors, including client satisfaction, which generally results from a number of project outcomes such as time and cost, as well as personal interactions on a project many, of which are hard to quantify. For a contractor, project success often comes down to the actual profit obtained on a project, or more specifically, the positive profit differential. Understanding what PIs lead to this success has been challenging to identify, and this aspect is not well represented in the literature regarding commercial building construction projects. Current methods for determining project success from the contractor's perspective are difficult to correlate with quantitative project factors, or for use as PIs, due to the lack of historical data readily available for analysis, as well as the limited literature indicating the relationship between project factors and profit margin [11,25,28,29]. Construction projects collect a large amount of data concerning project factors, the process, and the outcomes. Often, that information is held internally by the contractor and not released or readily available for analysis outside of the company. As such, limited methods are available in the literature to analyze construction project data to indicate success. Big data approaches proposed to demonstrate project analysis have limited applications for indicating success for any given construction company regarding a given project [29]. These are typically meta-analyses of the costs of public projects by type of project, or a compilation such, as analysis based on RS means data, and do not contain the internal project factors. With enough data, the Pearson correlation can be calculated to determine connections between project factors and success [30]; however, there is typically not enough historical data to determine correlation [31]. This study, with access to extensive project data on 23 completed projects from an ENR top 400 contractor, identified correlated factors of the completed construction project data that indicate project success by looking for correlations between project outcomes and contributing factors. The strength of these correlations can provide recommendations for project areas to closely manage and for further analysis.

Data analytics used in sports offer a parallel for analyzing project success according to performance factors. Recognized in the book *Moneyball* [1], statistical analysis of various in-game occurrences could indicate successful outcomes, such as games won, and be further used to build a more successful team. In a similar way, construction project factors could be observed, analyzed, and managed to deliver project success. In addition to their use in baseball, these types of analyses have been used in AF and tennis, where PIs can be analyzed using match outcomes, such as win-loss or score margin [32]; in tennis, it appears that individual performance factors are correlated to win rate among tennis players [33].

In this case, we parallel actual profit identified regarding construction projects to the win rate and look for correlation with contributing factors of other project recordables. The Pearson correlation of PIs, checked using a correlation matrix, indicated eleven factors with strong correlations to actual profit that could indicate a contribution to success, such as the size of the building in square footage, the estimated construction days, the contracted construction days, the initial price, the final project price, the budgeted profit, budgeted overhead and general conditions, the positive project profit differential, the number of addendums and owner incorporated changes, the total number of RFIs and ASIs, and the number of punch list items. The building square footage and number of addendums and owner incorporated changes are typically beyond the control of the contractor. Items such as the number of RFIs and ASIs, and number of punch list items, are areas over which the contractor does not have complete control, but over which he has some ability to manage the effects. The estimated construction days, contracted construction days, initial price, final project price, budgeted profit, budgeted overhead and general conditions, and the positive project profit differential are all factors within the contractor's realm of influence, and these could be determined by effective project leadership. Quantifying these effects and collecting future data should help project teams quantify factors that lead to success on a project, from the contractor's perspective.

Further, we can parallel profit differential on construction projects with win margin or win rate, looking for contributing factors of other project recordables. Since there is very limited literature that indicates the relationship between key attributes of construction projects and profit margin [29], this study provides the most comprehensive look at such a relationship, discovering that, in this instance, positive profit differential, or the amount above budgeted profit, is strongly correlated to only one factor, the number of RFIs and ASIs on a project, as indicated in Table 8. Although actual profit and budgeted profit are also strongly correlated to profit differential, that comes as no surprise, since those values create the profit differential factor. A deeper evaluation of how a larger number of RFIs and ASIs are correlated with higher actual profit than budgeted could be valuable to construction companies, influencing the leadership and priorities regarding construction projects.

Another outcome of interest to construction companies is the actual construction days for a project and the factors that affect this outcome. Actual construction days may be associated with many project-related factors that could also affect cost, ranging from contractual obligations and liquidated damages to general conditions and the daily charges for labor, equipment, and services. The Pearson correlation of PIs, checked using a correlation matrix, indicated eight factors with strong correlations to actual construction days. These factors including three other schedule values: the number of days estimated for the project in the proposal phase, the number of days included in the contract, and the number of days scheduled by the project team following project award. In addition, these five factors demonstrated strong correlations to actual construction days: overhead and general conditions, initial project price, final project price, budgeted profit, and the number of punch list items. Of those factors, the finding that a higher number of punch list items is related to a higher number of actual construction days seems to be an aspect of the project that should be quantified and examined to inform and influence successful project leadership.

This research targeted the gap in the literature concerning the analysis of construction company project data from actual projects to determine factors that indicate project success using an approach similar to sports analytics. The implication is that if PIs parallel project factors and match outcomes parallel successful projects, the key project performance factors can be identified. Similar correlation analysis was performed here for construction projects, where instead of win-loss or score margin, actual profit, profit differential, and actual construction days, along with other factors, were evaluated and analyzed as project success indicators, and correlated project factors were identified for this group of twenty-three projects. This data indicates that the number of punch list items, and the number of RFIs and ASIs, are PIs that affect project outcomes and indicate or influence the quantification of project success.

6. Conclusions

Current methods for determining project success from the contractor's perspective are difficult to correlate with quantitative project factors or use as performance indicators, due to the lack of historical data readily available for analysis, as well as the limited literature indicating the relationship between project factors and profit margin [11,25,28,29]. This study analyzed construction company project data from a portfolio of actual commercial building projects to determine factors related to project success using the Pearson correlation in an approach similar to that used in sports analytics. In what appears to be the first analysis of this type in the literature, 66 of the 253 relationships between the factors explored were found to have significant correlation. This analysis identified high correlation between final price and actual days, supporting Habibi et al.'s [28] assertion that construction project success can be attributed to effective time and cost performance. In addition, in this analysis, actual construction days has a strong correlation with the number of punch list items. Profit differential (actual profit less budgeted profit) demonstrated a strong relationship with the number of RFIs and ASIs on a project. Since RFIs and ASIs are indicators of incomplete design and/or design clarification, potentially affecting project scope, this result indicates that the successful pricing and clarification of scope leads to a more profitable project for the contractor, indicating project success.

Construction management as a highly competitive, project-based field of complex specialized services, creating or altering the built environment for a client. For construction management firms and contractors to be successful, understanding the relationship of performance indicators with project outcomes, such as cost, time, and profitability, are essential. For this ENR top 400-ranked construction firm, this data analysis can help in collecting and analyzing data for future projects to help achieve success. Despite the contributions of this study and valuable insight provided for this construction firm, it contains certain limitations. This study provides empirical results indicating the correlation of project outcomes and certain performance indicators; however, the results do not provide detailed information on the cause of these relationships. The research sample was limited to one construction firm and data previously collected.

6.1. Additional Data Collection for Future Research

In addition to the data collected from the projects in this dataset, future projects should collect any schedule change in days associated with change orders, as well as any approved contract days associated with the change order. Only change order cost was included in this data. Identifying the cost and schedule implications of RFIs and ASIs could help in clarifying the significance of their relationship with profit differential. Actual construction days, with a strong positive relationship to number of punch list items, should be explored further for any possible cost or schedule efficiencies.

6.2. Recommendations for Future Research

These findings are the first step of analysis leading to future research that could evolve into predictive indicators of success for building projects. Further research is needed to quantify the effect a performance factor would have on a project outcome and to identify the strength of the indication. Moreover, future research could look at additional samples of projects and data from additional construction firms.

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sustainability

Article

Contractual Governance for Dispute Resolution and Construction Sustainability: Case Studies from China

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Abstract: Disputes may disturb construction projects and stakeholders, and they may cause tremendous losses that hinder the sustainable development of construction. Therefore, contractual governance is significant in construction projects as a crucial method of dispute management. However, the interrelation of contract and dispute management has not been studied theoretically and comprehensively. In this regard, this paper aimed to propose a framework for dispute governance, including governance structures (GSs), governance mechanisms (GMs) and an additional conceptual model, by using a literature analysis method. The results suggest that dispute structures based on owner-centered (OC), owner- and supervisor-decentralized (OSD) and additional independent representatives (AIRs) are often used. Each kind of GS can be applied in a specified project. On the other hand, we considered that GSs could be divided into an external GS and an internal GS, which played different roles in motivation mechanisms. In addition, a conceptual model was developed through literature analysis. Case studies were presented to investigate the relationship between the GS and GM. Then, specified GMs were identified from case studies of Chinese construction contracts. Current research can provide valuable information allowing for contract drafters and managers to realize the sustainable development of projects.

Keywords: literature analysis method; construction sustainability; governance structure; governance mechanism; conceptual model; contractual governance

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1. Introduction

Conflict situations are common dilemmas in construction projects that may lead to disputes among parties [1]. People cannot neglect the negative influence and consequences of this phenomenon. Claims usually lead to a dispute regarding project delays and cost overruns [2,3]. The dispute arises and adversely affects the project performance due to poor communication and cooperation. More seriously, the construction project will fail due to inefficient dispute management. Project delays or even failures cause negative impacts on sustainable development of stakeholders, human resources, projects, industries and governments [4]. Disputes make it difficult for stakeholders to cooperate sustainably without the promising ability to meet their needs [5]. The development of human resources relies on organizational development and personal training [4]; however, project suspension makes it unsustainable. Project management is not only limited to its traditional success criteria, but also has a broad view of sustainability [6]. A project's quality may be damaged by disputes that endanger continued construction after it begins. Overall, arising disputes are not good for the sustainable development of stakeholders and projects. From a broader perspective, local economic development slows down when disruptions occur frequently in construction projects, which in turn affects the sustainable development of the region. The construction industry may ensure social sustainability by engaging, training and doing business [7] on the basis of project completion on schedule. Low-level development of the industry makes it difficult to achieve industrial upgrades, and the strategic objectives of the government cannot be fulfilled either. Therefore, inevitable disputes must be handled properly. In China today, many construction projects are also affected by unresolved disputes, and as such, Chinese projects need to allocate unnecessary costs, time and resources to conflict management and dispute resolution [8,9].

The conceptual notation of project governance is defined as project transactions. This term refers to the three factors of asset specificity, uncertainty and frequency [10,11]. It is thought that project management, as an integral part of social science, could be researched in governance theory. In the project management context, dispute management can also be studied using governance theory. Acharya et al. [12] claimed that conflict and dispute were two different notions, and that a dispute was the result of conflict after escalation. It was believed that a dispute was the external manifestation of conflict, while a claim was a disagreement directly leading to a dispute. The authors developed a continuum model based on conflict, claims and disputes to demonstrate the evolution of these notions [12]. For a project manager, conflict governance should be embedded in project management practices to avoid disputes in the early stages. The project governance method consists of contractual and relational governance, which should be studied in depth to mitigate project disputes [13]. However, contractual governance is relatively rigid compared to relationship governance, and disputes can be easily controlled. Contractual governance relies on clause drafting in the construction contracts. The content and formulation of clauses, as well as the logic and structure of a contract, have an unneglectable influence on the completeness of the contract. The contract drafter should be cautious of contract completeness when drafting a clause. The construction industry has realized the importance of dispute governance in projects, which is relatively effective in construction contracts. Contractual governance for disputes (CGD) mainly depends on clauses in three dimensions [14]:

- Clause specificity. A specified clause defines the roles and responsibilities that each party should assume [15].When the stakeholders have a high level of opportunism, a specified clause acts as a proactive approach to avoid disputes.
- Contractual obligatoriness. Contractual obligatoriness constrains each party [16]; through it, each party is forced to abide by the contract clause, reducing the incidence of opportunistic behaviors.
- Contingency adaptability. This refers to the contractual adaptability when a contingency occurs, leading stakeholders into a dispute. Adaptability means a flexible space for dispute negotiation according to the contract while disputants negotiate [17].

Nowadays, in China, specified clauses refer to dispute governance in construction contracts. However, the governance structure and mechanism for dispute resolution are not theoretically cognitive, especially when the interplay of GSs and GMs in the dispute is not clear. This paper attempts to reveal a dispute governance principle and discuss a possible way to handle disputes. The performances of the project and stakeholders are improved by managing disputes so that construction sustainability can be achieved. In Sections 4 and 5, the characteristics of the identified GS and GM are discussed in detail. In Section 6, the GS and GM are examined through a local case study. The contribution of the GS study helped the participants with a specified role in dispute management, while the GM studies discussed the "why" and "how" in handling the dispute. Based on the mentioned findings, researchers and practitioners could design the proper GS and GM for new project management tasks. It is noted that a clause for dispute management in the contract drafted from the view of the GS and GM was generally more effective than from other perspectives. In Section 7, a conceptual model depicts the interplay of GS and GM to clarify the working mechanism. To some extent, the working mechanism was effective, depending on the GS and its corresponding GM.

2. Literature Review

2.1. Dispute and Construction Sustainability

Conflict is evitable in project management, which probably causes a negative effect on the project [18]. The conflict escalates to a dispute if it is not managed correctly [19]. Researchers have contributed a noticeable amount of literature on the dispute in construction. Jones [20] argued that disputes were attributed to management, communication, economics and other fields. Some studies suggested that disputes could be viewed as a class or conflict that should be resolved [21]. Construction disputes could also be considered as the opposition to objectives, interests or even values [22–24]. Fenn et al. [25] and Acharya et al. [8] postulated that disputes were associated with distinct justiciable issues. Today, a dispute is explained in a new connotation that can be classified into three types: task event, relation event and process event [26,27]. In addition, some studies mentioned that disputes might originate from contracts and relationships [28–30].

The specified causes of disputes relevant to project management are complex and vary. For example, time and project scheduling are commonplace and worldwide causes of disputes [31–34]. Cost overruns generally led by the disputes adversely impact parties [2,35]. Besides, variations in the construction projects often disturb contractors [36–40]. Payment is an important material support for parties and projects. Delays or inadequate payment threatens the parties' interest and projects, which ultimately results in disputes [32,36,39]. Some of the literature emphasized other causes of disputes, such as uncertainty [40], culture [41] and the natural environment [42].

Due to the special status of the disputes, the investigation of dispute management plays a critical role in project management study. Dispute management influences not only the performance of a project, but also the interests of stakeholders. Researchers and project practitioners have focused on the study of dispute management for many years. Alternative dispute resolution (ADR) implies different coping resolution methods and has gained popularity as an ideal method to manage disputes [43]. Common options for managing dispute include arbitration [44], adjudication [45], mediation [46], negotiation [47,48], dispute resolution advisor systems [49], dispute review boards [50] and mini trials [51]. ADR has wide application in theoretical research [52–54] in solving many practical problems. Another hot topic is the dispute review board (DRB). Harmon [55] and Thompson et al. [56] suggested that DRBs could effectively manage construction disputes. It was reported that from 1975 to 2001, the number of projects under DRBs increased, indicating that DRBs became popular during that period in the U.S. [19]. Today, DRBs still dominate the organization structure for dealing with disputes in Western countries. Referring to the specified method, the multiattribute utility technique [57], multilayer perception neural network model [58], the K-nearest neighbor(KNN) pattern-classification-based knowledge-sharing model [59], the graph model [60], or other methods are adopted to manage practical disputes. With the development of technology, new theoretical models and ideas will be brought into dispute research, improving the development of project management.

Various dispute management evaluations are proposed for the effectiveness of dispute management practices. Much literature has analyzed dispute management effectiveness from two aspects: stakeholders [61,62] and projects. The effect of dispute management is generally described as a success [63] or a failure. So, dispute management evaluation becomes crucial for managers. The engineer ought to adjust the management method dynamically to reach the dispute management goal. Table 1 summarizes the background of the dispute research in the literature.

On the other hand, construction sustainability has gained worldwide attention from a long-term perspective. One reference reviewed the assessment indicators and taxonomy for social sustainability for construction projects [4]. Many indicators and taxonomy were discussed, and a social sustainability framework was contributed [4]. The project and its management were successfully implemented as major indicators enabling the creation of social sustainability [64]. The construction industry, with its long-term evolved culture and customs, enables sustainability [65]. It needs culture and traditional customs to cooperate spontaneously. For local governments, regulations and incentives are adopted to promote the sustainability development of the construction industry [66].The disputes lead to the project's suspension, and the performance cannot be fulfilled. Construction sustainability development is of course out of the question. Overall, a causal relationship exists objectively between disputes and sustainability whether for a project or construction industry.

Table 1. Overview of disputes in construction projects.

Identification of Construction Disputes and Their Management	Reference
1 Conceptual cognition of dispute	
1.1 Conflict after escalation	[19]
1.2 Viewed as a class	[21]
1.3 Opposition of objectives, conflict of interests or even values	[22–24]
1.4 Result of justification	[12,25]
2 Sources of dispute	
2.1 Task event, relation event and process event	[26,27]
2.2 Contract and relationship issue	[32–34]
2.3 Time or schedule overrun	[31–34]
2.4 Cost overrun	[2,35]
2.5 Variation in construction project	[36–38]
2.6 Payment not on time or inadequate	[32,36,39]
2.7 Uncertainty in construction project	[40]
2.8 Culture of project team	[41]
2.9 Natural environment change	[42]
3 Dispute management	
3.1 Alternative dispute resolution, including arbitration, adjudication, mediation, negotiation, dispute resolution advisor systems, dispute review boards and mini trials	[44–51]
3.2 Dispute review board and application in practice	[55,56]
3.3 Theoretical model in research	[57–60]
3.4 Evaluation of dispute management	[61–63]

2.2. Contractual Governance for Construction Projects

Governance is the engagement of actors in transactions that requires them to control the transaction, protecting the interests to share the benefits [67]. In a construction context, Poppo and Zenger [15] suggested that the specified clauses of a contract, so-called "contractual governance", could reduce the risk and resolve unforeseeable outcomes. Contractual governance is the dominant form, preventing opportunism behavior. Governance structure and governance mechanisms constitute the framework of the contractual governance. Ho et al. suggested a series of GS strategies and tactics in construction joint ventures [68]. Afterwards, Lin and Song [69] analyzed the impacts of GS strategies on the performance of joint ventures. In addition, the GS has a big impact on projects from other aspects. Transaction cost economics [70], corporate social responsibility and risk management [71] are all involved in GS as a basic foundation of a contract. On the other hand, the GM as a soft operation environment is indispensable for contract governance. The project manager attaches great importance to the GM mainly for its strategic role. Wang et al. [72] argued that there was interplay between GMs, namely trust, control and megaproject governance. The trust repair mechanism is an important variable that surely influences the decisions of contractors and subcontractors [73]. In general, the project's success depends on effective governance mechanisms [74].

Some existing, available studies have focused on the disputes and contractual governance, covering basic problems and practical application. However, there is still a gap, and their interplay is unclear. Few studies have concentrated on the association of the disputes and contractual governance. In light of this research situation, investigating the mechanism between these two is worth discussing further. To bridge the gap, this study attempted to investigate the contracts and summarize some common specified GSs and

GMs in Chinese construction contracts in order to verify the conceptual model proposed by the literature analysis method for disputes and contractual governance. To clarify, the governance principle lays the foundation for project success and long-term development. Construction sustainable development can be realized by handling disputes properly, which is the subject of this research.

3. Research Methodology

The completeness of contracts for dispute governance depends on clause drafting. The contract clients are unconscious about what GSs and GMs are, and they just make sure that construction disputes can be governed by a contract. In light of this, it is necessary to study governance theory for disputes to aid construction policy makers.

This study investigated the GS and GM for construction disputes through a case study. A case study is a methodology that explains the "why" and "how" for a phenomenon worth exploring [75]. In addition, multiple cases could strengthen the robustness of research conclusions instead of a single case [76]. The multiple in-depth case study (MICS) method was adopted to explore the research objectives of this paper.

The research idea of this manuscript includes proposing a framework of GS, GM and a conceptual model through a literature analysis method that is widely used at home and abroad [77].Contract clauses, which are the main form of contract, define rights and obligations of each party. GSs for disputes are relatively explicit in clauses compared to clauses related to GMs. It is noted that GM study is much more difficult than GS study [68]. The MICS method was adopted to study the GS and GM by analyzing and comparing clauses of contracts. The conceptual model was verified based on cases provided for contract drafters. The methodology of this research is shown in Figure 1.

Figure 1. General methodology of this research.

4. Governance Structure

Governance structure defines the organizational structure and stakeholders' role in a construction project. Organizational structure is the foundation of project operation. Effective organizational structure could improve the performance of the project [78]. When a dispute occurs, a preset organizational structure provides a basic framework for dispute management. The parties involved in the dispute can negotiate with each other based on the organization structure. Therefore, the design of the organization structure is the first step of project management. Miller and Hobbs [79] stressed that a suitable organizational structure was the foundation of project governance.

Stakeholders' roles are another aspect of GS that define each stakeholder's rights and obligations. Every stakeholder has his own responsibilities. Project failure is often attributed to failing to fulfill his promise [80]. Different stakeholders have different roles in various stages and situations in some complex or mega projects [81]. Dispute management depends on stakeholders with specified roles despite trivial matters. Another important factor affecting GS is the external environment, including the market environment and government regulation. It is common to see the GS influenced by the local market environment. The local construction market has customs for determining the GS of a project. The local government has a similar affection for GS to the construction market [82].

In the Chinese construction market, GS for disputes has its characteristics compared to the international market because of cultural differences [41]. In other words, GS for disputes considers the Chinese market and plans a suitable GS for Chinese construction projects. In recent years, construction managers have gradually realized the importance of dispute management. Various GSs for dispute governance have been gradually adopted and applied in projects for efficiency. From the owners' perspective, there are often GSs adopted from OC, OSD and AIR methodologies [83]. Each kind of GS has its own characteristics that are suitable for specified projects. The OC governance structure is widely applied in small projects and private projects or projects without a bidding process. The owner-centered type is rarely used in the modern construction market. The OSD governance structure is the most widely used, and this kind of GS also has the advantage of solving disputes within the team. The owner and supervisor are responsible for administrative coordination and professional affairs, respectively, with clear working boundaries and scope. The effectiveness is preferable, and the cost can be accepted. AIRs mean an independent third party that participates in dispute coordination. The most famous independent party is arbitrary and plays an important role in dispute coordination. AIRs as a supplementary form of GS are sometimes essential. The disadvantages of AIRs, including their high cost and time-consuming nature, are notable. Table 2 outlines the investigation of the proposed GSs.

Table 2. The investigation of the proposed GSs.

Governance Structure	Project Feature	The Third Party	Cost	Time
OC	Small, private, without bidding	NO	Low	Fast
OSD	Large	NO	Medium	Medium
AIR	Large	Yes	Relatively high	Consuming

In Western countries, governance structure for disputes generally refers to a dispute review board (DRB). DRBs are nonadversarial and temporary organizations preventing or solving disputes [59]. In the United States, DRBs are a success for solving disputes mainly because of their ability to reduce the price of projects [84]. Since then, the DRB has been gradually introduced into the Chinese construction market. Some contractual clauses relating to DRBs are emerging today to guarantee the completeness of dispute governance.

5. Governance Mechanism

The governance mechanism helps in system operation. As motivation for the system, GM planning plays a key role in project governance. The GM planning is a success if the system works smoothly to achieve the intended target. In contrast, if the system does not work, this can be partly attributed to an unsuccessful GM. In this regard, the client should perform an in-depth evaluation of current data for available projects and seek a proper GM. For a system, the GM is usually divided into an internal GM and an external GM in terms of different motivations. The internal governance mechanism (IGM) refers to the GM working in the system while the external governance mechanism (EGM) refers to external factors influencing the system [85]. Simply put, the IGM indicates how a system works while the EGM explains why it works. Almutairi and Quttainah [86] discussed the IGM and EGM of legislation in Kuwait and considered culture and market conditions as main factors. Furthermore, IGMs and EGMs are also applied in economy and finance research [85,87].

For dispute governance, IGM and EGM design for contract clauses should address the following items:

- How can the dispute be managed?
- Why should this be done?
- What roles should participants play?

To answer the above questions, a conceptual model is required to demonstrate the internal logical relationship of the IGM and EGM (Figure 2). Establishing a conceptual model can lead to a deeper understanding of the essence of the problem. The model exhibits the difference and connection between the IGM and EGM in jointly promoting dispute management. Decision makers can draft contracts with the help of a conceptual model, ensuring project completion.

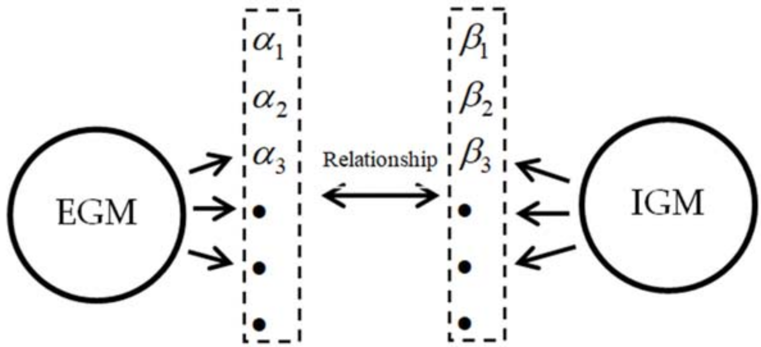

Figure 2. Model f. Conceptual model for the relationship of EGM and IGM.

6. Case Selection and Data Collection

The construction contract with dispute clauses is relatively common in contract series. The cases used in this study were selected from nearly 260 Chinese contracts between 2000 and 2020. The data were collected from most developing provinces, from building, transportation, coastal engineering, water conservancy projects and so on. However, not all the contracts satisfied the requirements of this study. Most contracts with few related contents were abandoned. Some projects with smaller and less influence were dismissed as well. In terms of rationality and effectiveness, six cases of rest contracts with relatively detailed dispute clauses were selected. It was found that the contracts had relatively complete sections regarding dispute governance with abundant information available. The cases covering multiple areas represented the current situation regarding dispute management in engineering. In addition, the selection of six cases was not random but rather took into account delivery and category in China. These cases were located in five provinces, Zhejiang, Guangxi, Hubei, Liaoning and Shandong, reflecting the current construction dispute situation in China.

The following six cases are outlined by an overview of the project, followed by a description of the project profiles:

- Case A. Lujiaba Community Construction in Huzhou, Zhejiang Province.
- Case B. Feiheshan Campus of Tiantai Primary School and Feiheshan Kindergarten Constructionin Taizhou, Zhejiang Province.
- Case C. Cangwu-Zhaoping Expressway in Guangxi Zhuang Autonomous Region.
- Case D. Weifang-Rizhao Expressway in Shandong Province.
- Case E. Hubei Communication Technical College New Campus Construction, Hubei Province.
- Case F. Culture Center of Coastal Economic Zone and Infrastructure Construction in Panjin, Liaoning Province.

The types of cases varied, and their locations were distributed in relatively developed regions in China. In this research, we selected various types of projects, including house building, expressway construction and infrastructure cases, which guarantee feasibility and reliability of this research. Table 3 presents a list of information about the location, types and parties of the contract and cost for each case.

Table 3. Overview of the selected cases.

Project	Location	Type	Owner	Contractor	Duration	Cost (CNY Million)
Case 1	Zhejiang	Building	Huzhou Estern Urban Construction Co., Ltd.	HG-ECG Co., Ltd.	Ten months	40
Case 2	Zhejiang	Building	Tiantai Bu. of Edu.	ZICIG Co., Ltd.	Two years	121
Case 3	Guangxi	Expressway	Guangxi Transport Department	ZIC Expressway Co., Ltd.	Four years	1600
Case 4	Shandong	Expressway	Shandong Transport Department	Shandong Expressway Group Co., Ltd.	Three years	10,800
Case 5	Hubei	Building	Hubei Communication Technical College	WH-TSC Co., Ltd.	Eight months	86
Case 6	Liaoning	Building and infrastructure	Panjin key public project construction management office	China Construction 6th Eng. Bu. Co., Ltd.	Six months	200

7. Findings and Discussion

7.1. Governance Structure for Disputes in Contracts

The cases reflect the prevalence of dispute governance in the Chinese construction market. By reviewing the contracts, it was found that they had very similar content on disputes. There were clauses on dispute management covering GSs to GMs in these contracts. From analyzing the contracts, the investigations of GS for six cases are outlined in Table 4. For research convenience, six construction contracts corresponding to six projects are labeled as C1 to C6.

Table 4. Review of GSs for disputes in six cases.

Contract Number	Signing Time	Governance Structure Type	DRB	Dispute Coordination Fee	Arbitrary	Litigation
C1	2016	OSD	Yes	Yes	Yes	Yes
C2	2018	OSD	Yes	No	No	Yes
C3	2021	AIR	Yes	Yes	No	Yes
C4	2011	–	No	No	Yes	Yes
C5	2015	–	No	No	Yes	Yes
C6	2015	OSD	Yes	No	Yes	Yes

As shown in Table 4, the governance structure is changing with the market development. About 50% of all contracts were characterized as OSD, i.e., C1, C2 and C6. Only C3, signed in 2021, pointed out the dependent third party could participate in coordination. The remaining two contracts, signed in 2011 and 2015, had no information about personnel composition or a DRB. From the case studies, it can be seen that the personnel composition for dispute management is gaining more attention than before. For DRBs, all DRB settings were present except for C4 and C5. DRBs are becoming more attractive due to their effectiveness in handling disputes. It was found that a dispute coordination fee as a new item has come into practice. A coordination fee for DRBs is an extra expenditure for stakeholders. In addition, it was noticeable that one-third of contracts did not mention arbitration as a way of managing disputes. The litigation as a final option for managing disputes was addressed by all the contracts, implying its authority in China.

7.2. Governance Mechanism for Disputes in Contracts

A perfect governance mechanism is the motivation basis for project operation. Thus, exploring GMs promotes the completeness of the contract. Undoubtedly, there is great significance in studying GMs for disputes in contract clauses. As a part of project governance, GMs for disputes are similar to project governance theories. GMs of trust and institutional support (TIS) [88] and coordination and handling (CH) [89] have been investigated and applied in construction projects. However, specified GMs still need to be deliberately arranged according to their functions. The disputes governed by external mechanisms of project performance assessment (PPA), project member assessment (PMA), dispute assessment and penalty (DAP) and reputation and credit assessment for employment (RCAE) are universal in contract clauses. Internal GMs, including dispute autonomy and transfer (DAT), core member decision (CMD), whole-process governance (WPG) and governance method and objective (GMO) should also be considered in clause drafting. These GMs could be found vaguely in the selected contracts (Table 5).

Table 5. GMs for the disputes in cases and their features.

Governance Mechanism	Types	Feature/Content	Clause Description
PPA	External	Pressure	• The contractor should take liability for breach of contract due to project delay (C1, C2, C3, C4, C5, C6). • The contractor is funded by the owner only if the milestone in project progress is achieved (C1). • The performance of project company is affected by one indicator of dispute management performances: public satisfaction (C2, C3) and ecological conflict (C3).
PMA	External	Pressure	• The manager is responsible for the project performance (C1). • Project members' income is a function of performance influenced by public satisfaction (C2, C6) and ecological conflict (C3).
DAP	External	Pressure	• The evaluation and satisfaction of disputes for the bureau and actual users (C2, C5). • The satisfaction of dispute management for user, client and resident along the expressway (C3, C4).
RCAE	External	Competition	• The partner with a good reputation has no unsettled disputes (C2). • Cooperators ought not to be on the blacklist (C6).
DAT(CH)	Internal	Path	• The contractor can seek help from arbitration or litigation if there is disagreement regarding the decision made by the DRB (C1, C4, C5, C6). • The parties have the rights to hand the disputes over to the local court provided that the disputes cannot be solved by the DRB (C2, C3).
CMD(TIS)	Internal	Decision-making	• The members of the DRB are determined (C1, C2, C3, C6).
WPG	Internal	phase	• The dispute management program is working over the entire course of the project (C1, C2, C3, C4, C5, C6).
GMO	Internal	Method and objective	• The plans and programs for handling disputes in the construction and operation period are distinct (C2). • The project cannot be suspended during dispute coordination. Otherwise, the contractor will be punished for contract-breaching behavior (C3, C5). • Generally satisfied is the lowest goal of dispute coordination evaluation (C4).

PPA as an external motivation for projects was discussed in nearly all the contracts. Public and ecological disputes can lead to project suspension. PMA plays a similar role to PPA, and DAP prevents troublemakers that arouse disputes. The satisfaction indicator is very low if the disputes are not solved properly. So, the penalty mechanism can be regarded as one of the GMs for dispute resolutions. Many clauses of contracts more or less refer to satisfaction. In RCAE, only C2 and C6 contain employment matters, especially blacklist matter mentioned in C6. PPA, PMA and DAP are all featured as pressure motivation whereas RCAE is competition-driven. For internal GMs, DAT is similar to CH, which has been studied by authors already. It tells us who is in charge of disputes and how to transfer responsibility. Most contracts resort to arbitration if organizations fail to handle disputes. CMD, regarded as a DRB, can be considered institutional support for dispute management. The WPG mechanism, of course, existed in all contracts in the light of the advocacy of whole-process management in China. The contracts about GMOs were not visible, but rather just vaguely related to dispute management methods and objectives in the dispute chapter.

7.3. Discussion and Conceptual Model for Dispute Governance

GS for disputes is determined by the project and social environment. GS is the basis for dispute coordination. Therefore, planning a proper GS is critical for successful dispute governance [78]. GM as an incentive mechanism motivates the operation of dispute management. Several GMs are discussed above in Table 5. It seems that the selected GMs should be determined by the planning GM. The GM can operate smoothly given the perfect GS. To some extent, planning GMs may not be applicable to other GSs. In a word, GSs have a one-to-one relationship with GMs. Li et al. [82] stressed that a practical governance framework could improve project performance, which was applicable to dispute management as well. Furthermore, it has been shown that the EGM explains why a dispute should be handled and the IGM explains "how" [86]. The MICS has instructed the relationship between EGM and IGM. In addition, governance structure is determined by the project overview, which is the operational skeleton for GMs. The selected GS, together with a proper GM, constitutes a conceptual model for dispute governance. Project success and sustainability are only possibly realized. In brief, a conceptual model based on cases is suggested as shown in Figure 3.

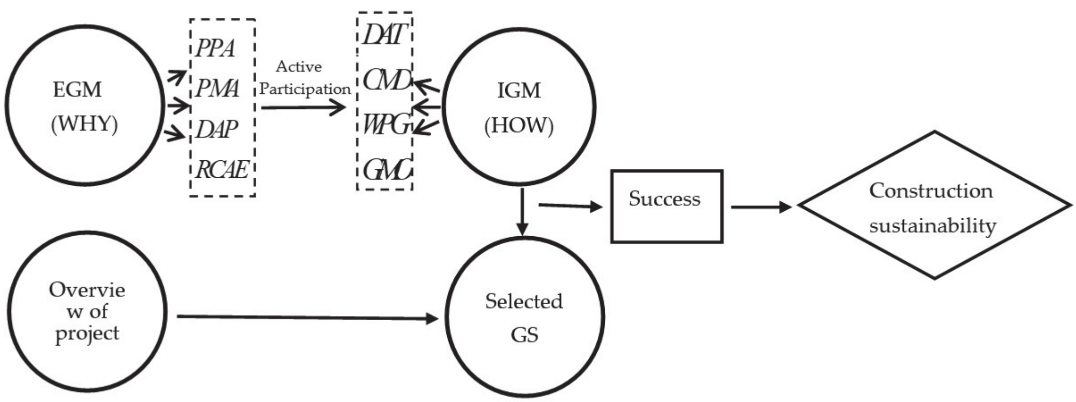

Figure 3. Conceptual model for dispute governance based on case study.

As seen from the MICS, many GMs are applied in contracts, and good results have been achieved. According to statistics reported, there were hundreds of conflicts and disputes arising in these projects, and DRBs resolved nearly all disputes. The rare disputes were transferred to arbitration, or even to litigation, but were resolved successfully with the efforts of all parties. There was evidence that the project sustainability could be significantly improved provided that the disputes were better managed via contractual governance. It was also seen that the governance framework was successful for six cases under Chinese national conditions.

8. Conclusions and Future Directions

As construction disputes have adverse effects on projects, professionals may encounter dispute problems in construction projects. This paper proposes a dispute governance framework for the project including a conceptual model proved by a MICS of six cases. This study provides dispute governing methods for contract clients so as to improve governance level and construction sustainability.

This paper began with a review of dispute and contractual governance in the literature. Then, GSs for dispute governance, including OC, OSD and AIRs, forming a DRB, were discussed. Correspondingly, GMs were divided into external GMs and internal GMs according to their function. Furthermore, a conceptual model investigated the relationship between the GS and GM and discussed their interplay through literature analysis. This model suggested a basic framework of dispute governance. Through a case study, the conceptual model was verified for the current Chinese conditions. This study investigated the existing literature on governance theory from the perspective of GSs and GMs for construction projects. Moreover, it handled the disputes in practice. It proved that correct dispute management contributes to project success, and the achievement of social sustainability is impressive for the selected cases. The current research enhances the understanding of dispute governance theory. Despite its contributions, this paper also has limitations, like any other paper. GSs and GMs may not be adequate but are popular in the current Chinese market. An empirical study is needed to fully explain some hypotheses, which is the following research plan.

In the future, empirical studies in this field will be considered. The interplay of GMs and the performance of projects will also be studied. Other urgent and significant topics of study will be on the agenda soon.

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Article

Exploring the Nature and Impact of Client-Related Delays on Contemporary Saudi Construction Projects

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Abstract: In rapidly developing countries such as the Kingdom of Saudi Arabia (KSA), where the construction of buildings and supporting infrastructure is critical to achieving strategic developmental milestones, delays to capital projects can derail other sectors of the economy and could derail the Vision 2030 agenda. Attempts have been made over the years to explore the causes of construction project delays, including those in Saudi Arabia. Many of these studies are either outdated, narrow in scope, or tend to use only qualitative data, and not many have focused on the client-related delay factors affecting projects critical to Vision 2030. This study investigates client-related delay factors in terms of their correlation with key characteristics of recently completed construction projects in KSA. This objective necessitated the use of historical data; hence, an archival analysis was conducted for 37 projects among three different public sector ministries. The data were subjected to manual extraction, descriptive statistical analysis, and the use of established models such as schedule performance index (SPI) and cost performance index (CPI), and inferential (correlation) in Statistical Package for the Social Sciences (SPSS) using point-biserial correlation coefficient (*rpb*, where $p > 0.05$) to explore association and impact of project characteristics on themselves and on client-related causes of delay. Results revealed eight unique client-related causes of delay, with SPI values of 0.71 to 0.82, as well as CPI values ranging from 0.84 to 0.89, suggesting very poor time and cost performance across all projects, as well as the magnitude of correlation of key project characteristics (cost, duration, additional time, and additional cost) with the eight client-related causes of delay. The findings can help the client (authorities) understand and curb delays that are due to their own making, and it is recommended that such delay factors, whose likelihood are now established and whose potential impact can be measured against key project characteristics, be developed into a delay risk impact tool. International joint ventures can bring technical expertise for Vision 2030, but they cannot eliminate delays due to government practices.

Keywords: Saudi Vision 2030; construction delay; optimism bias; cost overruns; schedule performance index (SPI); cost performance index (CPI)

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1. Introduction

Building construction projects deliver significant socio-economic benefits to stakeholders, including governments, as well as industry and society stakeholders, but they are prone to delays, which negatively affect their completion and expected impact. A construction project is said to be delayed if there is a time overrun in the original schedule, meaning the project is not finalized by the original contractually agreed date [1]. Many construction projects suffer from this challenge, with consequences in the form of lost income, increased client costs, penalties for contractors, and the postponement of project handover and the utilization of the investment by end users [2]. The tendency to make claims is also an issue that contributes to delays, as shown in a study that found six major categories of claim clauses that directly lead to time overruns, including inappropriate client action, contactor's incompetency, contractual problems, impediments caused by the client, bidding issues by the contractor, and problems due to uncontrollable project objectives [3]. In addition to the delays, such claims also have cost implications for the project. For example, in civil infrastructure projects, a study showed that factors such as 'delays in approval/permits' and 'late site handover' often led to financial compensation to the contractor, while change orders resulted in additional time [4]. These kinds of consequences have made the study of construction delays valuable and necessary.

Apart from impeding economic growth, such delays negatively affect the reputation of the industry [2], including those of emerging countries such as the Kingdom of Saudi Arabia (KSA). Faced with a fast-growing population at a time of crude oil-driven economic growth, KSA is witnessing expansive infrastructure development, including residential buildings [5] with ambitious targets such as being the world's largest investor in sustainable buildings [6]. Such ambitions are part of the Saudi Vision 2030, which comprises urban and rural renewal projects [7] and mega projects such as building, from scratch, a smart city (NEOM) in the middle of a desert with a bridge linking it to Egypt [8]. Such grand ambitions have led to many international joint ventures (IJVs) in order to bring in the foreign expertise required to transform the Kingdom into being among the most developed countries in the world by 2030 [9]. However, from the previous decade, a study [1] found that approximately 70% of construction projects for the KSA public sector were delayed, while recently Deloitte [10,11] stated that leading up to July 2014, the combined value of delayed building construction projects in KSA was estimated at US$146 billion, which has led to development pressures in the country. This is very crucial since the Saudi Vision 2030 hinged on not only the diversification of the economy but on the modernization of the country via the delivery of critical transportation infrastructure (e.g., the new Metro Line projects in Riyadh and Jeddah); modern facilities in healthcare; education; and the urbanization of rural communities [7].

Therefore, given the increasing number of delayed construction projects in general, further investigation of this phenomenon is required due to the potential impact on the Saudi Vision 2030 goals and beyond. This ambition inspired the KSA government to collaborate with the UN Habitat via the commissioning of the 'Future Saudi Cities Program' led by the Ministry of Municipal and Rural Affairs (MOMRA) [7]. However, achieving this vision is questionable given that only a few construction projects are completed on schedule and within the budget [1,12,13]. Specifically, this study is motivated by the need to empower the KSA government with better knowledge and understand how its role and behavior (as a client) contributes to specific kinds of construction project delays, with the appreciation of the likelihood of these delays occurring and their correlation/impact based on project characteristics. Given the established importance of certain kinds of construction to the KSA's development, this study has two objectives. The first objective is to understand the nature of client-related causes of delay in contemporary construction projects linked to the KSA's Vision 2030, particularly in terms of ranking them for the purpose of grasping the scale of the problem, prioritization by the client (government), and designing appropriate mitigation measures. Moreover, it is established that construction delays will generally lead to cost overruns [1,4,12,13]; there is a need to establish the strength of the correlations (association) between the different kinds of client-related causes of delay and project characteristics (including project cost). In this regard, the second research objective seeks to statistically establish the magnitude of correlation amongst four key project variables (project cost, contract period, additional time, and additional cost) as well as how each of these variables correlates with each client-related cause of the project delay. Numerous studies have examined the factors responsible for the delays in construction projects, so this study begins by critically reviewing the common causes globally before focusing on the KSA context.

2. Literature Review

2.1. Construction Delays in Global Context

From a global perspective, attempting to investigate or classify the various causes of delay in construction projects can seem daunting because the causes of delay can seem inexhaustible in the literature. For example, a study found up to 1057 causes from 47 peer-reviewed articles and concluded that 80% of these delays can be subdivided into three main categories: issues that arise at the execution stage, issues due to project administration, and issues related to labor disputes [14]. In another study, an exhaustive catalogue of the roots of construction project delays (CPD) was carried out through a systematic review of studies spanning three decades (1985 to 2018), leading up to 97 selected studies, from which 149 causes of CPD were extracted [15]. Findings showed that inadequate scheduling is a top-ranking cause of delay for both industry and academia, but one of the key gaps identified by this study is that there is need to investigate the inter-relationship (and reciprocal impacts) between several causes of delay. This is an interesting gap that this current study expects to fill. Furthermore, this study revealed that KSA was ranked 5th in the top 10 countries with research papers in this topic, and one of its top institutions—King Fahd University of Petroleum and Minerals (KFUPM)—was ranked as the top institution with the most papers. This suggests the importance that has historically been attached to research on construction project delays in KSA [15]. A more recent review of the historical causes of delay examined 168 studies done between 1982 and 2021 and found that six major themes emerged in construction delay research: the framework for analyzing delays, a dynamic building information modelling (BIM) 4D-BIM based analysis of delays, new models for delay analysis, the selection of methods for delay analysis, critical chain management, and blockchain/smart contracts in delay management [16].

Country-specific studies of the factors behind construction delays tend to provide a more manageable list. For instance, in Morocco, the top-10 reasons for delay were ranked in decreasing order of importance as follows: delayed progress payment, deficiency in training for workers, the absence of a management plan for construction waste, an unfeasible project duration, errors leading to re-work, the overuse of subcontracting, the delayed issuance of permissions from government, inadequate planning/scheduling, and uncoordinated planning and unskilled labor [17]. A study covering 37 construction companies in Pakistan, and which ranked the sources of construction delay, placed them in this order: (1) contractor, (2) owner/client, (3) consultants, (4) materials, and (5) equipment [18]. In Oman, it was found that client-side construction project delays are caused primarily by changing the scope of works, slowness of decision making, poor communication with stakeholders, and delayed progress payments [19].

Some delays are caused by supply chain factors (e.g., designers, contractors, and labor); natural phenomena (e.g., weather); and client-related factors, which in KSA, have been found to include recurrent design changes by clients and poor execution of works by the lowest bidding contractor as inherent in the KSA tendering system for public sector projects and delays in approving contracts [20]. A study conducted by Aziz and Abdel-Hakam [21] that reviewed the factors behind delays in construction projects based on 389 questionnaire respondents in Egypt revealed up to 293 different causes, indicating the wide range of issues contributing to construction project delay. From a list of 25 potential causes of delay, a study in India found the top 5 factors included financial difficulties of contractors, the non-payment of invoices, inadequate planning and scheduling, incompetent site administration, and the high volume of client-requested changes [22]. For healthcare projects in India, six construction delay factors were identified: a delay in progress payments, a lack of experience/ability of consultants/designers, variation and change order for scope of works, decision-making delays and litigation, inadequate coordination and communication among stakeholders, and a slow approval process by government agencies [23]. According to Van et al. (2015), [24], different levels of 'integrity' were found to be responsible for up to 19 factors contributing to government project failures and, in particular, the design phase was plagued by a lack of planning and a lack of clarity. A comparative investigation about the factors responsible for CPD in Australia and Ghana found the following causes: inexperienced contractors (43%), weak project control (21%), and the inaccuracy of potential contractors (14%) [25]. A similar study focused on government projects [24] identified 28 delay factors categorized into 6 groups, among which the 2 most important causes were the slowness of the client (government) in decision-making and financial difficulties by the client. A study by AlKharashi and Skitmore [12] investigated the delay factors by measuring the impact of the delays and the degree to which each delay factor can be addressed in practice, including those associated with clients, contractors, and consultants, as well as those associated with materials, labor, contract, and those causes related to the relationship.

Another investigation from Pakistan by Hussain et al. [26] involved a survey of 102 stakeholders and a pilot study with 16 experts in construction, from which they tested 52 delay factors as found in the literature. By comparing their results with previous studies in eight selected Asian countries, commonalities emerged, such as funding difficulties, delayed progress payment, and projects awarded to the lowest bidder. A study aimed at discovering the most significant factors that cause project delays and cost overruns investigated case studies from three countries (Australia, Ghana, and Malaysia) and found the most influential delay factors in Australia were a lack of adequate planning and scheduling, construction methods, and reliable feedback and monitoring, while for Ghana the most significant factors were a delay in payment certificates, the underestimation of project cost, and project complexity [25]. For Malaysia, the most significant delay factors were inadequate planning by contractors, inefficient site management, and deficiencies in the experience of contractors [25]. For Uganda, the most critical causes of construction project delays as found by Alinaitwe et al. 2013 [27] include changes to the scope of the work, delayed payments, inadequate monitoring/control, soaring capital expenditure, and political uncertainty, whereas financial problems of the contractor were the most crucial factor in India [22].

Additionally, various scholars [28–30] have identified paper-based inefficient processes as being among the critical reasons behind project delays. Traditional project management practices involve tedious paper-based manual process such as data entry, recording of measurements, quantity take-offs, project monitoring, scheduling and cost control, and general contract documentation. According to Azhar et al. (2008), these kinds of manual-based approaches are prone to errors and could lead to project delays, whereas adopting building information modelling (BIM) could alleviate or eliminate some of these issues [31]. Similar concerns were highlighted by others such as [32], who emphasized the inefficient and error-prone 'paper-based processes' used in site meetings, record keeping, works inspections, and monitoring, during which project deadline pressures could result in compromised accuracy or quality, hence contributing to delays. It was also shown that for an industry that is rich in data from sources such as BIM and Internet-of-Things (IoT) sensors in its project sites, the pace of adoption of artificial intelligence (AI) and machine learning (ML) for predicting and managing delays is slow [33]. One area where digital technology can support research into construction project delays is in understanding the synergy between delay factors. One example of a study on the interdependence of delay factors was carried out using ML algorithms for accurate prediction utilized two machine learning models (i.e., decision tree and naive Bayesian classification). The results were based on training the ML model on nine sources of delay risk, including clients, contractors, consultants, design, labor, material, project, equipment, and external factors, which produced 59 delay risk factors from data drawn from 51 construction projects in Egypt. Findings suggest that the sources of delay risk are very interdependent and complex, making time overruns challenging to manage, but using ML techniques (naive Bayesian model) provides a reliable predictive model, producing the necessary associations and allowing for better decision making that is evidence-based [34].

Another important factor to be considered in delays to construction projects is attributed to a phenomenon referred to as 'optimism bias', which is a cognitive bias that leads a decision-maker to downplay the extent to which an adverse situation or event could affect them [35]. In the construction industry, optimism bias could occur due to either the underestimation or overestimation of the expected duration or costs of a construction project [36]. This phenomenon plays out in the form of the 'Planning Fallacy', where construction planners and managers exhibit optimism bias when conceptualizing and evaluating a proposed project's duration, cost, and even benefits [37]. From many studies in the literature [38–42], it has been found that large infrastructure projects are often prone to such inaccurate time/cost estimates, and these have been attributed to optimism bias.

Other unique project characteristics that can result into delays include the type of building, where studies have found that healthcare projects are prone to delays for specific reasons. For instance, a US-based study on hospital construction found that such projects were often affected by changes much later in their execution phase due to clients changing end-user requirements and the fast-evolving nature of healthcare technologies, leading to disruptions and negatively affecting productivity, with obvious consequences for cost overruns [43]. The sophisticated nature of hospital projects has led to the adoption of non-traditional procurement models such as the private finance initiative (PFI) in the United Kingdom, with benefits including privately managed risks in aspects such as budget/cost controls and delay management [37,44], as well as managing over-optimistic schedules and a poorly defined scope [37]. For developing countries, it has been found that adopting the public private partnerships (PPP) model for hospital procurement can help stakeholders overcome some of the challenges associated with such complex projects. Some of the risk factors identified for PPP projects include the payment mechanism for the investors, as well as disputes, design flaws, material variations, cost overruns, and delays. The study concluded that a lack of effective risk allocation as well as a short-term view of healthcare investments are among the challenges that, when overcome, can improve the PPP delivery process [45]. However, the resilience expected from PPP procurement has not always been successful, and the UK's National Health Service (NHS) has been moving away from such models [46].

The unique role of government as a statutory authority and as the client for construction projects is also an important to consider. In Singapore, research based on two case study hospitals showed that although project managers had prepared detailed construction programs with properly estimated activity durations and sufficient float, both projects still experienced delays due to client-based factors such as additional requirements or the changing scope of works by stakeholders, regulatory restrictions placed by the Singapore government on bringing in foreign labor, and aggregate shortage due to a foreign government's ban on exporting aggregates [47]. Other government-related constraints that could contribute to delays in hospital projects include statutory design compliance issues, which can manifest in designs being delayed or reworked, and, in this regard, the automation of compliance checking can speed up the design process while minimizing future reworking [48]. The next section focuses on delays in the KSA context, where the issue of government/client-related delays will be examined further.

2.2. Delays in the KSA Construction Industry Context

The Saudi Vision 2030 identified the high quality of infrastructure as very important to meeting the needs of the country's growing population, in addition to other critical projects necessary for the modernization and 'Future Cities' program [7]. The projects necessary to achieve this vision have been subject to delays, as shown by a number of investigations conducted on the delays in KSA over the last two decades. A recent study based on 34 construction projects in KSA investigated the relationship between productivity and construction delays and found a strong association between delay factors and productivity factors (which include inefficient labor, inefficient coordination among construction stakeholders, inadequate manpower, design errors, and awarding a contract to the lowest bidder [49]). Another study [50] focused on Saudi Arabia reported that 662 projects valued at 40 billion Saudi Riyals were found to have suffered significant delays, which is a significant amount, with the material and technical capacity of the contractor being responsible for 82% of such delays, while regulatory obstacles were responsible for 12.2% of the delays.

Given the importance attached to key construction projects of the KSA government's Vision 2030 ambition and the 'Future Cities Program' [7], it is not helpful that many causes of delay are directly linked to the client, including poor communication, client interference, a delay in progress payment, slow decision-making by the client, changes to the scope of work, a shortage of funds from the client, and the bidding system [50]. These factors point to culpability on the part of the client. Although other causes were found, such as poor qualifications by skilled staff, inadequate capacity by the contractor, logistics and material delivery issues, poor design management, and low productivity, among a list of 56 factors in total [50], the prevalence of so many client-related factors is crucial to addressing delays in the Saudi context.

One study focusing on infrastructure [51] identified three groups of stakeholders that were found to be responsible for delays in Saudi public utility projects, including consultation officers, water and sewage project owners, and sewage contractors. The study found that financial difficulties (including cash flow) were the most important factor for delays, and these could be due to reasons such as delayed payments by client to contractor, inadequate planning by the contractor, and a government policy of awarding contracts to the lowest bidder, regardless of the capacity to deliver at the accepted bid price. This study found that contractors for many medium-to-large-scale projects requested additional time. For large construction projects in the Eastern Province of Saudi Arabia, Assaf and Al-Hejji [1] analyzed a group of stakeholders, which included 19 consultants, 15 owners, and 23 contractors, and deduced that change orders from the client were the only common cause of delay, while other main causes that were unique to each group of stakeholders included delayed progress payment and changing regulations (client), inadequate planning/scheduling (consultants and contractors) and poor and site management, a lack of necessary workforce, and construction accidents (contractors). From consultants' perspective, a survey of 51 construction projects in the Northern Province of Saudi Arabia revealed that delays were caused by changes to design specifications, awarding contracts to lowest bidders, unrealistic project durations, frequent deviations from the original design, inflation in the cost of materials, shortages of manpower, low productivity, and delays between the completion of design and the commencement of works [52]. A further review of the literature revealed many studies on the causes of construction delays in KSA, as summarized in Table 1. The research methods used by these studies were often questionnaire surveys, with an analysis carried out using statistical techniques such as the frequency index, importance index, and severity index, but there were similarities in the factors identified by these studies.

Table 1. The top factors contributing to client-related construction delays in KSA.

Client-Related Factors Contributing to Delay	Authors
Ineffective planning and scheduling of the project	[1,12,51,53–56]
Poor qualification, skills, and experience of the contractor's staff	[1,12,51,53–56]
Delay in progress payment by the client	[1,12,51,55,56]
Changes during construction by the client	[1,12,51,56]
Regulatory obstacles	[1,20,50]
Slowness in decision-making by the client	[1,12,55]
Poor communication and coordination between construction parties	[1,12,49,51,55]
Assigning contracts to the lowest bidder without regards to qualification	[1,12,20,49,51,56]

3. Materials and Methods

This study is based on case studies of construction projects executed under three KSA government agencies: The Ministry of Health (MOH), the Ministry of Education (MOE), and the Ministry of Municipal and Rural Affairs (MOMORA). The rationale for choosing these government agencies is their key role in the Saudi Vision 2030 and their accessibility to sufficient historical data. In particular, it was important to access historical construction project documents (drawings, minutes of meetings, contract documents, etc.) since these would provide a more objective source of data, as opposed to questionnaire or interview data, which could be subject to inaccuracies, forgetfulness, or some other form of bias. The use of such historical data from completed and properly documented projects would help one achieve the stated objective of this study (exploring the nature and impact of delays on contemporary construction projects), and a 10-year period (2007–2017) was used since more recent projects were either inaccessible or subject to on-going disputes. This approach is helpful since the use of documentary materials is regarded as an important source of information in terms of objectivity and critical analysis since it was generated outside of the research study's influence [57]. Additionally, the novelty and originality in such a study can be established through a validated assessment of publicly available documented evidence [58], and this reveals the point of departure between this study and similar studies done for KSA in particular. Archival data are regarded as valuable sources since they make the replicability and validation of research easier and more transparent than primary data [59], and even though the term 'archival' has historical implications, it can be applied to recent documents that are stored for record-keeping purposes [60].

The distinction between archival data and secondary data is important because although all historical records are essentially secondary data, archival research uses data that resulted from factual day-to-day occurrences (and are integral to the reality under investigation), whereas secondary data may be relevant but would have been collected for a different purpose [61]. In other words, archival research enables research questions that focus on past events to be answered and viewed through the lens of time, even though the nature and format of the archival records will dictate the extent/type of questions that are answerable. In this study, the archival data source from three Ministries is comprised of prequalification request documents, tender documents, contract documents (including designs), minutes of meetings, email messages, payment requests, requests for information (RFIs), change orders, and hand-over documents. Not all data were usable, and only projects that had the above kinds of documentation and for which access was granted to researchers were shortlisted. These are known constraints as it has been established that an archival research strategy can be disadvantaged by the unavailability of information, inaccessibility to information for security reasons, and the censoring of some information for confidentiality purposes [61]. The archival data used in this study was originally published by a co-author [62], with further refinement and analysis done subsequently.

Based on the objectives outlined earlier and the type of data that was available to work with, two key research questions (RQs) were identified: RQ1: which client-related delays are the most common in terms of frequency of occurrence and impact on cost overruns? and RQ2: what is the extent (magnitude) of the relationship (correlation) amongst the different projects characteristics as well as with the client-related causes of delay?

For studying delays, which often relate to cost overruns, the Project Management Institute [63] has recommended some mathematical models for quantifying variations in duration and cost for the whole project performance. The equations are used to compute different kinds of variations such as schedule performance index (SPI) (Equation (1)) and cost performance index (CPI) (Equation (2)).

$$\text{Schedule Performance Index} = \frac{\text{Contracted Duration}}{\text{Actual Duration}} \tag{1}$$

$$\text{Cost Performance Index} = \frac{\text{Contracted Cost}}{\text{Actual Cost}} \tag{2}$$

Finally, statistical analysis of the archival data was done using descriptive statistics and correlation analysis/tables. The correlation was necessary for ascertaining the relative associations and impacts that project variables have on cost and delays. In this regard, a point bi-serial correlation for measuring the strength of association between two variables was used with the SPSS package [39]. This technique enables a single measure of association (R-value) to be established using the ranges of −1 (perfectly negative correlation) to +1 (perfectly positive correlation), while 0 connotes no correlation. In between these extremes, there are intermediate scales, e.g., 0.8 is not perfect but strong positive correlation, while 0.3 is a mild or weak positive correlation. Correlation is not causation, but it provides an interdependency measure, e.g., for positive correlation, as X increases Y also increases [64].

4. Results

4.1. Overview of Case Study Organisations

The summary of the archival project documents obtained for the three case study organizations—the Ministry of Health (MOH), the Ministry of Education (MOE), and the Ministry of Municipal and Rural Affairs (MOMRA)—is provided in Tables 2–4 below [62]. In total, sufficient information was collected from 37 projects across these organizations: 12 MOH projects; 14 MOE projects; and 11 MOMRA projects. The collected data were cleaned and formatted to present uniformity and establish commonalities towards ease-of-generalization analysis. Project characteristics such as name, region, size, cost, start and end dates, additional cost, and additional time were captured. Further data extracted per project include the client-related causes of delay, the consequences of such delays in terms of additional time granted to contractors, and the cost implications of such delays. This approach to formatting the archival data would enable the examination of the delay factors, including statistical analysis and sorting, and the ranking of these factors.

Table 2. Historical project data from the Ministry of Health (MOH) [62].

S/N	Project Name	Region	Clinical Capacity (Beds)	Project Cost (SR)	Start Date	Contract Period (Months)	Finish Date	Additional Time (Months)	Additional Cost (SR)	Client-Related Causes of Delay **
1	Project#1	East Region	100	134,128,792	4 February 2012	36	1 January 2015	11	39,259,323.15	1, 2, 3
2	Project#2	Makkah	100	225,410,765	15 June 2012	24	25 May 2014	16	70,307,463.45	2,
3	Project#3	Hail	200	392,000,000	9 June 2012	36	1 May 2015	25	9,485,951.00	1, 3, 4
4	Project#4	Tabuk	200	390,000,000	18 June 2012	36	16 May 2015	17	69,264,402.54	1, 2, 3
5	Project#5	Medina	300	416,292,960	17 June 2012	24	26 May 2014	13	82,030,685.40	1, 2, 3, 6
6	Project#6	Riyadh	200	222,766,616	25 June 2012	36	23 May 2015	12	22,276,660.75	1, 3, 6, 7
7	Project#7	Riyadh	200	157,280,793	22 June 2012	24	31 May 2014	18	105,367,247.44	2, 3, 6, 7
8	Project 8	Jeddah	400	378,652,682	9 September 2012	36	7 August 2015	12	53,030,068.10	1, 2, 3, 7
9	Al Takhassusi Hospital	Jazan	500	719,028,164	10 September 2012	36	8 August 2015	14	119,068,840.37	2, 3, 6
10	Rmah General Hospital	Riyadh	50	35,000,000	12 August 2013	36	27 July 2016	6	5,203,993	3, 7
11	GP Kabshan	Dwadmi	GP	2,885,207	4 April 2015	24	15 April 2017	2	208,520	1, 3, 6
12	Halaban Hospital	Riyadh	50	28,500,000	27 July 2015	24	26 July 2017	2	2,757,000	3, 6

** 1 = Variations and errors in design; 2 = delay in progress payment; 3 = change order and delay in approving it; 4 = lack of finance to complete the work by client; 5 = soil condition issues; 6 = poor communication between the project parties; and 7 = ineffective planning and scheduling of project.

Table 3. Historical project data from the Ministry of Education (MOE) [62].

S/N	Project Name	Region	Description (Classes/Pupils)	Project Cost (SR)	Start Date	Contract Period (Months)	Finish Date	Additional Time (Months)	Additional Cost (SR)	Client-Related Causes of Delay **
1	Primary and Sec. School Almonasiah	Jeddah	2 * (20/600)	17,840,270	18 July 2009	24	26 June 2011	3	800,000	2, 3
2	Secondary school (12)	Riyadh	20/600	4,600,888	12 July 2007	20	21 February 2009	4	500,000	4, 5, 6
3	Secondary school (8)	Al Medina	20/600	4,244,442	23 November 2008	20	8 June 2009	3	450,000	1, 2, 3, 4
4	Alshifa School	Dammam	17/680	6,403,774	23 November 2008	20	5 July 2010	14	750,000	5, 6
5	Schools combined Alagrabi	Riyadh	3 * (17/680)	21,996,614	30 July 2009	24	8 July 2011	6	1,201,900	2, 3, 4
6	Secondary school in Twiaq	Riyadh	22/860	6,662,592	14 September 2009	22	26 June 2011	2	250,000	4, 5, 6
7	The Office of Edu. Supervision	Al-Qassim	Medium project	6,320,604	15 February 2009	20	27 September 2010	6	1,205,000	3, 5
8	Al gasser secondary school	Riyadh	22/860	8,445,246.00	29 September 2009	22	10 July 2011	6	745,525.60	6
9	Schools combined alkhadeer	Tabuk	3 *(18/540)	24,840,162	7 November 2009	24	16 October 2011	3	350,000	2, 3, 4

Table 3. *Cont.*

S/N	Project Name	Region	Description (Classes/Pupils)	Project Cost (SR)	Start Date	Contract Period (Months)	Finish Date	Additional Time (Months)	Additional Cost (SR)	Client-Related Causes of Delay **
10	King A Aziz combined boys school	Riyadh	Prim., Interm. and Sec.	22,316,052	21 March 2008	24	21 March 2010	6	2,135,500.20	5, 6
11	Khyber Schools combined	Khyber	Prim., Interm. and Sec.	22,226,629	22 December 2013	24	12 December 2015	13	2,225,600	1, 3
12	Alsahafah Schools combined	Riyadh	3*(18/540)	23,997,770	22 January 2010	24	10 December 2011	3	350,000	3, 6
13	Al-Artawiah combinded school	Al-Majmaah	Interm. and Secondary	13,838,347	25 October 2010	24	20 October 2012	7	1,225.834.7	3, 4
14	Expand Faculty (Dentistry, Female)	Riyadh	Medium project	64.947.000	21 January 2007	54	18 August 2014	15	54,947,000	3, 4

** 1 = Variations and errors in design; 2 = delay in progress payment; 3 = change order and delay in approving it; 4 = poor communication between the project parties; 5 = ineffective planning and scheduling of project; and 6 = delay in approving the amended bill of quantities. * = multiplication of building capacity.

Table 4. Historical project data from the Ministry of Municipal and Rural Affairs (MOMRA) [62].

S/N	Project Name	Region	Project Cost (SR)	Start Date	Contract Period (Months)	Finish Date	Additional Time (Months)	Additional Cost (SR)	Client-Related Causes of Delay **
1	Municipal anti-flood and storm water drainage	Riyadh	7.521.215	18 July 2009	22	26 June 2011	3	745,121.50	2, 3
2	Development of Pedestrian Passage (Second Stage).	Makkah	9,796,974.00	6 March 2016	12	1 February 2017	5	920,697	2, 3, 4
3	Asphalting, sidewalks and lighting for Taif and villages	Al Taif	91,955,970	30 October 2015	24	25 October 2017	6	9,200,597	1, 2, 3, 4, 6
4	Asphalting, pavements and lighting municipalities	Najran	87,659,325	17 February 2015	36	15 February 2018	16	7,765,935.50	4, 5, 6
5	Municipality of Najran	Najran	10,458,028.00	31 May 2016	24	22 May 2018	4	1,032.845.8	2, 3, 4
6	Municipality of Rass	Al-Qassim	6,662,592	14 September 2009	22	26 June 2011	2	655,259.20	2, 3
7	Al-Basra Park	Al-Qassim	9,468,634	30 December 2015	24	28 December 2017	3	930,763	2, 4, 5
8	Prince Sultan Cultural Center	Al-Qassim	25,000,000	27 January 2015	24	20 January 2017	6	1,500,000	1, 2, 3
9	Development project for Southern Al-Saif Corniche	Jeddah	70,207,305	1 October 2015	16	1 February 2017	5	6,920,730	2, 3, 4
10	Development of the Heritage Village	Al Baha	8,835,20	11 May 2014	12	21 May 2015	3	500,000	2, 4
11	Building a bridge on Wadi Adlam	Adlam	12,798,288	7 January 2015	16	10 June 2016	2	1,179,928	5, 6

** 1 = Variations and errors in design; 2 = delay in progress payment; 3 = change order and delay in approving it; 4 = poor communication between the project parties; 5 = ineffective planning and scheduling of project; and 6 = site problems, as well as delays in starting projects.

4.2. Analysis of Ministry of Health (MOH) Projects

The 12 MOH projects comprised of hospitals across different regions of KSA (Table 2) have an average capacity of 210 beds and were executed between the period of 2014 and 2017. A ranking of the client-related delays (Table 5) was based on the frequency of the occurrence of each delay factor from the archived documents, where 'change order and delays in approving it' was the top-ranking factor, followed by 'delayed progress payment'.

Table 5. A ranking of client-related causes of delay in MOH projects [62].

Rank	Client-Related Causes of Delay in MOH Projects	Frequency
1	Change order and delays in approving it	12
2	Delayed progress payment	7
3	Variations and errors in design	7
4	Poor communication between the project parties	6
5	Planning and scheduling of project	4
6	Finance to complete the work by client	1

Further analysis of these 12 MOH projects showed that, on average, the additional time added to these projects was 40% (Figure 1), with the average cost of delay being 20%

additional costs (Figure 2). The maximum delay was for a project for which the additional time was 75% of the original duration, and the causes of its delay were found to be a combination of many factors, including a delay in payment by client, change order and delays in approving it, ineffective scheduling and planning, and poor communication.

Project No	Contract period (months)	Additional time (months)	% Rise in Project Duration
1	36	11	31
2	24	16	67
3	36	25	69
4	36	17	47
5	24	13	54
6	36	12	33
7	24	18	75
8	36	12	33
9	36	14	39
10	36	6	17
11	24	2	8
12	24	2	8
AVG	**31**	**12**	**40**

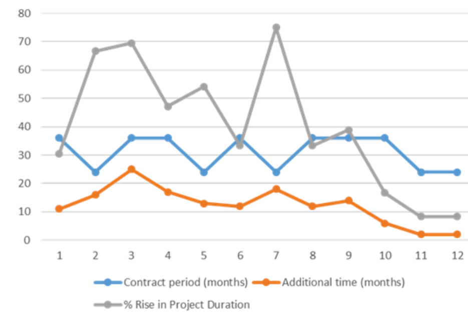

Figure 1. The increase in duration in the MOH projects.

Project No	Project cost	Additional cost	% Rise in the Cost
1	134,128,792	39,259,323.15	29
2	225,410,765	70,307,463.45	31
3	392,000,000	9,485,951.00	2
4	390,000,000	69,264,402.54	18
5	416,292,960	82,030,685.40	20
6	222,766,616	22,276,660.75	10
7	157,280,793	105,367,247.44	67
8	378,652,682	53,030,068.10	14
9	719,028,164	119,068,840.37	17
10	35,000,000	5,203,993	15
11	2,885,207	208,520	7
12	28,500,000	2,757,000	10
Average	**258,495,498**	**48,188,346**	**20**

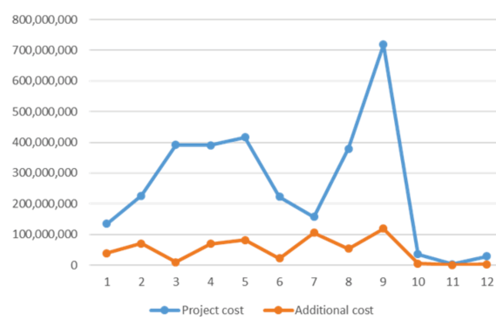

Figure 2. The increase in cost of the MOH Project.

Evidence of optimism bias could be deduced from Project #6 and Project #7, which both represent hospitals based in Riyadh City, with a similar capacity (200 beds) and started at around the same time (June 2012) yet that exhibit significant differences in contract duration (36 and 24 months, respectively). Project #6 had an initial cost of ~SR 222 million and required 12 months additional time at a cost of ~SR 22 million, while Project #7 had an initial cost of ~SR 157 million and required additional 18 months and additional cost of ~SR 105 million. With an additional 67% cost increase, Project #7 had a significantly higher additional cost than other projects, as even Project #6 only had a 10% increase in costs. Both projects experienced three similar delay factors (out of a total of four), with the differences being 'variations and error in design' (Project #6) and 'delay in progress payment' (Project #7). It is evident that both time and cost for Project #7 were either grossly underestimated or the multiple causes of delay (leading up to 18 additional months) had a knock-on effect and accrued towards the additional costs.

The magnitude of delays and additional costs for MOH projects can be shown to have a relationship as there appears to be a relationship between the percentage increase in project duration and the percentage increase in additional time (Figure 3). The similarity in trend is interesting because the combination of delay factors is not the same for each project. It can also be seen that Project #7 is indeed an outlier or relatively extreme in both time and cost increments. It is also evident that all projects experienced the delay factor 'change order and delay in approving it', and almost all projects experienced either 'variations and errors in design', 'delay in progress payment', or both (Table 2).

Project No	%Rise in Cost	%Rise in Duration
1	29	31
2	31	67
3	2	69
4	18	47
5	20	54
6	10	33
7	67	75
8	14	33
9	17	39
10	15	17
11	7	8
12	10	8
AVG	20	40

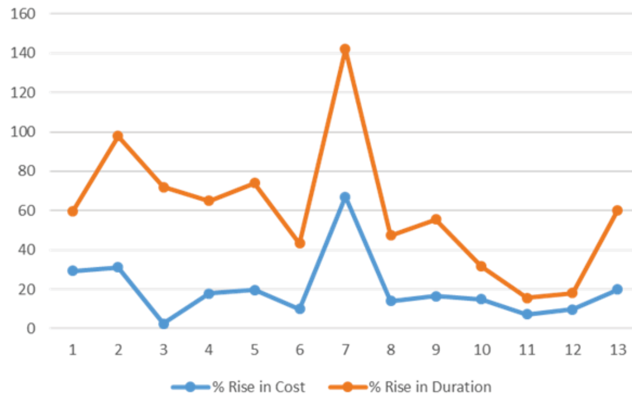

Figure 3. The relationship between the increase in duration and the increase in cost of the MOH Projects.

4.3. Analysis of Ministry of Education (MOE) Projects

For the 14 projects under MOE (Table 3), six kinds of client-related causes of delay were found (Table 6). Most of these delay factors were similar to those of the MOH projects in terms of type and ranked order, but a new cause delay (a delay in approving and amending the bill of quantity) was discovered and came in as the third most common cause of delay. This new cause of delay occurred in six of the 14 MOE projects.

Table 6. A ranking of the client-related causes of delay in MOE Projects [62].

Rank	Client-Related Causes of Delay in MOE Projects	Frequency
1	Change order and delay in approving it	9
2	Poor communication between the project parties	7
3	Delay in approving the amended bill of quantities	6
4	Ineffective planning and scheduling of project	5
5	Delay in progress payment	4
6	Variations and errors in design	2

The 14 MOE projects had an average additional time of 7 months, representing a 26% average increment in duration (Figure 4). Although it was not the biggest project in cost or size, Project #4 (a 17-classroom school for 680 pupils, costing ~SR 6.4 million with 20 months duration) was found to have required the largest additional time of 14 months, representing a 70% rise in project duration. This project was also unique in having only two causal factors for its delay: 'delay in approving the amended bill of quantities' and 'ineffective planning and scheduling of project'. The smallest increase in additional time was for Project #6, which had a project cost similar to Project #4 (22 classrooms for 860 pupils, costing ~SR 6.6 million and having a 22 duration of months) and had only a 9% increase in additional time (2 months). The causes of delay for this project were found to be 'ineffective planning and scheduling', 'poor communication', and 'delay in approving the amended bill of quantities'. Setting aside the possible differences in project factors, e.g., location, and the one-year difference in contract award dates, the significant contrast in these rather similar projects is a possible indication of optimism bias. The relatively smaller Project #4 had a 12% cost overrun compared to Project #6, which had only a 4% increase in cost.

Project No	contract period (months)	Additional time (months)	%Rise in Duration
1	24	3	13
2	20	4	20
3	20	3	15
4	20	14	70
5	24	6	25
6	22	2	9
7	20	6	30
8	22	6	27
9	24	3	13
10	24	6	25
11	24	13	54
12	24	3	13
13	24	7	29
14	54	15	28
AVG	25	7	26

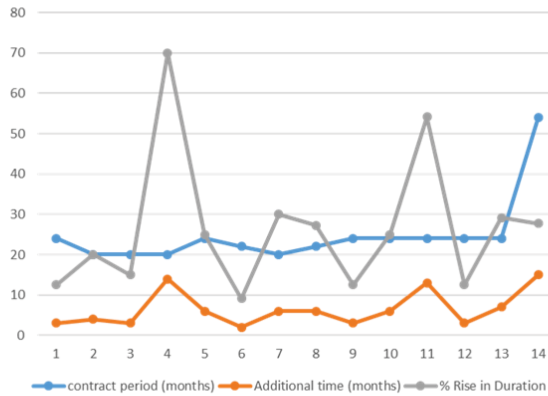

Figure 4. The increase in duration of the MOE projects.

Overall, the MOE projects were on average found to have a 14% increase in cost, (Figure 5) with the largest cost overrun occurring in Project #14 (85%), in which 'change order and delay in approving it' and 'poor communication between the project parties' were the causes of delay. It was noted, however, that this project (expanding the Faculty of Dentistry) was more sophisticated than the majority (secondary schools).

Project No	%Rise in Duration	%Rise in Cost
1	13	4
2	20	11
3	15	11
4	70	12
5	25	5
6	9	4
7	30	19
8	27	9
9	13	1
10	25	10
11	54	10
12	13	1
13	29	9
14	28	85
AVG	26	14

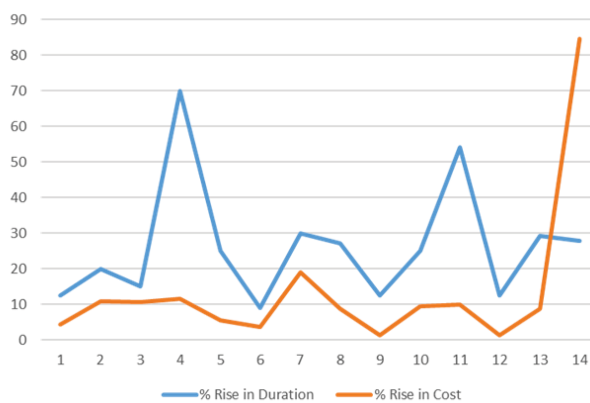

Figure 5. The increase in cost in the MOE projects.

There was more similarity in the pattern of percentage increments in additional time and cost (Figure 5) than in the patterns of project cost and additional cost (Figure 6), and the latter could be due to the significant variation in scope and cost of projects. Nevertheless, percentage-wise, the rise in duration correlates with an increase in cost (Figure 5), demonstrating a trend similar to what was observed previously with MOH projects. 'change order and delay in approving it' occurred in majority of projects, while 'poor communication' was a recurring theme in half of these projects.

Project No	project cost (SR)	Additional cost (SR)	% Rise in Cost
1	17,840,270	800,000	4
2	4,600,888	500,000	11
3	4,244,442	450,000	11
4	6,403,774	750,000	12
5	21,996,614	1,201,900	5
6	6,662,592	250,000	4
7	6,320,604	1,205,000	19
8	8,445,246.45	745,525.60	9
9	24,840,162	350,000	1
10	22,316,052	2,135,500.20	10
11	22,226,629	2,225,600	10
12	23,997,770	350,000	1
13	13,838,347	1,225,834.70	9
14	64,947,000	54,947,000	85
AVG	17,762,885	4,795,454	14

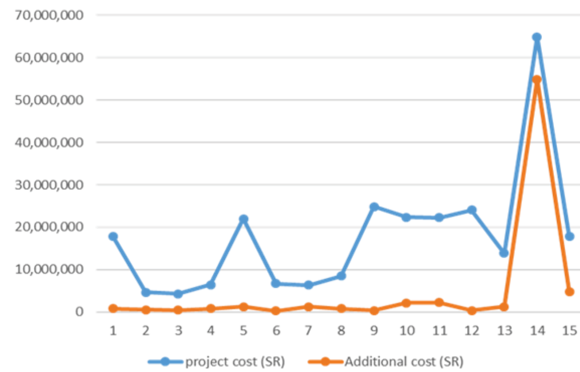

Figure 6. The relationship between an increase in duration and an increase in the cost in Saudi Riyals (SR) for MOE projects.

4.4. Document Analysis for Ministry of Municipal and Rural Affairs (MOMRA)

The 11 projects analyzed for MOMRA (Table 4) are more varied in type and cost, ranging from drainage works to pavements and parks and completed between 2011 and 2018. Only five kinds of client-related delay factors were found, with the highest-ranking factor being 'change order and delay in approving it' occurring in nine projects. Two other causes—'ineffective planning and scheduling of the project' and 'poor communication between the project parties'—occurred in seven projects (Table 7). A new delay factor appears in the MOMRA projects in the form of 'site problems as well as delays in starting projects'.

Table 7. A ranking of client-related causes of delay in MOMRA projects [62].

Rank	Client-Related Causes of Delay in MOMRA Projects	Frequency
1	Change order and delay in approving it;	9
2	Poor communication between the project parties	7
3	Ineffective planning and scheduling of project	7
4	Site problems, as well as delays in starting projects	3
5	Delay in progress payment	2

For the MOMRA projects, it was found that client-related causes of delay led to an average of 23% (5 months) of time added to projects (Figure 7). Similar to what was observed in MOH and MOE, the analysis showed a significant underestimation of project duration. The project with the largest percentage increase in duration (44%) happened to be the costliest (Project #4), requiring 16 additional months. The prime delay factors for this project were 'site problems', 'delays in starting projects', and 'ineffective planning and scheduling of project'. Overall, a pattern could also be deduced between the contract duration and additional time (Figure 7).

The average cost overrun for the 11 MOMRA projects is 14%, which is within the range found for MOH and MOE. However, the maximum cost overrun of 57% which occurred in Project #10 (Heritage Village), was due to two delay factors only: 'variations and errors in design' and 'delay in progress payment'. Proportionately, the lowest cost overrun was for Project #8, for which saw only a 6% increase (Figure 8).

Project No	contract period (months)	Additional time (months)	% Rise in Duration
1	22	3	14
2	12	5	42
3	24	6	25
4	36	16	44
5	24	4	17
6	22	2	9
7	24	3	13
8	24	6	25
9	16	5	31
10	12	3	25
11	16	2	13
AVG	**21**	**5**	**23**

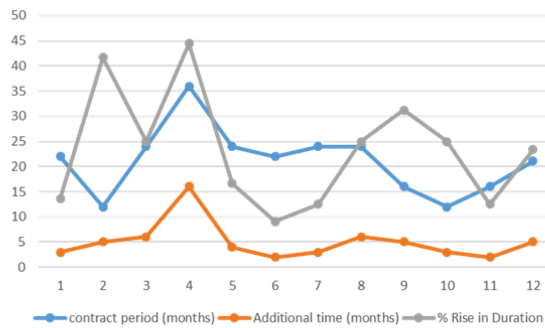

Figure 7. The increase in duration in the MOMRA projects.

Project No	project cost (SR)	Additional cost (SR)	% Rise in the Cost
1	7,521,215	745,121.50	10
2	9,796,974.00	920,697	9
3	91,955,970	9,200,597	10
4	87,659,325	7,765,935.50	9
5	10,458,028.00	1,032,845	10
6	6,662,592	655,259.20	10
7	9,468,634	930,763	10
8	25,000,000	1,500,000	6
9	70,207,305	6,920,730	10
10	883,520	500,000	57
11	12,798,288	1,179,928	9
AVG	**30,219,259**	**2,850,171**	**14**

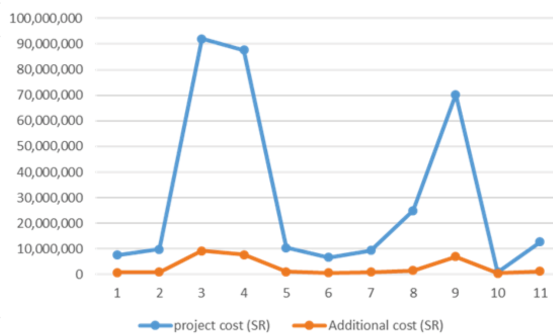

Figure 8. The increase in the cost in Saudi Riyals (SR) for MOMRA projects.

Unlike MOH and MOE, the pattern of increments in additional time and additional costs seemed irregular (Figure 9). This could be linked to the many varieties of projects executed under this Ministry (Table 4). Additionally, some projects experienced significant delays, but the associated cost overruns were low.

Project No	% Rise in Duration	% Rise in the Cost
1	14	10
2	42	9
3	25	10
4	44	9
5	17	10
6	9	10
7	13	10
8	25	6
9	31	10
10	25	57
11	13	9
AVG	**23**	**14**

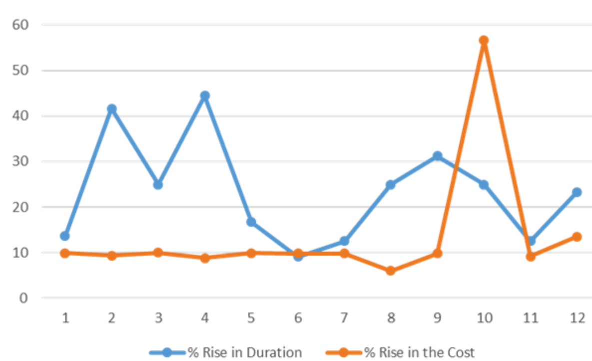

Figure 9. The link between the increase in duration and the increase in cost (the MOMRA projects).

4.5. Combined Analysis from All Projects in Three Minsitries

When data from all 37 projects across three ministries (MOH, MOE, and MOMRA) are merged, the analysis showed a combined total of eight client-related delay factors with 'change order and delay in approving it' being outrightly the most frequent cause of delay occurring in 30 out of 37 projects, representing 81% of total occurrences (Table 8). The second place for the most frequent cause of delay is shared among three factors, each of which occurred in 20 projects (54%), and one of these factors is most directly associated with optimism bias, i.e., 'ineffective planning and scheduling of project'. The least common delay factor 'finance to complete the work by the client' occurred only once. These results provide a unique understanding of the most important client-related causes of delay. Additionally, the frequency-derived rankings provide an objective insight into the likelihood of occurrence for each client-related delay factor.

Table 8. The ranking of client-related causes of delay for 37 case study projects [62].

Rank	Client-Related Causes of Delay in All Projects	Frequency	Proportion
1	Change order and delay in approving it	30	81%
2	Poor communication between the project parties	20	54%
3	Ineffective planning and scheduling of project	20	54%
4	Delay in progress payment	20	54%
5	Variations and errors in design	11	30%
6	Delay in approving the amended bill of quantities	6	16%
7	Site problems as well as delays in starting projects	3	8%
8	Finance to complete the work by the client	1	3%

It has been implied in the literature that there would be interdependencies, synergy, or 'domino effect' between these delay factors when, for example, inadequate planning/scheduling by the consultants or contractor leads to poor communication among stakeholders and results in delays in progress payments. The same could be said for some variations and errors in design. Further statistical analysis carried out (as presented by correlation matrix in subsequent section) provides further insights into these synergies and the weight of each delay factor relative to others.

The schedule performance index (SPI), which deals with delays, and the cost performance index (CPI), which deals with cost overruns for the combined projects, were computed for all projects. For both SPI (Table 9) and CPI (Table 10), the ideal values should not approach 1.0, meaning that the SPI/CPI value of 0.2 is preferrable to the SPI/CPI value of 0.8. For all projects, the average SPI showed negative scheduling performance, with SPI values of 0.71 (MOH), 0.8 (MOE), and 0.82 (MOMRA). The best SPI values were found to be 0.57 (MOH), 0.59 (MOE), and 0.69 (MOMRA), which themselves are on the high side. Similarly, the average CPI of all projects was also negative, with values of 0.8, 0.92, and 0.89 for MOH, MOE, and MOMRA, respectively. The best CPI for MOH was 0.6, while for MOE and MOMRA, their best CPIs were 0.84 and 0.64, respectively, again revealing the relatively poor CPIs for all projects.

The combination of escalated/additional project duration and the high SPI values across all projects is an indication that scheduling and planning have been ineffective, reflecting a tendency to underestimate the duration of projects (optimism bias) across all ministries.

Table 9. A comparison of SPI for the MOH, MOE, and MOMRA projects [62].

S/N	MOH					MOE					MOMRA				
	Contract Period (Months)	Additional Time (Months)	Actual Duration	% Rise in Project Duration	SPI	Contract Period (Months)	Additional Time (Months)	Actual Duration	% Rise in Duration	SPI	Contract Period (Months)	Additional Time (Months)	Actual Duration	% Rise in Duration	SPI *
1	36	11	47	31	0.77	24	3	27	13	0.89	22	3	25	14	0.88
2	24	16	40	67	0.60	20	4	24	20	0.83	12	5	17	42	0.71
3	36	25	61	69	0.59	20	3	23	15	0.87	24	6	30	25	0.80
4	36	17	53	47	0.68	20	14	34	70	0.59	36	16	52	44	0.69
5	24	13	37	54	0.65	24	6	30	25	0.80	24	4	28	17	0.86
6	36	12	48	33	0.75	22	2	24	9	0.92	22	2	24	9	0.92
7	24	18	42	75	0.57	20	6	26	30	0.77	24	3	27	13	0.89
8	36	12	48	33	0.75	22	6	28	27	0.79	24	6	30	25	0.80
9	36	14	50	39	0.72	24	3	27	13	0.89	16	5	21	31	0.76
10	36	6	42	17	0.86	24	6	30	25	0.80	12	3	15	25	0.80
11	24	2	26	8	0.92	24	13	37	54	0.65	16	2	18	13	0.89
Avg.	32	13	45	43	**0.71**	22	6	28	27	**0.80**	21	5	26	23	**0.82**

* SPI: schedule performance index.

Table 10. A comparison of CPI for the MOH, MOE, and MOMRA projects [62].

	MOH					MOE					MOMRA				
	Project Cost (SR)	Additional Cost (SR)	Actual Cost of Project (SR)	% Rise in the Cost	CPI	Project Cost (SR)	Additional Cost (SR)	Actual Cost of Project (SR)	% Rise in Cost	CPI	Project Cost (SR)	Additional Cost (SR)	Actual Cost of Project (SR)	% Rise in the Cost	CPI *
1	134,128,792	39,259,323	173,388,115	29	0.77	17,840,270	800,000	18,640,270	4	0.96	7,521,215	745,121	8,266,337	10	0.91
2	225,410,765	70,307,463	295,718,228	31	0.76	4,600,888	500,000	5,100,888	11	0.90	9,796,974	920,697	10,717,671	9	0.91
3	392,000,000	9,485,951	401,485,951	2	0.98	4,244,442	450,000	4,694,442	11	0.90	91,955,970	9,200,597	101,156,567	10	0.91
4	390,000,000	69,264,402	459,264,402	18	0.85	6,403,774	750,000	7,153,774	12	0.90	87,659,325	7,765,935	95,425,261	9	0.92
5	416,292,960	82,030,685	498,323,645	20	0.84	21,996,614	1,201,900	23,198,514	5	0.95	10,458,028	1,032,845	11,490,873	10	0.91
6	222,766,616	22,276,660	245,043,276	10	0.91	6,662,592	250,000	6,912,592	4	0.96	6,662,592	655,259	7,317,851	10	0.91
7	157,280,793	105,367,247	262,648,040	67	0.60	6,320,604	1,205,000	7,525,604	19	0.84	9,468,634	930,763	10,399,397	10	0.91
8	378,652,682	53,030,068	431,682,750	14	0.88	8,445,246	745,525	9,190,772	9	0.92	25,000,000	1,500,000	26,500,000	6	0.94
9	719,028,164	119,068,840	838,097,004	17	0.86	24,840,162	350,000	25,190,162	1	0.99	70,207,305	6,920,730	77,128,035	10	0.91
10	35,000,000	5,203,993	40,203,993	15	0.87	22,316,052	2,135,500	24,451,552	10	0.91	883,520	500,000	1,383,520	57	0.64
11	2,885,207	208,520	3,093,727	7	0.93	22,226,629	2,225,600	24,452,229	10	0.91	12,798,288	1,179,928	13,978,216	9	0.92
Avg.	279,404,180	52,318,469	331,722,648	21	**0.84**	13,263,388	964,866	156,510,799	9	**0.92**	30,219,259	2,850,171	33,069,430	14	**0.89**

* CPI = cost performance index.

4.6. Statistical Analysis for Combined Projects (MOE, MOH, and MOMRA)

Further statistical analysis was carried out to investigate the relationships that project variables such as project cost, contract period, and additional time and cost have with client-related causes of delay. The statistical questions of interest include: do the different projects characteristics have a significant relationship with the project delay causes? how strong is the association between the client-related causes of construction project delays and (a) the size of a construction project and (b) the contract period? The results are provided below.

To assess the relationship that project variables (project cost, contract period, as well as additional time and additional cost) have among themselves and with client-related causes of delay, a correlation analysis was carried out using the point bi-serial technique of association (Table 11). Four project characteristics (project cost, contract period, additional time, and additional cost) were of interest in terms of how they correlate with each other. Based on the point-biserial correlation coefficient (*rpb*, where $p > 0.05$) analysis carried out, it was found that project cost correlated very strongly with additional time (*rpb* = 0.662) and additional cost (*rpb* = 0.805), indicating that as a project becomes costly, the likelihood of additional time and additional cost being required is high. Project cost correlated moderately with contract period (*rpb* = 0.481), meaning that the cost of a project is only moderately linked to its contract period. As expected, additional time correlated strongly with additional cost (*rpb* = 0.632). These findings as summarized in Table 11, and while the associations are not surprising, the strengths/magnitude of the correlations present interesting insights since the 37 projects are of different sizes and types.

Table 11. A correlation summary matrix for selected causes of delay (N = 37).

		1	2	3	4	5	6	7	8	9	10	11	12
1	**Project cost**	-											
2	**Contract period**	**0.481 ***	-										
3	**Additional time**	**0.662 ***	**0.589 ***	-									
4	**Additional cost**	**0.805 ***	**0.451 ***	**0.632 ***	-								
5	Variations/Error in design	**0.420 ***	0.317	**0.396 ***	0.225	-							
6	Delay in progress of payment	**0.464 ***	0.155	0.241	**0.558 ***	0.243	-						
7	Change order and delay	0.236	0.168	0.067	0.248	0.274	**0.356 ***	-					
8	Lack of client finance	0.305	0.212	**0.490 ***	−0.046	0.294	−0.123	0.081	-				
9	Poor communication	−0.028	−0.09	−0.252	0.078	−0.109	0.111	0.247	−0.181	-			
10	Ineffective plan/schedule	−0.161	−0.167	−0.048	−0.128	−0.241	−0.3	−0.275	−0.145	−0.071	-		
11	Delay in approval of BoQ	−0.24	−0.199	−0.16	−0.242	−0.249	−0.324	**−0.724 ***	−0.073	−0.183	0.208	-	
12	Site problems/ delayed start	−0.117	−0.013	−0.048	−0.14	−0.168	−0.219	**−0.362 ***	−0.05	−0.322	0.14	−0.131	-

* $p < 0.05$.

Concerning how the project characteristics correlate with client-related causes of delay, the results revealed some insights. The first project characteristic (**project cost**) was found to have a significant positive correlation with two client-related causes of delay: (i) 'variations and error in design' (*rpb* = 0.420) and (ii) 'delay in progress of payment' (*rpb* = 0.464). The strength/magnitude of the relationship between the initial project cost and these two causes of delay is moderate. Therefore, it can be deduced that both causes of delay (variations and error in design, and delay in progress of payment) would moderately contribute to a delay in projects with higher initial project costs. The study did not establish any other significant relationship causes ($p > 0.05$) between the initial project cost and the rest of the client-related causes of delay.

The second project characteristic (**contract period**) did not have any significant correlation with client-related causes of delay, except 'lack of finance by client' had a weak positive correlation (*rpb* = 0.212). The third project characteristic (**additional time**) had a statistically significant positive relationship with two client-related delay causes: 'variations and error in design' (*rpb* = 0.396) and 'lack of finance to complete the work' (*rpb* = 0.490). The strength/magnitude of the relationship between additional time and these two causes of delay was a moderate relationship. These results suggest that variations/error in design as well as insufficient funds to complete a project by the client are significant causes of delay that have a moderate likelihood of leading to additional time in construction projects. It can also be concluded that construction projects with higher additional time tend to be delayed due to variations/error in design as well as a lack of adequate finance by the client to finish the work. The study did not establish any other significant relationship ($p > 0.05$) between additional time and the rest of the project delay causes.

The fourth project characteristic (**additional cost**) had a statistically significant moderate positive relationship with 'only one client-related cause of delay: 'delay in project payment' (*rpb* = 0.558). In other words, when there is a delay in making payment on a project, there is a moderate likelihood that it will result in an additional cost to the project. Other causes of delay did not have a significant relationship ($p > 0.05$) with additional cost in construction projects.

To better appreciate the consequences of these correlations, the ranking of the client-related causes of delay, which was based on the frequency of their occurrence (Table 8), was designated as 'likelihood' such that each cause of delay was presented in a red-yellow scale heatmap (Figure 10). Subsequently, another heatmap on a blue-green scale was used to depict the correlations between each of the four project characteristics and the causes of delay, as well as the strength of the correlation between the delay factors themselves (Figure 10). This combined heatmap matrix is insightful because it shows that for each client-related cause of delay, there is a likelihood of occurrence and a consequence (correlation) with project characteristics.

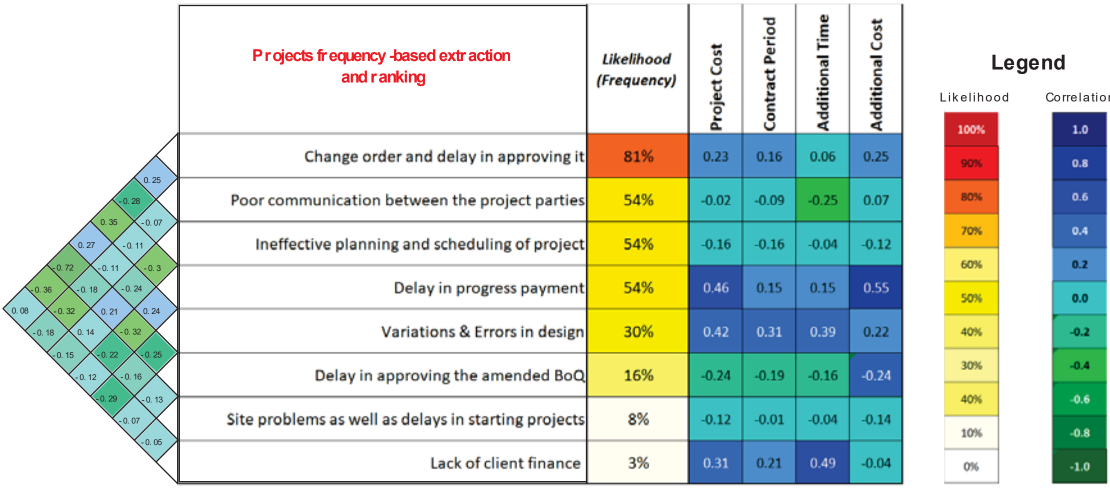

Figure 10. The heatmap matrix for the frequency (likelihood) of delay factors and their correlation (magnitude of impact) with the project characteristics.

5. Discussion

Delays are common in construction projects, with many not being completed on the specified contractual date [1]. With 70% of public sector construction projects suffering delays [1], the issue has for long been of significant interest in KSA, which, according to an extensive three-decade review, ranked the country as 5th in the top 10 countries in terms of research outputs for construction delay, with a premier institution (KFUPM) being the global number 1 for outputs in this area [15]. For the KSA government, construction delays can affect the ability to deliver the Saudi Vision 2030. As found in the literature, the consequences of such delays are many, including higher capital expenditure, financial losses for the investment, and a delay in handover/utilization by end users [25–27]. It is in the KSA government's interest (as client) that it endeavors to reduce/eliminate delays, especially the ones for which it is responsible (client-related), e.g., regulatory obstacles that account for 12.2% of construction project delays in KSA [50]. Therefore, in this study eight commonly recognized client-related delay factors were explored using historical data. These delays were ranked in order of frequency to reveal their likelihood of occurrence in different project types based on the archival analysis of past projects from three ministries (MOH, MOE, and MOMRA) where, across 37 construction projects, the most common (#1) delay factor was 'Change order and delay in approving it'. This was followed by 'poor communication between the project parties' (#2); 'ineffective planning and scheduling of project' (#3); 'delay in progress payment' (#4); and 'delay in the decision-making process' (#5). Each of these causes of delay will have different kinds of associated impacts on key project characteristics. Furthermore, the synergy or correlation between these delay factors was re-affirmed by a previous study [62] that Change order could occur as a result of insufficient planning and scheduling in the early stages.

For the 37 case study projects, a significant positive correlation that was established between project cost and two causes of delay, including variations and error in design, which has been identified previously as being critical [31,32], and delay in progress payment [1,51], indicating a general level of agreement between the study and literature. A statistically significant positive relationship was also found between additional time and variations and error in design. This kind of association has not been previously explored in the literature. In quantifying the magnitude of delays, using duration variance, the schedule performance index (SPI) metric showed an average 43% increase in duration for the MOH hospital projects, with an SPI value of 0.71. The SPI value for the MOE and MOMRA projects was found to be 0.80 and 0.82, with an average increase in project duration being 27% and 23%, respectively. There were no precedence studies in literature to compare these values with, but they provide a reasonable insight into the magnitude of delays. These delays have a cost consequence, as suggested by the cost performance index (CPI), calculated as 0.84 (MOH), 0.92 (MOE) and 0.89 (MOMRA).

The hospital projects under MOH were responsible for the highest number of the top-ranked delay factor, i.e., the change order and the delay in approving it. These projects also had the highest average additional time (40%) and the highest average additional cost (20%). This makes MOH projects much riskier in terms of timely delivery and cost overruns that could be attributed to the late (and plentiful) design changes, which a previous study [43] has attributed to fast evolving and better healthcare technologies becoming available towards the end of such projects. From MOMRA data, a unique delay factor, i.e., 'site problems as well as delays in starting projects' appeared in three infrastructure projects: asphalting, sidewalks, and lighting for Taif and villages, in Al Taif; asphalting, pavements, and lighting municipalities, in Najran; and construction of a bridge in Wadi Adlam, in the Adlam area. This agrees with a study [4] that showed 'late site handover' and 'delays in approval/permits' as delay factors that result in financial compensation for contractors, usually after a claims process that itself leads to delays [3].

There are no peculiar delay causes associated with specific project types, but in terms of impact we produced a likelihood-magnitude matrix that showed: "change order and delay in approving it" (81% frequency); 'delay in progress payment (54% frequency)'; ' variations and errors in design' (30% frequency); and 'lack of finance by client' (3% frequency) as the key delay factors that have a statistically significant positive correlation with project characteristics. The only statistically significant negative correlation was found between 'poor communication between the project parties' and 'additional time' ($rpb = -0.24$).

Previous studies have shown the interdependence of delay factors, but such interdependence has not been well understood or managed, leading to efforts to automate and predict the inter-relationships using ML [34]. The findings from this study not only support the existence of such interdependencies, but the strength of associations was also estimated using a correlation matrix (Table 11). Additionally, based on the frequency of each client-related delay factor, a matrix was produced that achieves three purposes. First, it uses a red-yellow heatmap to illustrate the frequency (likelihood) of occurrence of all the eight delay factors. Second, the matrix shows the strength of correlation amongst the eight delay factors of concern. Third, the delay factors were correlated in terms of magnitude of impact on the four key project characteristics (Figure 10).

The presence of optimism bias [35,37] was best exemplified by two MOH hospitals (Project #6 and Project #7), which were very similar in terms of capacity, location, and start time and were also affected by similar kinds of delay factors. There were vast differences in the contract duration and initial costs, and most importantly in the additional time required for each. Without any evidence that either of these projects was more sophisticated or needed more expensive last-minute changes in scope/requirements (e.g., due to emerging healthcare technologies [43]), it could be argued that Project #6 could have been over-budgeted and under-scheduled, relative to Project #6.

6. Conclusions

Given the costly and widespread cases of construction project delays in KSA, the aim of this study was to explore client-related construction project delay factors in terms of their singular and synergistic impacts. The motivation and expected benefit is to help the government (as public sector client) to achieve its Vision 2030 goals. Using archival data from 37 public sector construction projects drawn from three government ministries, i.e., the Ministry of Health (MOH), the Ministry of Education (MOE), and the Ministry of Municipal and Rural Affairs (MOMRA) and completed within a 10-year window (2007–2017), eight client-related delay factors were commonly identified among the case study projects drawn from three different ministries. Four project characteristics (project cost, project duration, additional cost, and additional time) were used as benchmark for assessing the magnitude of each delay factor.

The archival analysis revealed that the most critical client-related delay factor occurring in almost every project with 81% frequency is 'change order'. The next most common causes of delay that occurred in 20 out of 37 projects (54%) are ineffective planning and scheduling of a project; poor communication between the project parties; and delay in progress payment. Optimism bias was found to be prevalent in projects that suffered from 'ineffective planning and scheduling of project'. Other causes include variations and errors in design (30%); delay in approving the amended bill of quantities (16%); site problems as well as delays in starting projects (8%); and lack of finance by a client to complete the work (3%). These frequency-derived rankings provide an objective insight into the likelihood of occurrence for each client-related delay factor. These four factors, namely, 'change order and delay in approving it'; 'delay in progress payment; ' variations and errors in design'; and 'lack of finance by client', were shown to have a statistically significant positive correlation with the four essential project characteristics.

These delay factors do not always act in isolation because there is synergy and knock-on effect amongst them. For instance, studies and results show that inadequate planning or scheduling is linked to issuing of change orders and can translate into payment for executed items of work made by the client. Additionally, poor communication aggravates the insufficiency of planning and scheduling, while change orders can also lead to payments by the clients being delayed. It was found that insufficient planning led to conflicts in relationships, resulting in time overruns. Such delays would then manifest in the form of financial problems for the contractor and cost overruns for the client. The calculated schedule performance index (SPI) and cost performance index (CPI) computed for all projects showed very poor time and cost performance overall, with average SPI values of 0.71 (MOH), 0.8 (MOE), and 0.82 (MOMRA) and average CPI values of 0.8, 0.92, and 0.89 for the same ministries.

In conclusion, the KSA government is embarking on an ambitious modernization via the 'Saudi Vision 2030' and 'Future Cities Program' with the aim of making the country one of the most developed by 2030 (in less than 10 years). For this ambition to be achieved, many crucial and capital-intensive buildings/infrastructures have to be put in place as quickly as possible. Delaying such projects could derail the Vision 2030 target because in spite of the government reliance on international joint ventures (IJVs) to achieve this vision, the client-related delays investigated here are not solvable simply by bringing in foreign expertise. As a result of this study's findings and with the backing of an extensive literature review, the following recommendations are made:

1. The government should prioritize the management of delay factors based on the prioritization (likelihood of occurrence) drawn from their rankings carried out in this study. Where socio-cultural or socio-economic realities differ from those of KSA, the approach used in this study can be replicated to achieve a context-based ranking to aid decision-making.
2. With the correlational impact of delay factors having been measured statistically, public sector clients now have a better understanding of how each delay factor affects the essential project characteristics linked to cost and time.
3. The top five delay factors found in 37 projects of this study with frequency of occurrence ranging from 30 to 81% can be addressed wholly or partially (as suggested by literature) by adopting BIM processes, which would enhance collaboration, transparency, improve design quality, and improve communication among stakeholders. While this study was not aimed at BIM, the evidence of its potential can be observed in how it can help address these top five delay factors.
4. The KSA government should use the IJV partnerships created for the actualization of Vision 2030 (such as those for NEOM city) as an opportunity to establish benchmarks for timely construction project delivery for adoption across the whole industry and as a future reference.

5. Further research should be supported for investigating those delay factors caused by contractors and consultants to obtain a more holistic picture. Research based on historical/archival quantitative data is encouraged as a lot of previous studies have relied on primary (experiential and opinion based) data, with little impact in terms of losses attributed to delays. In this regard, the KSA government should encourage the unhindered and uncensored access to archival data for the benefit of researchers.
6. The heatmap matrix of delay factors that measures the likelihood of occurrence for each delay factor and maps it to project variables can be further developed into a 'delay risk impact tool'.
7. A longitudinal study that tracks completed construction projects and their delays would be helpful so that the eight client-related delay factors can be monitored in terms of their reduction frequency and impact. This can be achieved by supporting researchers with immediate access to completed projects' data.

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Privatization in Rural Water Supply and Customer Satisfaction: An Empirical Case Study in Vietnam

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Abstract: This article investigates the private sector participation in investment, management, and operation in rural water supply schemes in Vietnam. Different organizations manage rural water supply facilities, including the private sector, public sector, and others. This paper aims to compare the different characteristics affecting user satisfaction of water supply facilities managed by the private sector and the remaining sectors. An ordered logit model was utilized for calculation with the data collected from semi-structure questionnaires with 1200 households using water from rural water supply systems managed by different sectors in Vietnam. The results indicate that the water-user satisfaction with rural water supply projects managed by the private sector is higher than that in other sectors (community, cooperative, commune people's committee), whereas there is no significant difference in customer satisfaction between systems managed by the public sector and the private sector (enterprise, private management). The water availability and quality of schemes greatly influence the customer satisfaction. Findings from this study provide considerable information for the private sector on how to improve the management and operation of water supply systems efficiently through customer satisfaction assessment.

Keywords: customer satisfaction; privatization; private sector participation; rural water supply; water user

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1. Introduction

The private sector plays a vital role in the investment, management, and operation of water supply schemes in many countries [1,2]. The private sector participation helps to mitigate the capital constraint for infrastructure development while improving the sustainability of exploiting water supply systems [3–5]. The private sector participation (PSP) brings many benefits such as the balance of socio-economic development, effective risk sharing, cost savings, efficient project implementation, technological innovation, and generate more investments in water supply infrastructure [6–8]. In addition, the private sector participates in the management and operation of water supply projects to improve operational efficiency and labor productivity [9–12], save costs and reduce water loss rate [11,13]. The involvement of public–private partnership (PPP) provides good water quality, expanded water supply networks, and higher levels of water-user satisfaction than before the implementation of policies involving PPP [14]. PSP is an effective approach to solve the challenges of water supply in rural areas and small towns [15,16]. Shifting rural water supply works from the public sector to the private sector is increasingly common due to the rapid population growth in small towns and rural commercial centers. This trend is becoming increasingly popular in Africa, especially in French-speaking countries such as Benin, Burkina Faso, Mali, Nigeria, Rwanda and Senegal [7,15], and in European countries Greece, Austria and Spain [7]. A similar pattern can also be seen in many European countries as they are expanding PSP by developing a comprehensive policy framework and consider

PSP as the primary tool to address issues related to infrastructure [17]. For instance, the proportion of PSP in investment, management, and operation of water supply systems in France has increased from 17% to 80% during the period of 1939–2001 [18]. Privatization of rural water supply is one of the essential decisions of the government to provide water supply services in rural areas, especially small towns. Preliminary evidence indicated an improvement in private sector-managed facilities' financial and operational indicators [19]. However, PSP also has some clear disadvantages, such as loss of control for state management agencies over water supply systems and higher price for consumers [20,21]. In some cases, the PSP did not bring significant improvements in efficiency [22] and did not offer significant improvements in the indicators of performance or customer satisfaction [23–26]. These contradictory claims warrant further investigation into the issue of PSP in water supply management.

Before the year 1999, most people used low-cost and straightforward water supply systems such as rainwater, water tanks, and wells in Vietnam. Since 2000, the Government of Vietnam has implemented a national strategy on rural water supply and environmental sanitation under Decision No. 104/2000/QD-TTg. Rural water and sanitation program was implemented in three phases between the years 2000–2005, 2006–2010, and 2011–2015. After 2016, the rural water supply and sanitation program has been integrated into the national target program to build new rural areas. After two decades, around 16,573 centralized water supply schemes have been built to supply water to 88.5% of the population and plays an important role in enhancing living conditions in rural areas [27]. In Vietnam, there are five different management models of water supply works, including (1) community, (2) cooperative, (3) enterprise, private; (4) commune people's committee, (5) provincial centre for rural water supply and environmental sanitation. In these five types, it can be divided into three management sectors, including (1) private sector (enterprise, private management); (2) public sector (provincial centre for rural water supply and Environmental Sanitation); (3) other sectors (community, cooperative, commune people's committee) [28].

In implementing the national target program on water and sanitation, the Government of Vietnam has issued several policies to attract the private sector participation such as decision no. 131/2009/QD-TT dated November 2, 2009, namely "several key preferential policies, encouraging investment, management, and exploitation of rural water supply work." Rural water supply projects with the private sector participation are entitled to preferential policies on land, tax, or support for initial investment costs. Many provinces of Vietnam have implemented incentive policies, provinces that have decided to implement preferential policies, the rate of "sustainable" operating works is 1.13 times higher than provinces without decided to implement preferential policies [29]. In addition, the government also issued Decree No. 57/2018/ND-CP in 2018 "mechanisms and policies to encourage enterprises to invest in agriculture and rural areas," which supports 3 million VND/m^3/day with capacity for new construction or 2 million VND/m^3/day incapacity for upgrading and renovating water supply factory and supporting up to 50% of water pipes line costs. The private sector is significantly involved in the management of the rural water supply, especially in Red River Delta, Southeast and Mekong River Delta and constitutes a share of 66.8%; 29.1% and 24.9%, respectively [30]. Depending on each local authority, the private sector will be eligible for incentive policies of water supply works. Overall, PSP in investment, management, and operation of water supply facilities in rural areas leads to greater operational efficiency and reduced rates of water loss in water supply facilities of Vietnam [28].

Customer satisfaction considerably affects the financial performance of water supply enterprises [31]. Many organizations and state agencies use customer satisfaction as one of the aspects to comprehensively evaluate the performance of water supply systems [32]. Customer satisfaction is one of the indicators contributing to the performance evaluation of water supply works [33]. Customer satisfaction significantly affects the business efficiency of water supply systems [34], impacting the management, operation, and maintenance of rural water supply schemes [35]. The factors associated with the characteristics of the water supply work affecting customer satisfaction are the length of the pipeline, number of households [36], and lifespan of work [37]. Moreover, the level of user satisfaction of water supply systems depends on different factors such as water availability time, water pressure, water quality [38,39], or distance from the pump station to household [40]. Water prices and customer satisfaction are inter-related in a negative relationship [41,42]. However, no relationship was found between customer satisfaction and economic characteristics [40,43].

To compare the customer satisfaction of two water supply works corresponding to two different management organizations, it is necessary to consider the characteristics of the two works; this means that the two water supply works must be comparable in features. Therefore, an assessment model is needed to measure customer satisfaction of water supply systems. Some essential criteria such as water quality, the quantity of supplied water, and company responsibilities are used in the proposed model [38]. Decentralized techniques are used to integrate all these indicators in one unit indicator. The proposal model combines customer opinion into one unit to measure customer satisfaction. In the states of the Gaza Strip [39], the results of this study show that most of the respondents were dissatisfied with water services due to the amount of water, quantity, and continuity of water. Variables related to the system's features affecting the satisfaction are the pipeline length and the number of households by design [36]. Customer satisfaction is not related to economic, social, and demographic characteristics [40,43]. Service life affects customer satisfaction, often considered when designing a construction [37]. Water prices and customer satisfaction correlate, and it is an inverse relationship [41,42]. Water supply systems are classified as a natural monopoly due to the particularities of the operation and the required technical requirements [44]. It is unrealistic to build parallel water supply systems in the same area because investment costs are very high. It is challenging to have competition in the management and maintenance of water facilities [45]. Therefore, to assess the sustainability of a water supply scheme managed by an organization, it is necessary to incorporate an additional important factor, customer satisfaction, as a comparison method.

The private sector participation is significantly increasing in water supply projects, especially in rural areas, with management qualifications, and water supply systems are often small and medium-size. It is necessary to consider the customer satisfaction of the private sector compared with other sectors to assess service quality and improve the service quality of water supply in the private sector. Findings from this study may provide helpful information for the public sector, private sector, and other sectors to consider appropriate criteria to improve organization and management in the future. The remainder of this paper is organized as follows: Section 2 shows a research model used to evaluate customer satisfaction with rural water supply projects managed by different organizations; Section 3 describes data collection, including the characteristics of the data collection location and the water users; Section 4 explains the features of different water supply groups; Section 5 details the study results and discussion will be presented. The paper ends with some conclusions in Section 6.

2. Research Model

The Ordered Logit regression model is used to evaluate the satisfaction of water users with rural water supply projects managed by different organizations. Many studies used this model to assess customer satisfaction when the dependent variable has an ordinal like the Likert scale [22,26,46,47]. Some case studies have used this model to evaluate customer satisfaction [48,49]. This paper uses the Likert scale to assess water user satisfaction, which is appropriate and commonly used in social and behavioral science research [50,51].

Respondents rank their satisfaction with the rural water supply system from 1 to 5 (1 mean "very dissatisfied," 5 mean "very satisfied"). Let y_i be individual i's response to the survey question, and assume that this can take one of the integer values 1, 2, 3, . . . , j. Let y_i* $-\infty < y_i^* < +\infty$ be the underlying latent variable representing respondent i's propensity to agree with the statement advanced. Ordered Probit models are based on the assumption that y_i*depends linearly on x_i, according to the following [52]:

$$y_i{}^* = x_i\beta + \varepsilon_i \quad (1)$$

in which

$y_i{}^*$: is latent variable or customer satisfaction.

x_i: is a vector of independent variables, there are 12 independent variables described in Table 1.

Table 1. Independent variables in the model.

No	Variable	Description	Symbol	Sources
1	Gender	Respondent (1–male; 0–female)	X_1	[26,48,53]
2	Age	Age of respondent	X_2	[26,48,53]
3	Educational level	Respondent's qualifications (1–Unschooling, 2–Below elementary school, 3–Under secondary school, 4–Below high school, 5–Professional high school/college, 6–Undergraduate, 7–Post graduate)	X_3	[26]
4	Income	Income of respondents (1–Below 2 million VND, 2–From 2 to 5 million VND, 3–From 5 to 10 million VND, 4–Above 10 million VND)	X_4	[26]
5	Color of water	Ranking 5 Likert scale (1–Very Bad, 2–Bad, 3–Normal, 4–Good, 5–Very Good)	X_5	[38,39]
6	Smell of water	Ranking 5 Likert scale (1–Very bad, 2–Bad, 3–Normal, 4–Good, 5–Very good)	X_6	[38,39]
7	Taste of water	Ranking 5 scale (1–Salty, 2–Brackish, 3–Sour, 4–Good, 5–Very good)	X_7	[38,39]
8	Available water time	Time available for water supply schemes (1–24h, 2–day only, 3–night only, 4–Half a day, 5–days with days or not, 6–times sometimes or not)	X_8	[33,38,39]
9	Lifespan	Lifetime of schemes (years)	X_9	[37]
10	Design capacity of the project	Design capacity of water supply schemes in rural areas (m^3/day–night)	X_{10}	[36]
11	Water price	Water price of water supply schemes (VND/m^3)	X_{11}	[26,41,42,48,53,54]
12	Management sectors	Management areas included (1–Private sector; 2–Public sector; 3–Other sectors)	X_{12}	[26]

Source: Summarized by the authors.

ε_i: is random error.

i = 1,2, . . . n is the i^{th} respondent, where n is the sample size (This study n = 1200).

β: is a vector of parameters that do not contain an intercept. Those parameters are considered as parameter slope in linear regression.

Respondents' choice is linked to latent variable with five options in the study as follows:

$y_i = 1$ (very dissatisfied) if $-\infty \le y_i{}^* < a_1$

$y_i = 2$ (not satisfied) if $a_1 \le y_i{}^* < a_2$

$y_i = 3$ (normal) if $a_2 \le y_i{}^* < a_3$

$y_i = 4$ (satisfied) if $a_3 \le y_i{}^* < a_4$

$y_i = 5$ (very satisfied) if $a_4 \le y_i{}^* < +\infty$

The parameter a_m, with m = 1,2,3,4 and where $a_1 < a_2 < a_3 < a_4$ mean that four parameters are ranked hierarchically, and separated by cutoffs or threshold parameters. That is, we observe an individual y_i in five hierarchical classifications that are separated by threshold parameters or cutoffs, i.e., coefficients a. In other words, threshold parameters demarcate the limits of different classifiers.

In this study, the authors use two models to examine the influence of different factors on customer satisfaction with rural water supply projects. In particular, the first model considers the management sector, interviewee characteristics, water quality, and availability of water. In comparison, the second model includes all factors of model 1 and adds more features of water supply systems, including the design capacity and lifespan of the system.

3. Data Collection

3.1. Characteristics of Location

In order to ensure the representativeness of management organizations and users of the water supply system from beginning to end of the system, this research uses a stratified sampling method according to three groups of water users included at the top, the middle, and the bottom of the system. In 2015, a survey was conducted with 30 systems in three provinces, namely Thai Binh, Ha Nam, and Long An. Each system was randomly selected to survey 30 households from the beginning to the bottom each system. In 2018, Nghe An province (central region) selected two rural water supply systems; each scheme selected 150 households using water consisting of a beginning, middle, and end of the system with 50 households of each location.

The questionnaire survey to evaluate the level of satisfaction of rural water users includes 35 questions divided into three parts: (1) availability and access to water resources; (2) reliability of water supply service; and (3) water quality.

The questionnaire survey was funded by the Australian Government Department of Foreign Affairs and Trade (DFAT). Four organizations participated in collecting data including Institute for Sustainable Futures at the University of Technology Sydney (ISF-UTS), Institute for Water Resources Economics and Management (IWEM), East Meets West Foundation (EMWF), and the Center for Environmental and Natural Resources Research, Vietnam National University, Hanoi (CRES-VNU). This research updated missing information, including (1) Age, (2) Education level, (3) Occupation, (4) Income per capital, and (5) Water price. The authors conducted a telephone survey with 900 water users belonging to 30 rural water supply schemes in Ha Nam, Thai Binh, and Long An province in 2018. At the same time, a survey (see Table 2) collected 300 households using water from rural water supply schemes in Nghe An province (Central region), including 150 households using water managed by the community (other sectors), and 150 households using water managed by Provincial Centre for Rural Water Supply and Environmental Sanitation (the public sector).

Table 2. Number of households selected for the survey by three regions of Vietnam.

Region/ Province	Number of Schemes			Number of Households			Collection Time
	Private Sector	Public Sector	Other Sectors	Private Sector	Public Sector	Other Sectors	
Northern	**10**	**2**	**8**	**330**	**70**	**200**	
Ha Nam	5	1	4	150	30	120	2015, 2018
Thai Binh	5	1	4	180	40	80	
Central	**0**	**1**	**1**	**0**	**150**	**150**	
Nghe An		1	1		150	150	2018
South	**5**	**3**	**2**	**150**	**90**	**60**	
Long An	5	3	2	150	90	60	2015, 2018
Total	**15**	**6**	**11**	**480**	**310**	**410**	
		32			**1200**		

Source: Area survey of authors.

3.2. User Characteristics

Collected survey data shows that 54% of the interviewees are male, of which the age group 25-63 accounts for 85%. The education level of the interviewees is mainly below high school (see Table 3).

Table 3. Descriptive statistics of households using water.

No	Interviewee Characteristics	Number of Households	Ratio (%)
1	**Sex**		
	Male	774	64.50
	Female	426	35.50
2	**Range of age**		
	Under 35	14	1.17
	From 35 to < 45	241	20.08
	From 45 to < 55	393	32.75
	From 45 to < 65	391	32.58
	Above 65	161	13.42
3	**Educational level**		
	Unschooling	29	2.42
	Under elementary school	142	11.83
	Under secondary school	576	48.00
	Under high school	359	29.92
	Professional high school/college	78	6.50
	Undergraduate	10	0.83
	Post-graduate	6	0.50
	Total	**1200**	**100**

Source: Author's collection results.

4. Characteristics of Private, Public, and Community Groups

In Vietnam, there are currently 16,573 projects, of which around 1579 works are managed by the private sector, accounting for 9.5%. The private sector participation is concentrated in lowland areas with higher population density and income than the other regions. The Red River Delta area has the most significant number of projects participating in the private sector, accounting for 66.8% [52]. As shown in Table 4 below, most rural water supply systems are well managed; the total of rate of sustained and medium status accounts for 68.4%. Sustained status works are mainly located in the Red River Delta and Mekong River Delta with 60% and 65.1%.

The increasing requirements for water quality make it difficult to ensure sustainable maintenance of the achieved results. Vietnam currently has 51% of the rural population using water that meets the standards by the end of 2020. Over 31 million people in rural areas account for 49% of the rural population without access to hygienic water. The percentage of people using hygienic water from concentrated water supply works in many localities is still low, and there is a large disparity between different regions. As shown in Table 4, the current water supply works operate inefficiently, and the inactive status is relatively high (31.6%), leading to a lack of sustainability in water supply activities. In addition, with the extreme impacts of global climate change and the increasing demand for socio-economic development, water resources are reduced in quantity and quality, especially in areas having frequent drought, water shortage, saltwater intrusion, and water pollution. The future demand for water supply systems for households in rural areas is increasing. The quality of water supply services is a multi-dimensional value, which means when providing a better-quality service, the more resources and costs are required. Therefore, the different water prices can be explained because the service quality of water supply systems is not the same [55].

By 2021, in Vietnam, the average price of water from rural areas for domestic use is approximately 8,000 VND/m^3. Specific water prices of water supply works are issued by each locality but are based on the price bracket of the Ministry of Finance. Water prices in rural areas are applied at roughly the same rates as in urban areas, but some localities have higher water prices in rural areas than in urban areas due to population density, higher investment, and management costs.

Table 4. Current status of systems by 2020.

Subgroups			**Area**						**Total**
			Northern Mountain	**Red River Delta**	**North Central**	**South Central**	**Highlands**	**South East**	
Total		N	8655	801	1364	1326	1300	316	16,573
		%	100	100	100	100	100	100	100
Management Organization	Community	N	6,652	29	572	119	832	52	8,340
		%	76.86	3.62	41.94	8.97	64.00	16.46	50.32
	Cooperative	N	111	66	16	42	12	27	300
		%	1.28	8.24	1.17	3.17	0.92	8.54	1.81
	Private sector	N	156	535	38	52	7	92	1579
		%	1.80	66.79	2.79	3.92	0.54	29.11	9.53
	Commune People's Committee	N	1675	126	712	1006	325	24	4785
		%	19.35	15.73	52.20	75.87	25.00	7.59	28.87
	Provincial Centre for Rural Water Supply and Environmental Sanitation	N	61	45	26	107	124	121	1,569
		%	0.70	5.62	1.91	8.07	9.54	38.29	9.47
Current Status	Sustained	N	2151	481	301	326	276	124	5489
		%	24.85	60.05	22.07	24.59	21.23	39.24	33.12
	Medium	N	3473	185	585	411	396	116	5847
		%	40.13	23.10	42.89	31.00	30.46	36.71	35.28
	Ineffective	N	1698	52	290	332	221	44	2814
		%	19.62	6.49	21.26	25.04	17.00	13.92	16.98
	Inactive	N	1333	83	188	257	407	32	2423
		%	15.40	10.36	13.78	19.38	31.31	10.13	14.62

Source: General Department of Water Resources (2021); N: the number of water supply systems.

The private sector's water supply facilities are more extensive than those managed by the public sector and other sectors. The capacity of the facilities managed by the private sector and public sector are medium, and large-scale projects with a service capacity of over 2000 m^3/day–night, about over 2000 households. However, facilities managed by the private sector are more diverse than those managed by the public sector; for example, water supply schemes under public sector management are at least 640 m^3/day–night, while those managed by the private sector are 300 m^3/day. However, the design capacity of the largest project managed by the private sector is three times higher than that of the public sector and five times higher than that of other sectors. Meanwhile, water supply works managed by other sectors mainly have a small capacity, simple treatment system, with a minimum capacity of 100 m^3/day–night. Most of the schemes managed by the private and public sectors are intercommune and interdistrict projects. Meanwhile, the schemes managed by other sectors are concentrated mainly in one village or one commune (see Table 5).

Table 5. Design capacity classified by management sectors.

Indicator	**Private Sector (m^3/Day–Night)**	**Public Sector (m^3/Day–Night)**	**Other Sectors (m^3/Day–Night)**
Mean	2548.94	2322.10	802.14
Maximum	10,500.00	3515.00	1720.00
Minimum	300.00	640.00	100.00
Standard Deviation	2934.75	1204.60	709.16

Source: Calculated by the authors.

5. Research Results and Discussion

5.1. Data and Description of Variables

Among the total number of interviewees, the number of households using water supply systems managed by the private sector is the highest, followed by the other sector, and the public sector with 480, 410, and 310 respondents, respectively (see Table 2). The private sector's level of satisfaction (including satisfied and very satisfied) accounts for the highest rate with 62.98%, followed by the public sector accounting for around 60.32%, and other sectors represent approximately 40.95% (see Table 6).

Table 6. Satisfaction of water users by different sectors.

Sector	Very Dissatisfied	Dissatisfied	Normal	Satisfied	Very Satisfied	Total
Private sector	0.85%	6.60%	29.57%	52.55%	10.43%	100%
Public sector	3.23%	7.10%	29.35%	49.03%	11.29%	100%
Other sectors	6.90%	14.05%	38.10%	37.14%	3.81%	100%
Total	3.58%	9.33%	32.50%	46.26%	8.33%	100%

Source: Calculated by the authors.

As can be seen in Table 7, the proportion of men interviewed accounted for 64.50%; the average age was 53.21 years, and the education level was mainly below high school (about 90% of total interviewees). The household's average income is about 2–5 million VND/month, accounting for approximately 50%.

Table 7. Characteristics of water users and rural water supply facilities.

Variable	Variable in Model	Mean	Standard Deviation	Min	Max
X_1	Gender (1–Male, 0–Female)	0.645	0.479	0	1
X_2	Age (year old)	53.213	10.398	26	90
X_3	Educational level (1–Unschooling, 2–Under elementary school, 3–Under middle school, 4– Under high school, 5–Professional high school/college, 6–Undergraduate, 7–Postgraduate)	3.308	0.914	1	7
X_4	Income (1–Below million VND, 2–From 2 to 5 million VND, 3–From 5 to 10 million VND, 4–Above 10 million VND)	2.283	0.720	1	4
X_5	Color of water (1–Very bad, 2–Bad, 3–OK, 4–Good, 5–Very good)	3.635	0.655	1	5
X_6	Smell of water (1–Very bad, 2–Bad, 3–OK,4–Good, 5–Very good)	3.400	0.675	2	5
X_7	Taste-water (1–Salty, 2–Brackish, 3–Sour, 4–Good, 5–Very Good)	4.221	0.818	2	5
X_8	Time (1–24 h, 2–day only, 3–nightonly, 4–Half a day, 5–days with daysor not, 6–times sometimes or not)	3.358	1.864	1	6
X_9	Lifespan (year)	9.502	6.675	2	30
X_{10}	Design capacity of the project	1876.227	2134.171	100	10,500
X_{11}	Water price (VND/m^3)	6640.667	1185.273	3000	10,000
X_{12}	Management sectors (1–Private sector, 2–Public sector, 3–Other sectors)	1.958	0.861	1	3
Y	Satisfaction (1–Very dissatisfied, 2–Dissatisfied, 3–Normal, 4–Satisfied, 5–Very satisfied)	3.464	0.904	1	5

Source: Calculated by the authors.

For water quality, according to users, the color of water rated as "good" accounted for 67.39%, compared to the smell of water, approximately 90% of water users rated "good" and "very good". Regarding water taste, water users rated approximately 85% of water taste as “good" and "very good". For the amount of water, the total rate of "24 h”, “day only”, “night only”, “half a day" is 68%, which shows that the availability of water is not low.

Regarding the characteristics of the rural water supply system, the average lifespan of schemes in 2018 is 9.5 years, including a minimum of two years and a maximum of 30 years. This number indicates that most water supply systems have stabilized operation and management. The average design capacity of the project is 1876 households; the minor scale is 100 households, and the largest one is in 10,500 households.

The average water price is 6641 VND/m^3 approximately 0.263 EURO per m^3; minimum is 0.119 EURO/m^3, and the maximum is 0.397 EURO/m^3 (the currency exchange rates 1 EURO = 25,242.76 VND, 10 March 2022 of Vietcombank). Water price is equal to 0.119% of GDP per capita of rural people in Vietnam in 2021 (General Statistics Office of Vietnam). The proportion of surveyed water supply schemes managed by the private sector accounted for 39%, while the public sector accounted for 26%, and other sectors managed 35% (see Table 7).

5.2. Results and Discussion

As mentioned above, this research will analyze two models to choose the most suitable model. Model 1 included factors affecting water user satisfaction such as user characteristics (gender, education level, income), water quality (color, odor, and taste), duration of water availability, and economic factors (administration sector, water price).

With model 2, we keep the variables of model 1 and adding variables related to the characteristics of the building, such as size and lifespan. This model compares the characteristics of water supply projects in rural areas through the scale of the schemes (designed capacity) and lifespan. Water supply works have exclusive characteristics, significant investment costs, and specific technical requirements [44]; building two parallel water supply systems in one area is unrealistic [45] (see Table 8).

Model 1 with Chi-Square value resulted in 620.32 and was statistically significant. Therefore, the assumption was rejected because all regression coefficients of independent variables are 0 (Prob > chi2 = 0.000) with Pseudo R_2 of 0.2037. With economic factors, water-user satisfaction in systems is managed by the private sector is higher than that of other sectors. The higher the water price, the lower the customer satisfaction. Water prices in the private sector are higher than public sector [28,36,56] and other sectors [28].

Respondent’s characteristics, including age, gender, and education level, do not affect customer satisfaction; this result is similar to previous research [26,48,53]. The higher the income of the interviewee, the lower the water-user satisfaction, and the results are similar to a previous study [26]. The better the water quality, the higher user satisfaction. The smell of water has the most significant influence on customer satisfaction, and the color of water does not affect customer satisfaction much. Moreover, the time availability of water influences customer satisfaction; similar to previous research [33,39], the longer water is available, the higher the customer satisfaction.

Model 2 has Pseudo R-squared and LR Chi-squared equal to 634.64 larger than model 1; therefore, model 2 is more appropriate and explains factors affecting user satisfaction better than model 1. The influencing factors include economic factors, interviewee characteristics, water quality, and water availability time, similar to model 1. However, model 2 depends on other variables such as system characteristics, lifespan, and design capacity schemes.

The larger the scale of rural water supply work, the lower the satisfaction of water users. Small-scale systems with a capacity of < 500 m^3/day/night are mainly managed by the community, Commune People’s Committee, or cooperative. This result is similar to the findings of other studies [37].

According to the results, interviewee features do not affect customer satisfaction. Comparing the schemes managed by other sectors and the private sector, the level of “satisfied” and “very satisfied” increased by 4.76% and 2.41%, respectively. In contrast, for “undecided”, “dissatisfied”, and “very dissatisfied”, water users in other sectors are higher than in the private sector by 3.63%, 2.29%, and 1.25%, respectively (see Table 9).

Table 8. Ordered Logit model results on water user satisfaction.

Variables	Model 1 Coefficient (Standard Error)	Model 2 Coefficient (Standard Error)
Economic factor		
Management area		
Public sector	−0.0582 (0.160)	−0.158 (0.163)
Other sectors	−0.420 *** (0.156)	−0.422 ** (0.165)
Price	−0.000147 *** (0.0000552)	−0.000166 *** (0.0000561)
Respondent's characteristics		
Gender	−0.107 (0.126)	−0.0974 (0.127)
Age	−0.00275 (0.00600)	−0.00291 (0.00602)
Education level		
Below level 1	0.200 (0.405)	0.203 (0.408)
Below level 2	0.379 (0.381)	0.375 (0.384)
Below level 3	0.470 (0.388)	0.432 (0.392)
Professional high school/college	0.526 (0.439)	0.501 (0.442)
Undergraduate	0.215 (0.731)	0.204 (0.733)
Postgraduate	0.683 (0.863)	0.608 (0.863)
Income		
From 2 to 5 million VND	−0.492 *** (0.190)	−0.456 ** (0.192)
From 5 to 10 million VND	−0.417 ** (0.207)	−0.391 * (0.209)
Over 10 million VND	-0.221 (0.357)	−0.213 (0.356)
Water quality		
Color		
Bad	−1.083 (1.617)	−1.150 (1.601)
OK	−0.902 (1.619)	−0.941 (1.602)
Good	−0.0436 (1.617)	−0.0972 (1.601)
Very good	1.799 (1.709)	1.590 (1.695)
Smell		
OK	0.656 *** (0.245)	0.679 *** (0.245)
Good	1.578 *** (0.264)	1.587 *** (0.264)
Very good	3.270 *** (0.434)	3.294 *** (0.436)
Taste		
Sour	0.394 (0.325)	0.291 (0.327)
Good	1.429 *** (0.322)	1.366 *** (0.325)
Very good	1.280 *** (0.323)	1.190 *** (0.330)
Time available for water		
Day only	−0.371 ** (0.184)	−0.593 *** (0.195)
Night only	−1.559 *** (0.354)	−1.693 *** (0.357)
Half a day	−1.078 *** (0.202)	−1.295 *** (0.212)
Days with days or not	−2.354 *** (0.236)	−2.461 *** (0.241)
Times sometimes or not	−1.050 *** (0.196)	−1.189 *** (0.201)
Characteristics of rural water supply schemes		
Lifespan		−0.0413 *** (0.0112)
Design capacity of project (m3/day/night)		−0.0000788 ** (0.0000358)
Constant cut1	−4.614 *** (1.722)	−5.575 *** (1.727)
Constant cut2	−3.009 * (1.719)	−3.965 ** (1.723)
Constant cut3	−0.559 (1.717)	−1.493 (1.720)
Constant cut4	3.026 * (1.719)	2.128 (1.719)
Observations	1.199	1.199
Log likelihood	−1212.26	−1205.1022
Pseudo R squared	0.2037	0.2084
LR Chi-squared (*p*-value)	620.32 (0.000)	634.64 (0.000)

Note: Standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Source: Calculated by the authors.

Table 9. Marginal effects for Model 2.

Variables	Very Dissatisfied	Dissatisfied	Normal	Satisfied	Very Satisfied
Economic factors Management sector					
Public sector	0.00424 (0.00448)	0.00815 (0.00846)	0.0143 (0.0147)	−0.0168 (0.0176)	−0.00980 (0.0100)
Other sectors	0.0125 ** (0.00511)	0.0229 ** (0.00919)	0.0363 ** (0.0148)	−0.0476 ** (0.0195)	−0.0241 *** (0.00934)
Price	0.00005 *** (0.00002)	0.00009 *** (0.00003)	0.00001 *** (0.00005)	−0.00002 *** (0.00006)	−0.00010 *** (0.00003)
Respondent's characteristics					
Gender	0.00296 (0.00387)	0.00528 (0.00688)	0.00789 (0.01030)	−0.01040 (0.01350)	−0.00576 (0.00751)
Age	0.00009 (0.00018)	0.00016 (0.00033)	0.00024 (0.00049)	−0.00031 (0.00064)	−0.00017 (0.00036)
Education level					
Below level 1	−0.00759 (0.0160)	−0.0119 (0.0243)	−0.0144 (0.0279)	0.0238 (0.0487)	0.0102 (0.0195)
Below level 2	−0.0132 (0.0153)	−0.0215 (0.0230)	−0.0278 (0.0260)	0.0427 (0.0460)	0.0198 (0.0182)
Below level 3	−0.0149 (0.0155)	−0.0245 (0.0234)	−0.0324 (0.0269)	0.0486 (0.0468)	0.0233 (0.0189)
Professional high school/college	−0.0168 (0.0165)	−0.0281 (0.0257)	−0.0381 (0.0318)	0.0555 (0.0508)	0.0276 (0.0231)
Graduate	−0.00761 (0.0265)	−0.0120 (0.0425)	−0.0145 (0.0534)	0.0239 (0.0845)	0.0102 (0.0378)
Postgraduate	−0.0197 (0.0250)	−0.0336 (0.0448)	−0.0473 (0.0720)	0.0659 (0.0855)	0.0347 (0.0561)
Income					
2–5 million VND	0.0124 ** (0.00489)	0.0234 ** (0.00948)	0.0390 ** (0.0174)	−0.0454 ** (0.0179)	−0.0294 ** (0.0136)
5–10 million VND	0.0103 * (0.00531)	0.0198 * (0.0103)	0.0338 * (0.0187)	−0.0383 * (0.0197)	−0.0257 * (0.0145)
>10 million VND	0.00523 (0.00916)	0.0104 (0.0178)	0.0189 (0.0312)	−0.0198 (0.0343)	−0.0147 (0.0239)
Water quality Color					
Bad	0.0354 (0.0308)	0.0697 (0.0743)	0.103 (0.177)	−0.153 (0.171)	−0.0551 (0.110)
OK	0.0263 (0.0300)	0.0547 (0.0737)	0.0892 (0.177)	−0.122 (0.170)	−0.0481 (0.110)
Good	0.00187 (0.0295)	0.00457 (0.0733)	0.0107 (0.178)	−0.0106 (0.170)	−0.00651 (0.110)
Very good	−0.0155 (0.0295)	−0.0448 (0.0736)	−0.170 (0.185)	0.0580 (0.172)	0.172 (0.139)
Smell					
OK	−0.0296 ** (0.0130)	−0.0478 ** (0.0191)	−0.0483 *** (0.0140)	0.106 *** (0.0390)	0.0199 *** (0.00617)
Good	−0.0510 *** (0.0134)	−0.0952 *** (0.0203)	−0.144 *** (0.0213)	0.220 *** (0.0424)	0.0704 *** (0.0100)
Very good	−0.0642 *** (0.0139)	−0.136 *** (0.0208)	−0.316 *** (0.0354)	0.235 *** (0.0488)	0.281 *** (0.0589)
Taste					
Sour	−0.0160 (0.0191)	−0.0213 (0.0245)	−0.0118 (0.0115)	0.0406 (0.0456)	0.00848 (0.00901)
Good	−0.0523 *** (0.0187)	−0.0876 *** (0.0250)	−0.0971 *** (0.0160)	0.178 *** (0.0458)	0.0595 *** (0.0109)
Very good	−0.0483 ** (0.0188)	−0.0785 *** (0.0252)	−0.0798 *** (0.0160)	0.158 *** (0.0466)	0.0485 *** (0.0104)

Table 9. *Cont.*

Variables	Very Dissatisfied	Dissatisfied	Normal	Satisfied	Very Satisfied
Time available for water					
Day only	0.00732 *** (0.00268)	0.0209 *** (0.00712)	0.0727 *** (0.0240)	−0.0537 *** (0.0182)	−0.0472 *** (0.0161)
Night only	0.0365 *** (0.0138)	0.0848 *** (0.0246)	0.190 *** (0.0334)	−0.214 *** (0.0549)	−0.0974 *** (0.0169)
Half a day	0.0228 *** (0.00505)	0.0577 *** (0.0105)	0.154 *** (0.0264)	−0.151 *** (0.0270)	−0.0836 *** (0.0152)
Days with days or not	0.0781 *** (0.0141)	0.147 *** (0.0196)	0.222 *** (0.0232)	−0.333 *** (0.0330)	−0.115 *** (0.0148)
Times sometimes or not	0.0198 *** (0.00458)	0.0513 *** (0.00970)	0.143 *** (0.0248)	−0.135 *** (0.0244)	−0.0792 *** (0.0150)
Characteristics of rural water supply schemes					
Lifespan	0.00125 *** (0.000376)	0.00224 *** (0.00063)	0.00334 *** (0.00091)	−0.00439 *** (0.00121)	−0.00244 *** (0.000681)

Note: Standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Source: Author's calculation.

For water prices, price increases to 1000 VND/m^3, the probability that users rank "satisfied", and "very satisfied" will decrease by 6.00% and 3.00%. Currently, the Vietnamese Government has implemented water price compensation for the private sector participating in investment, management, and operation. Therefore, when transferring rural water schemes from other sectors to the private sector, the probability of increasing the level of "satisfied" and "very satisfied" is 7.17%.

As a result, household income is higher; satisfaction tends to decrease. In contrast, the income of water users increases from "less than 2 million VND" to "2–5 million VND"; "satisfied" and "very satisfied" decrease by 4.54%, and 2.94%, respectively. The percentage of interviewees having around 2–5 million VND income accounts for 50% of the total number of respondents; 2–5 million VND is the average income of households in Vietnam. However, customers' income is more than 10 million VND; satisfaction is not affected.

For water quality, the smell of water increased from "bad" to "very good", the level of "satisfied" increased to 23.50%, and the level of "very satisfied" increased to 28.10%. Taste of water affects customer satisfaction less than the smell of water; taste of water changes from "brackish" to "very good"; water user satisfaction increases to 15.8% (assuming these factors are constant).

For water time, this factor is changeable to customer satisfaction. When water availability is "24 h" to "night only", customer satisfaction reduces to 21.40% (assuming these factors are constant). With water availability from "24 h" to "days with days or not", the level of "satisfied" and "very satisfied" decreased to 33.30% and 11.50%, respectively. Thus, water availability has a direct and significant impact on customer satisfaction.

Regarding features of rural water supply system, if the lifespan of schemes increases by one year (assuming other factors remain constant), the level of "satisfied" decreases by 0.439%, and "very satisfied" decreases by 0.244%. Satisfaction levels decrease as the scale of the system increases. As a result, the capacity of managers to operate rural water supply facilities is still limited [29]. System capacity increases, and satisfaction decreases slightly; as the model, the capacity of the water supply system increases to 1 m^3/day–night, and the level of water user satisfaction decreases by 0.008%.

6. Conclusions

This study aims to compare the level of customer satisfaction in rural water supply facilities managed by the private sector, public sector, and other sectors. The authors analyzed 1200 households using water from 32 schemes from three regions of Vietnam (North, Central, South) in which Ha Nam and Thai Binh are two provinces in the North; Nghe

An is a province in the Central region, Long An is a province in the South. Water facilities managed by the private sector have higher water user satisfaction than other sectors (Communities, Cooperatives, and Commune People's Committees). Comparing the schemes managed by other sectors and the private sector, water user satisfaction rated at "satisfied" and "very satisfied" by water supply systems managed by the private sector is 7.17% higher than the other sectors. On the other hand, the other sector has a rating of "dissatisfied" and "very dissatisfied", 3.54% higher than the private sector. There is no significant difference in customer satisfaction for projects managed by the private and public sectors. According to the results, interviewee features do not affect customer satisfaction.

In contrast, for "undecided, "dissatisfied", and "very dissatisfied", water users in other sectors are higher than in the private sector by 3.63%, 2.29%, and 1.25%, respectively. Characteristics of interviewees, including gender, age, and education level, do not affect customer satisfaction. The income of water users highly affects customer satisfaction, especially household income with 2–5 million VND/month. Among the factors of color, smell, and taste of water, the smell of water has the most significant influence on water user satisfaction. When the smell of water ranked at "good" or higher, customer satisfaction at "satisfied" and "very satisfied" increased by 29.04% and 51.60%, respectively. Water user satisfaction is quite sensitive to water availability. From continuous daytime to intermittent water availability, the level of "satisfied", and "very satisfied" decreased by 44.8%. In addition, as lifespan and water price increase, customer satisfaction decreases. The research results are a basis for the private sector to consider improving their service quality in rural water supply system factors that highly affect water user satisfaction, such as water quality, water availability. For state management organizations, it is necessary to support technical capacity of the private sector to improve their management capacity. It is advisable to encourage systems transfer from other sectors to the private sector to improve service quality. The limitation of this study is that the survey time to collect data has two different periods in 2015 and 2018; the homogeneity of data may slightly affect the analysis results. In this study, the data of selected water supply works belong to two provinces in the North (Ha Nam, Thai Binh), one province in the Central region (Nghe An), and one province in the South (Long An). Therefore, in the future, there should be extensive and more profound investigation research in the Central and Southern regions to balance the data range and have a detailed assessment.

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Institutional Factors Impacting on International Construction Market Selection: Evidence from Chinese Contractors

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Abstract: Institutions can be understood as the mechanism by which the rules societies operate under are formulated. As such, the international construction market is heavily affected by institutional factors. International market selection (IMS) is a fundamental decision that project contractors must make when entering the overseas arena. A variety of clues show that institutional factors have a complex impact on contractors' IMS, but papers in this field tend to cover just one or two institutional factors or even ignore their role. Institutional factors exist in a multi-level social system, and the role of broader institutional factors in contractors' IMS needs to be systematically explored. This study extensively collects institutional factors predicted to impact contractors' IMS by literature review, selects 10 specific institutional factors from different perspectives, theoretically deduces their effects on contractor's IMS, and takes international Chinese contractors' IMS practice as the empirical research material and collects data for logistic regression analysis to test the assumptions. The results show that the IMS of contractors is affected by institutional factors from different levels and the effect of some factors on IMS must be weighted in a specific context. Specifically, IMSs of Chinese contractors are negatively affected by institutional distance but are not sensitive to the institutional environment. The results also confirm that if the host country and China have signed a trade agreement, belong to the same regional organization, or if China has provided foreign aid to a host country, Chinese contractors are more willing to choose the host market and central enterprises become more active in IMS than other firms. These findings can be expected to supplement IMS decision-making, with the empirical data presented affording an extension to the body of knowledge on contractors' IMS process.

Keywords: construction market; international market selection (IMS); institutional factors; Chinese contractors; logistic regression analysis

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1. Introduction

In the construction market, the production organization is centered on the project location, the main transaction mode is tendering and bidding, governments are often the main purchaser of giant projects, and project participants come from multiple sources. These characteristics determine that the construction market needs more rules and regulations to regulate and restrict the behavior of all participants in the project than other markets based on general production and sales. Thus, the international construction market exhibits unique qualities, characterized by both intense institutional regulation and strong market competition, while the industry stands out as project-based, requiring mobility of the means of production. Moreover, the stages of the construction project—bidding, design, procurement, financing, construction, delivery, maintenance, and concessionaire operations—are all subject to various, sometimes conflicting rules, overseen by a range of ministries and government institutions.

When contractors expand offshore, international market selection (IMS) is the principal problem to be faced and is inevitably predicated on institutional considerations, such as how to obtain local institutional knowledge, whether they can integrate into the local institutional environment, and how to ensure legitimacy in the whole process of project implementation. The 'institution-based view' provides strong theoretical explanatory power regarding the many issues impacting IMS and complements the two other predominant theoretical lenses, the industry-based and resource-based view [1]. Researchers have invested a great deal of attention in developing market-entry decision-making models, knitting together influential factors about the economy, technology, geography, culture, etc. However, despite the overwhelming impact institutions have over construction projects, papers in this field tend to cover just one or two institutional factors or even ignore their role. The decision-making quality of IMS affects the long-term development of contractors in the international market. The factors considered as comprehensively as possible in the decision-making model are the basis of success. Institutional factors exist in complex social systems, thus the role of broader institutional factors in a contractor's IMS presents an urgent topic for investigation. In this vein, this study aims to explore more comprehensive institutional factors affecting contractors' IMS and clarify their impact.

This aim is achieved in five steps. First, institutional factors that may influence contractors' IMS were identified by way of a thorough, systematic literature review. Second, hypotheses related to the impact of institutional factors on IMS are proposed based on theoretically informed deductions. Third, data collection and variable measurements are carried out. In this stage, the IMS of 54 Chinese contractors across 80 countries were observed, with data collected from multiple sources. Fourth, statistical analysis models are constructed and validated, and logistic regression analyses are conducted. Because the dependent variable is binary, logistic regression analysis is used in this study which is a mature and frequently used method in research on international market entry strategies. Finally, the results of the logistic regression analysis are compared to the hypotheses and conclusions are drawn out.

This study sorts out the institutional factors that may affect contractors' IMS and clarifies the role of specific institutional factors empirically, which can encourage researchers and contractors to consider more institutional factors in the research and practice of IMS. The findings can be used in the IMS decision-making model to improve its quality and can also be used as an important reference for contractors' IMS practice.

2. Literature Review

2.1. Institutional Theory and International Market Strategy

Institutional theory can generally be viewed from the perspective of economics and organizational sociology. Institutions are the 'rules of the game' in society, with their major role being to reduce uncertainty, by establishing and maintaining a stable (though not necessarily efficient) structure for the facilitation of human interaction [2]. Institutions can be parsed into formal and informal types [2], or regulatory, normative, and cognitive [3]. Regulatory institutions constitute formal regimes as they wield incentives while also being able to impose sanctions on individuals or organizations. They emerge out of government or other authorities empowered to regulate and constrain behaviors. On the other hand, normative and cognitive institutions are essentially informal, being typically long-standing social platforms, considered to be objective and naturally formed by stakeholders, rather than artificially developed [4]. Formal institutions develop political, judicial, and economic rulings, mandated by the constitution, statute law, common law, or specific bylaws, which ultimately give force to civil contracts [2]. However, laws in one country may be vastly different from laws in another, making for the problematic interpretation of acceptable codes of conduct and professional practice. Institutional distance, therefore, is defined as the difference between the institutional environments of any two countries and remains a matter of great concern in cross-border interactions [5,6].

For multinational enterprises, institutions act as a background against which competition plays out and directly influence which strategies should be invoked to enhance firm competitiveness [1]. The influence of institutional factors on an enterprise's international market strategy can be explained by transaction cost theory [4]. Access to foreign markets requires overcoming the institutional barriers of the host country, such as market entry barriers stipulated by the host country's laws and regulations [7]. Then, having entered, transnational corporations need to adapt and respond to the formal system of laws and regulations of the host country [8,9]. The quality of formal institutions in a country can be differentiated according to the extent to which they contribute to local development [10,11]. High institutional quality signifies a stable and regulated operating environment, which can reduce transaction costs for multinational operators in the host country [10], and confers legitimacy [7,12,13]. Contrarily, institutional differences between countries create a 'liability of foreignness' for transnational operators who lack local institutional knowledge, leading to a handicap in having to undergo a costly learning curve [13–15].

Scholars argue that institutional analysis of international market strategies should consider both domestic and host country institutional contexts in order to systematically deconstruct their impact on a company's decision-making [16]. Applications of institutional theory within multinational corporations range from conceptualization of institutional environments to explanations of market strategy choice and organizational practices [17].

2.2. Institutional Theory Applied in the Construction Industry

Construction is project-based, with practitioners and scholars alike prioritizing the acquisition and implementation of projects [18,19]. This is evidenced by representative journal papers in engineering management, principally reflecting on institutional theory as it applies at the project level [20]. Representative themes are: how to influence construction safety management strategies [21]; how to handle institutional complexity in mega project organizations [22]; how to manage mega projects in the light of institutional environments [23]; how a host country's institutions shape infrastructure projects [24]; and how to understand the mutual constitution and dynamics of projects and institutions [25]. Orr and Scott, for example, investigated how firms engaged in large-scale global projects respond to unforeseen costs after failing to comprehend cognitive-cultural, normative, and/or regulative institutions in an unfamiliar host societal context [14]. Ling and Zhang explored the impact of cultural intelligence on the performance of international construction projects and the moderating effect of institutional distance and compared the differences between Chinese contractors and Korean contractors [26].

Certain studies have applied institutional theory at the enterprise level. Examples include the role of institutional norms in construction partnering [27]; how firms acquire local institutional knowledge during internationalization [28]; and how institutional and task environment relationships influence the performance of construction firms [29]. Broadly, the findings support the perception of strong industry norms promoting partnering [27], while under highly stringent conditions, institutional relations are shown to be associated significantly with performance [29]. Ye and Lu explored the roles of institutional distance and host country contexts on the corporate social responsibility practices of international construction companies [30].

There are also studies examining the role of institutional factors at the construction market and industry levels. Lee and Han evaluated construction market risks across various countries, with consideration given to the institutional environment. They found that countries with advanced institutional systems show relatively low growth rates in the construction market [31]. Stricker and Baruffini estimated the impact of the application of the bilateral agreement of the Free Movement of Persons between Switzerland and the EU-15 countries on the labor market outcomes in the Swiss main construction sector [32].

From the literature, it can be found that the role of institutional factors in international construction exists in a multi-faceted context. However, relevant studies have selected only one or two indicators for research and have not tried to incorporate more comprehensive and multi-dimensional institutional factors.

2.3. Institutional Factors Related to Contractors' International Market Selection

The outcome of an international market selection decision for a specific country can be simply 'enter' or 'don't enter' [18]. In arriving at this decision, contractors must consider comprehensive factors, including the international and domestic environment, the market environment of the target country, evaluating a firm's resource conditions, and predicting the probability of host-country project acquisition along with the feasibility of implementation and expected profitability to be derived from the target market [33,34]. Various institutional factors may affect the contractor's market choice. Papers applying institutional theory in international market strategy [7,9,16] and even foreign direct investment [10,35,36] have been published. Moreover, there is a body of work that refers to the market strategies of international construction majors [19,37–40]. These point out that the construction industry is characterized by both intense institutional regulation and strong market competition [29], and is, therefore, subject to institutional environments; though none address the problem from an institutional-based view [14,41].

In these papers, culture, institutions (often representing formal institutions), cultural distance, and institutional distance are the most studied factors, followed by legal entry restrictions or entry barriers. Other factors include country risk, political risk, political culture, the existence of strict quality requirements, host-home country relationship, colonial links, the attitude of the host government, and the firm's endowments of property, assets, and political support. Most studies descriptively note these factors as influencing international market strategy or project contracting, but they do not go further to test the impact of these factors through empirical methods [18,41].

Though the concepts and connotations of these factors often overlap and definitions blur across studies, the elements that constitute the institutional environment related to international engineering market selection decision-making can be clarified as follows: (1) institutional environment, which for formal institutions manifests as stability, and which for informal institutions manifests as industrial culture; (2) institutional difference between home and host country, including institutional distance and culture distance; (3) links between home and host country, including colonial legacies, bilateral agreements, regional organizations, and foreign aid; (4) vestiges of embodied attitude of the host government and its people arising from nationalist or other elements; (5) restrictions on foreign activities, such as capital, employment or resource utilization requirements, trade barriers and tariffs, and limits on repatriation of profits; and finally, (6) the nature of firm ownership, combined with political ties that will determine the degree of support afforded by the home country government. The range of institutional factors that may affect the IMS of engineering contractors are summarized in Table 1.

Table 1. Institutional factors potentially impacting a contractor's international market selection.

Institutional Factor	Relevant Description Examples	Sources
Institutional stability/Institutional quality	The quality of the institutional system can impact project performance and international expansion; countries with mature and stable institutional systems show relatively low growth rates in the construction market.	[12,14,31,33–35,39,40,42,43]
Institutional distance/Cultural distance	The institutional distance can impact market choice and entry modes by causing trouble for firms across it. A high institutional distance deters the firm's performance.	[10,15,26,30,44–47]
Country risk/Politic risk/Institutional risk	Country risks include economic, political, and institutional risks. Institutional risks can impact project costs and schedules.	[41,48,49]

Table 1. *Cont.*

Institutional Factor	Relevant Description Examples	Sources
Politic culture/Cultural characteristic	Different characteristics of countries' business systems, economic, financial, and administrative practices will affect managerial decisions.	[15,24,33,41,50]
Institutional restrictions	Legal entry restrictions; the existence of strict quality requirements. These barriers make it hard for firms to enter or operate in international markets.	[12,31,33–35]
Host-home country relationship	Colonial link, regional economical organization, bilateral agreements, foreign aid, and political ties/support. These relations can change the competitive advantage by offering reciprocal conditions and knowledge resources.	[10,15,32,36,38,41,50–55]
Attitude of the host government	Attitude toward foreign investors and profit can impact project performance.	[42,48]
Firms' ownership property	Chinese SOEs can create a specific ownership advantage by deriving benefits from the domestic capital market.	[41,53,56–58]

3. Hypotheses

Institutional factors exist at different levels including international, country, industry, and enterprise. In order to explore the impact of institutional factors on contractors' IMS, 10 specific institutional factors from four levels were selected for further analysis within the scope of empirical capacity. The factor categories and selected institutional factors are shown in Figure 1. This section infers the impact of selected factors and hypotheses were proposed based on theoretical derivations.

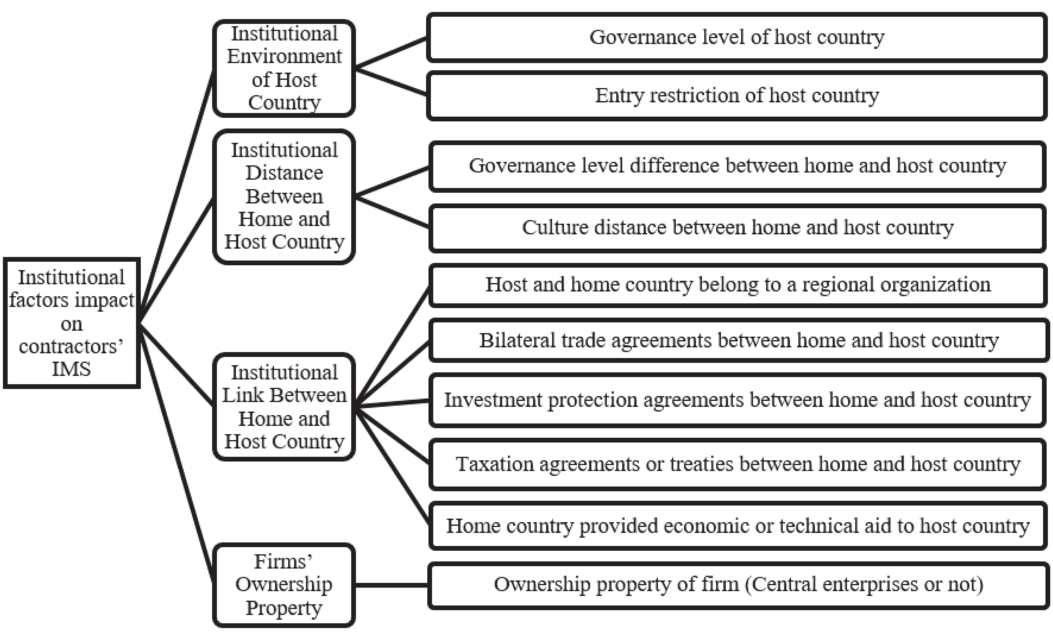

Figure 1. Selected institutional factors from multiple levels for analysis.

3.1. Institutional Environment of Host Country

Institutional environments reflect the overall context of the formal and informal institutions of a host country. Nevertheless, it is hard to define the kinds of institutions that may be considered ideal in all contexts. Scholars rank formal institutions according to governance efficiency, maturity, and stability [10,12]. Higher institutional quality means a stable and efficient institutional environment, which is generally associated with advanced economies, while lower institutional quality may generate obstacles to firm growth and higher transaction costs and exacerbate the risks to project profitability [31]. However, high-quality institutions are often complex and may lead to the imposition of significant costs if they are to be achieved and maintained [7,12,13,24]. For international contractors, institutions thus function as a 'double-edged sword.' Hence, it is supposed that:

Hypothesis 1a. *The higher the institutional quality of a host country, the more contractors tend to enter the host country.*

Market entry barriers are used to protect the domestic market in many countries. These barriers may manifest as ownership requirements, capital requirements, local-content requirements, local-employment requirements, quality standards, permit systems, rating systems, and licensing systems. These restrictions create an 'invisible wall' for foreign contractors attempting to access a country's market. Foreign contractors may jump the fence by adopting particular entry strategies, such as through joint ventures, but it becomes more difficult for foreign contractors to find an acceptable entry strategy where there are greater restrictions and they are less likely to enter the market [18,33,39,40]. Thus, the following hypothesis is developed:

Hypothesis 1b. *The more entry restrictions of a host country, the fewer contractors tend to enter the host country.*

3.2. Institutional Distance between Home and Host Country

Informal institutions mainly refer to culture, and since it is hard to determine which forms of the informal institution are preferable, a more useful proxy in measuring this variable, as is the precedent used in most studies, is cultural distance.

Institutional distance is a measure of cross-country differences with respect to the similarity or dissimilarity that exists between the regulatory, normative, and cognitive institutions of two countries [6]. The regulatory environment comprising elements such as constitutions, laws, and property rights, varies in different countries, leading to 'regulative distance' or 'formal institutional distance' between home and host countries. Countries also vary significantly across normative and cognitive dimensions that include elements such as informal norms, values, shared beliefs, imperatives to action, mental modes, and practices that guide behavior and decisions [44,45]. The cognitive and normative dimensions of a country's institutional context are conceptually close to culture [17]. So, institutional distance is usually divided into two distinct parts: formal institutional distance and cultural distance [18,59].

When foreign contractors first enter an unfamiliar country, they lack local institutional knowledge, such as legal requirements, traditional practice, and so on. This kind of deficiency imposes a relative weakness as compared with local contractors, which scholars have dubbed the 'liability of foreignness' [15]. Generally speaking, the greater the institutional distance between home and host country, the more conspicuous the liability of foreignness imposed on foreign contractors, and the greater the cost of establishing legitimacy, communication, and understanding [13,14]. Contractors are assumed to be reluctant to choose markets that have a greater institutional distance [60]. Therefore, it is proposed that:

Hypothesis 2a. *The greater the formal institutional distance between home and host country, the fewer contractors tend to enter the host country.*

Hypothesis 2b. *The greater the cultural distance between home and host country, the fewer contractors tend to enter the host country.*

3.3. Link between Home and Host Country

From an institutional perspective, the link between the home and host country is fundamentally embodied in cooperation agreements or reciprocal treaties. Globalization and bilateral and multilateral free trade agreements have facilitated increased business opportunities for construction firms across the globe [43]. These agreements set out the cooperation framework and enable enterprises to garner certain institutional advantages when operating offshore [61]. Close linked economies serve transnationals by reducing operational costs, such as transaction costs, communication costs, and financial costs. For example, regional trade agreements among member countries [62], bilateral trade agreements, taxation treaties, and investment treaties [36] are evident institutional pull factors [51]. A conducive attitude exhibited by the host government provides a positive inducement to foreign contractors, which in turn facilitates greater opportunities to gain contracts while reducing conflict and political risk in the delivery of local projects [54,55]. Although a heavy investment in relationship building is the norm when currying favor with local governments, the economic and technical assistance provided by the home government to the host country is certainly an effective contributing factor [52,63]. Thus, close links between the home and host country promote more active cooperation. Therefore, it is proposed that:

Hypothesis 3a. *If the home and host country belong to the same regional economic organization, more contractors tend to enter the host country.*

Hypothesis 3b. *If the home and host country have signed trade agreements, more contractors tend to enter the host country.*

Hypothesis 3c. *If the home and host country have signed taxation agreements, more contractors tend to enter the host country.*

Hypothesis 3d. *If the home and host country have signed investment protection agreements, more contractors tend to enter the host country.*

Hypothesis 3e. *If the home country has provided foreign aid to the host country, more contractors tend to enter the host country.*

3.4. Firms' Ownership Property

Some specific international contractors enjoy more resource advantages related to institutional factors than other enterprises. For example, Bechtel Reston, VA, USA, Hyundai E&C Seoul, South Korea, and ENKA Istanbul, Turkey have received abundant funds and project resource support from their home governments in their international development. The most representative case occurs in China, which is dominated by the public-owned economies. Most Chinese project contractors active in the international market are state-owned enterprises [37,38]. Although SOEs are known to underperform relative to private competitors [56], they have a greater advantage when it comes to obtaining subsidized loans, and given state support, rarely succumb to bankruptcy [57]. Moreover, Chinese international SOE contractors have greater political and economic resources at their disposal and, consequently, enjoy a greater capacity to mitigate foreign marketplace risks [41]. This leads them to gravitate to countries serving China's political aims, places with plentiful natural resources, while not shying from dubious political environments; whereas private firms will clearly remain normative market seekers [58].

Chinese state-owned contractors are directed by the central or local governments. Chinese central enterprises are controlled by the State-owned Assets Supervision and Administration Commission (SASAC). The SASAC was established by the State Council in 2003 as the primary government institution charged with managing the state-owned assets embedded in non-financial sectors. SASAC is China's biggest investor and owner of China's non-financial SOEs and serves as the leading managing agency for these assets. The commission has wide-reaching responsibilities, resources, and power [53]. Central enterprises are positioned as an important catalyst for national economic development. It is to be expected, therefore, that central government enterprises receive more support from the home country than from the host government when operating abroad. Therefore, it is proposed that:

Hypothesis 4. *Central enterprises are more active in the international construction market than other enterprises.*

4. Methodology

In order to test whether the role of institutional factors on contractors' IMS decision-making practice conforms to theoretical assumptions, empirical research is conducted based on historical cross-sectional data.

4.1. The Materials

Over the past 20 years, Chinese contractors have been the fastest growing force in the international construction market. Based on data supplied by ENR's top 250 international contractors list, Chinese contractors' market share has risen to first place, displacing Spain's 13.10%, with 17.20%, in 2014, and reaching a record of 25.6% in 2020 [64–68]. A total of 78 Chinese enterprises comprise ENR's top 250 list. This gives legitimacy to the choice of Chinese contractors as the sample set for IMS observation. Meanwhile, as a developing country, China's large international contractors are mainly state-owned enterprises. In this special context, selecting Chinese contractors for observation has more potential to find interesting phenomena related to institutional factors.

Average data for a continuous five-year period are collected to reduce the impact of accidental factor fluctuations. The ENR 'Top 250 International Contractors' (hereinafter referred to as TIC) annual report ranks contractors based on the previous year's international revenue, and tables relevant data on 'Where the Top 250 International Contractors Worked-by Country' (hereinafter referred to as TIC-WTW). This data source is utilized for measuring the dependent variable. This study began with an idea in 2017. However, the ENR TIC 2016 report omitted the TIC-WTW component, and consequently, the research period was constrained to 2010–2014 [64–68].

In order to ensure representativeness, the sample is restricted to those Chinese contractors with continuous operation experience in international markets. Companies qualified for sampling if they appeared on the TIC list at least three times over the research period. That precondition supplied a sample of 54 Chinese contractors who were collectively active across 80 countries. As a result, a total of 4320 (54×80) data points were generated by matching the sampled contractor's IMS across sampled countries. The sampled contractors list is summarized in Table 2.

Table 2. The number of sampled Chinese contractors by listed times on ENR TIC 2011–2015.

Listed Times on ENR TIC 2011–2015	Number of Sampled Firms
3	9
4	11
5	34
Total	54

4.2. Variables Measure

4.2.1. Dependent Variables

The dependent variable—International Market Selection (IMS_{ij})—is a dummy variable indicating whether the i contractor has entered the j market. In the TIC-WTW reports from

2011 to 2015, if i is active in j country for at least one year, the IMS_{ij} is 1. The form of IMS can be projected by contracting or investment. This is confirmed by retrieving publicly available data from company websites and the overseas enterprises (agencies) activities summary recorded by the Ministry of Commerce of China. If i contractor has established a local agency in the j market, i is considered to have entered the j market, and the value of IMS_{ij} is 1. Otherwise, the IMS_{ij} is 0.

4.2.2. Explanatory Variables

- Governance level of the host country (GL_j)

In light of previous research [7,10], the World Governance Indicators (WGI) developed by World Bank were used to measure the formal institutional quality of a host country. According to the Worldwide Governance Indicators Methodology and Analytical Issues, governance was defined as the traditions and institutions by which authority in a country is exercised [11]. The WGI index includes six sub-indicators: (1) transparency and accountability; (2) political stability; (3) government effectiveness; (4) regulatory quality; (5) legal system; and (6) corruption control. Collectively, these comprehensively reflect the institutional quality of a country, including its administration and judicature. The detailed data on the six sub-indicators of the WGI from the years 1996 to 2015 are given on the World Bank's website, at: http://info.worldbank.org/governance/wgi/index.aspx#home (accessed on 24 February 2017). Consistent with the research period, data from 2010 to 2014 is used.

The six sub-indicators are highly correlated. To simplify the original sub-indicators, we refer to the precedent set by Chan [7] in order to conduct a Principal component analysis (PCA) using IBM SPSS version 23 software. The process converts the six sub-indicators into a one-dimension index for measuring the formal institutional quality of a country. That index is nominated as the Governance Level.

- Governance level difference between host country j and China (GLD_j)

Thus, the absolute difference in Governance Level between host country j and China is used to quantify a comparative formal institutional distance.

- Belongs to a regional organization as China (BO_j)

BO_j is a dummy variable. If country j partakes in a regional trade or economic organization where China is also a member, the value of BO_j is 1, otherwise, it is 0. Prior to 31 December 2014, the main regional economic organizations to which China belonged were the Asia-Pacific Economic Cooperation (APEC) and Shanghai Cooperation Organization (SCO). While China joined the World Trade Organization (WTO) in 2001, almost all countries can be counted as WTO members, which nullifies its usefulness as a metric, and therefore the WTO is not considered here.

- Bilateral trade agreements (TA_j), Bilateral investment agreements (IA_j), and Taxation agreements or treaties (TAT_j)

TA_j, IA_j, and TAT_j are dummy variables. The China commerce yearbook, 2015, provides a list of countries or regions that have signed trade agreements, investment protection agreements, tax arrangements, or treaties with China, as of 31 December 2014. If any such agreement exists between China and country j, the corresponding variable TA_j, IA_j, or TAT_j is 1, otherwise, it is 0.

- Foreign aids (FA_j)

FA_j is also a dummy variable. As per the data lodged on the website of the Foreign Aid Department of the Chinese Ministry of Commerce and White Paper on China's Foreign Aid (2014), if records reveal that the Chinese government provided economic or technical aid to country j before 31 December 2014, the FA_j is 1, otherwise, it is 0.

- Entry restriction (ER_j)

The specific measurement method of ER_j follows the precedent set by Chen (page 309–310) and need not be repeated here [37]. The main data sources regarding entry restrictions are the sector-specific commitments for construction and related engineering and technical barriers to trade as a WTO member country. Supplementary data are derived from the Investment Guide to Foreign Countries, issued by the Ministry of Commerce of China.

- Ownership property (OP_i)

OP_i is a dummy variable. Since the sampled enterprises are all state-owned enterprises (SOEs), property ownership is determined on the basis of whether or not the firm is a central enterprise. If firm *i* is a central enterprise, OP_i has a value of 1, and 0 otherwise. Chinese central enterprises are directly controlled by the State-owned Assets Supervision and Administration Commission of the state council (SASAC). Following strategic restructuring and decentralization, the SASAC released a list of 97 central national state-owned enterprises (SOEs) on 27 December 2017. Central enterprises are regarded as critical drivers of national economic development.

- Cultural Distance (CD_j)

Cultural distance is regarded as arising from informal institutional factors. Certain empirical studies have confirmed its negative effect on international market selection [18]. The measure of cultural distance borrows from the work of Geert Hofstede. Professor Hofstede's measurement of cultural distance comprises four dimensions: Power distance, Individualism/Collectivism, Masculinity/Femininity, and Uncertainty Avoidance. Subsequently, two further dimensions were identified: Long Term Orientation and Indulgence. The scores for each dimension are posted on the website https://geert-hofstede.com/albania.html (accessed on 26 June 2016). There are currently data from 101 countries, though data for two new dimensions are not yet available.

If I_{kj} represents the score of country j in the k dimension, I_{kc} represents the score of China in the k dimension, V_k represents the variance of the k dimension, and n_j is the number of dimensions of *j* country. The following formula is used to determine the cultural distance between China and country *j*:

$$CD_j = \sum_{k=1}^{4\sim6} [\left(I_{kj} - I_{kc}\right)^2 / V_k] / n_j \tag{1}$$

4.2.3. Control Variables

In addition to the above institutional factors, the market selection of Chinese contractors is also affected by many other factors. According to the existing empirical research, several factors are selected here as control variables.

- Geographic distance (GD_j).

In selecting an international market, the geographic distance between countries is a matter of concern. It is generally believed that an increased distance between home and host countries diminishes the likelihood that a multinational company would enter that country [60]. Country distance is a separate matter from an institutional distance. Here geographic distance is chosen as a control variable that has been studied for its impact on international contracting market selection [18]. Geographic distance is derived from the CEPII GeoDist Database. The distance from the host country's capital to the capital of China, Beijing, is taken to be the geographical distance between the two countries.

- GDP and GDP growth ($LnGDP_j$ and $GDPGrowth_j$).

The market size and market potential of the host country will affect the market selection of international contractors, where international project contractors are more likely to choose markets with a larger size and potential [18,37]. In many studies, the gross domestic product (GDP) of a country is used to reflect the country's market size, and the market potential is reflected in GDP growth. The market size and market potential of the host country can thus be calculated by the average GDP and GDP growth rates, from 2010 to 2014. Since the magnitude of GDP is cumbersome, we use *LnGDP* as an alternative to GDP.

- Competition intensity (CI_j).

Competitive intensity within host markets can be expected to increase the entry difficulties of international contractors, and detract from operational profitability. Theoretically, international contractors are more likely to choose markets where competition is lower [18]. This study focuses on the field of international contracting, thus competitive intensity is measured by the entry of international engineering contractors within a target market. Extrapolating from ENR's reports, the number of international contractors operating in various markets on a year-by-year basis is noted, and a total is calculated for the period from 2010 to 2014, to generate the market competition intensity index CI_j.

- Firm size and Multinational experience (FS_i and MNE_i).

Internal construction company characteristics also play into a firm's international market selection. These include considerations such as strategy, firm size, and multinational experience. Strategy is a factor relatively difficult to assess, so the control variables are limited to company size and multinational engineering experience. Firm size (FS_i) is measured by the average of total revenues, as reported by ENR, from 2010 to 2014. Multinational experience (MNE_i) is measured by the sum of different markets entered each year, from 2005 to 2014.

4.3. Logistic Regression Models

When the dependent variable is binary, the logistic regression analysis is a suitable statistical analysis method. The logistic regression analysis has been widely used in research on international market entry strategy and shows merits such as reliable analysis results and strong interpretability. Therefore, this study chooses the logistic regression model as the main vehicle. For the linear relationship between *GL* and *GLD*, their effect on the dependent variable will be tested in logistic regression models 1 and 2, respectively.

Model 1:

$$\begin{aligned} Logit\ (P_{ij}) &= log\ [P_{ij}/(1-P_{ij})] \\ &= \beta_0 + \beta_1 GL_j + \beta_2 BO_j + \beta_3 TA_j + \beta_4 IA_j + \beta_5 TAT_j + \beta_6 FA_j + \beta_7 ER_j + \beta_8 OR_i + \beta_9 CD_j \\ &\quad + \beta_{10} GD_j + \beta_{11} LnGDP_j + \beta_{12} GDPGrowth_j + \beta_{13} CI_j + \beta_{14} FS_i + \beta_{15} MNE_I \end{aligned} \quad (2)$$

Model 2:

$$\begin{aligned} Logit\ (P_{ij}) &= log\ [P_{ij}/(1-P_{ij})] \\ &= \beta_0 + \beta_1 GDL_j + \beta_2 BO_j + \beta_3 TA_j + \beta_4 IA_j + \beta_5 TAT_j + \beta_6 FA_j + \beta_7 ER_j + \beta_8 OR_i + \beta_9 CD_j \\ &\quad + \beta_{10} GD_j + \beta_{11} LnGDP_j + \beta_{12} GDPGrowth_j + \beta_{13} CI_j + \beta_{14} FS_i + \beta_{15} MNE_I \end{aligned} \quad (3)$$

where P_{ij} = probability that Contractor i enters Country *j*.

Explanatory variables: GL_j, GLD_j, CD_j, BO_j, TA_j, IA_j, TAT_j, FA_j, ER_j, and OP_i = the governance level, the distance of governance level, cultural distance, belonging to the same organization, trade agreements, investment agreements, tax agreements or treaties, foreign aid, entry restriction, and ownership property, respectively.

Control variables: GD_j, $LnGDP_j$, $GDPGrowth_j$, CI_j, FS_i, and MNE_i = geographic distance, Ln of GDP, GDP growth rate, competitive intensity, firm size, and international experience, respectively.

Regarding the interpretation of the model, it can be summarized into three cases: (1) If $\beta_m = 0$, the change of explanatory variable m is irrelevant to P_{ij}; (2) if $\beta_m > 0$, when other variables remain unchanged, as variable m increases, the value of P_{ij} increases, that is to say, as variable m increases, IMS_{ij} is more likely to be 1; and (3) for the same reason if $\beta_m < 0$, as variable m decreases, IMS_{ij} is more likely to be 0. This study was concerned about the direction of the influence of the variables on IMS, thus the direction of the coefficient β and the significance was interpreted.

5. Data Analysis

5.1. Model Test

Prior to conducting a logistic regression analysis, the correlation of the independent variables was tested to see if there was any sign of multiple collinearities in the data. From the results of the correlation test (see Table 3), *GL* and *GLD* in the correlation matrix prove to be highly significantly correlated. This is due to their inherent relationship. However, and importantly, because they do not occur in the same model, this resolves the problem. Of the other 119 correlation coefficients, 6 were more than 0.5 but less than 0.6, and 2 were close to 0.5. These 8 correlation coefficients were at a medium level, and they do not exceed 7% of the total. Consequently, there is no concern that multicollinearity will significantly tarnish the results.

As a further test, multicollinearity diagnosis was performed on the two models and the tolerance coefficients and variance inflation factors for all independent variables were calculated (see Table 4). Results confirm a minimum tolerance coefficient of 0.3118, with a maximum variance inflation factor of 3.2068. Together, these indicate that any multicollinearity will not seriously affect the analysis results [69].

Amongst scholars, there remains no absolute criterion to judge a model's goodness-of-fit. It is generally accepted that the logistic regression model is significant if the *p*-value of '−2Log likelihood' is less than a given significance level. The Cox and Snell R-Squared and the Nagelkerke R-Squared are usually considered to comprise the total explanatory effect of independent variables. The closer the value is to 1, the better the fit of the model. From the data found at the bottom of Table 4, both models prove to be significant, with a 39% explanatory effect. Therefore, both models exhibit a good degree of fit.

Chatterjee and Hadi suggest that max (n_1/n, n_2/n) can be taken as a threshold standard when using the 'Correct classification rate' to judge the validity of a logistic regression model [70], where n is the sample size, n_1 and n_2 are, respectively, the numbers of 0 or 1 of the observed values of the dependent variables. If the 'Correct classification rate' is greater than max (n_1/n, n_2/n), the model can be considered valid. As seen from Table 5, the 'Correct classification rates' 84.7% and 85.1% are bigger than max (n_1/n, n_2/n) = 3477/4320 = 80.5%.

Thus, the two models can be considered to be valid.

5.2. Logistic Regression Analysis and Hypotheses Test

A binary logistic regression analysis was conducted using SPSS 23. For all dummy independent variables, 0 is used as the reference group. The analysis results of models 1 and 2 are shown in Table 4. Seven of the ten explanatory variables are statistically significant ($p < 0.01$ or $p < 0.05$) which indicates that the corresponding institutional factors have salient impacts on the contractor's IMS. Positive regression coefficients show that the explanatory variables *BSO*, *BTA*, *FA*, and *OP* increase the possibility of IMS. By contrast, negative coefficients show that the explanatory variables *GL*, *GLD*, and *IPA* decrease the possibility of IMS. Three of the ten explanatory variables *TAT*, *ER*, and *CD*, however, are statistically insignificant ($p > 0.05$) which may indicate that Chinese contractors' IMS is not meaningfully influenced either way by those three factors.

Having calculated the statistical impact of the 10 variables, the logistic regression analysis results were compared with the developed hypotheses drawn out of the literature, and the outcomes for the hypotheses were determined (see Table 5).

Both hypotheses regarding the institutional environment—H1a and H1b—are not supported. Although significant, the negative coefficient of *GL* suggests that Chinese contractors tend to choose host countries with lower formal institutional quality, which is contrary to hypothesis H1a. Moreover, the insignificant coefficient of *ER* indicates that Chinese contractors' IMS are not sensitive to the legal entry restrictions of host countries, refuting hypothesis H1b.

Table 3. Correlation matrix and description statistics.

Variables	GL	GLD	BO	TA	IA	TAT	FA	ER	OP	CD	GD	lnGDP	GDPGrowthCI		FS	MNE
GL																
GLD	0.969 **															
BO	0.129 **	0.140 **														
TA	0.132 **	0.169 **	0.125 **													
IA	0.245 **	0.190 **	0.114 **	0.493 **												
TAT	0.318 **	0.342 **	0.130 **	0.448 **	0.434 **											
FA	−0.584 **	−0.578 **	0.012	0.109 **	0.023	−0.328 **										
ER	−0.132 **	−0.181 **	0.030 *	0.199 **	0.223 **	0.243 **	0.061 **									
OP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000								
CD	0.107 **	0.106 **	−0.044 **	0.068 **	0.066 **	0.087 **	0.015	0.213 **	0.000							
GD	−0.111 **	−0.124 **	−0.101 **	−0.321 **	−0.322 **	−0.578 **	0.118 **	−0.134 **	0.000	0.030						
lnGDP	0.372 **	0.418 **	0.392 **	0.311 **	0.201 **	0.574 **	−0.351 **	0.058 **	0.000	0.096 **	−0.221 **					
GDPgrowth	−0.167 **	−0.279 **	0.078 **	−0.149 **	0.035 *	−0.169 **	0.146 **	0.141 **	0.000	−0.068 **	0.075 **	−0.211 **				
CI	−0.116 **	−0.064 **	0.495 **	0.309 **	0.102 **	0.295 **	−0.048 **	0.377 **	0.000	0.035 *	−0.196 **	0.587 **	0.072 **			
FS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.314 **	0.000	0.000	0.000	0.000	0.000		
MNE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.373 **	0.000	0.000	0.000	0.000	0.000	0.578 **	
Mean	0.54	1.48	0.16	0.93	0.83	0.71	0.53	7.29	0.50	2.26	9.06	5.20	0.03	146.09	9.30	117.80
Standard Deviation	1.38	1.26	0.37	0.26	0.38	0.45	0.50	3.99	0.50	2.93	3.82	1.73	0.03	92.82	20.08	136.93

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

Table 4. Determinants of International Market Selection: Binary Logistic Test (n = 4320, entry = 843, no entry = 3477).

Variable	Model 1				Model 2			
	B	Sig.	Tol.	VIF	B	Sig.	Tol.	VIF
Intercept	−6.1020	0.0000			−5.6787	0.0000		
GL	−0.3412	0.0000	0.4249	2.3534				
GLD					−0.3567	0.0000	0.4339	2.3049
BSO	0.2968	0.0269	0.6365	1.5712	0.2636	0.0483	0.6445	1.5515
BTA	2.0305	0.0000	0.5614	1.7814	2.0787	0.0000	0.5542	1.8043
IPA	−0.3302	0.0253	0.6127	1.6320	−0.4354	0.0027	0.6295	1.5886
TAT	−0.2766	0.0818	0.3458	2.8922	−0.2117	0.1846	0.3475	2.8781
FA	0.5060	0.0003	0.4839	2.0665	0.5658	0.0000	0.5060	1.9764
ER	0.0086	0.5203	0.6533	1.5306	−0.0022	0.8705	0.6466	1.5465
OP	0.4794	0.0000	0.8462	1.1818	0.4779	0.0000	0.8462	1.1818
CD	−0.0174	0.2554	0.8990	1.1124	−0.0181	0.2359	0.8974	1.1143
GD	−0.0403	0.0041	0.6153	1.6254	−0.0391	0.0055	0.6152	1.6255
lnGDP	0.1425	0.0028	0.3118	3.2068	0.1269	0.0072	0.3178	3.1465

Table 4. *Cont.*

Variable	Model 1				Model 2			
	B	Sig.	Tol.	VIF	B	Sig.	Tol.	VIF
GDPgrowth	13.6387	0.0000	0.8374	1.1942	12.0162	0.0000	0.8249	1.2123
CI	0.0049	0.0000	0.3191	3.1341	0.0055	0.0000	0.3440	2.9073
FS	0.0030	0.1823	0.6549	1.5269	0.0030	0.1849	0.6549	1.5269
MNE	0.0068	0.0000	0.6251	1.5998	0.0068	0.0000	0.6251	1.5998
−2 Log likelihood	3048.979 [a]				3055.454 [a]			
Cox and Snell R Square	0.2453				0.2441			
Nagelkerke R Square	0.3909				0.3890			
Correct Classification rate (%)	84.7				85.1			

Note: [a] Because the change in the parameter estimate is less than 0.001, the estimate is terminated at the sixth iteration.

Table 5. Explanatory variable description and hypotheses test results.

Explanatory Variables	Description	Hypotheses	Effects Assumed	B Value in Model 1	B Value in Model 2	Support or Not
GL	Governance level of the host country	H1a	+	−0.3412 **		contrast
ER	Entry restriction of the host country	H1b	−	0.0086 #	−0.0022 #	no
GLD	Governance level difference between the host country and China	H2a	−		−0.3567 **	yes
CD	Cultural distance between the host country and China	H2b	−	−0.0174 #	−0.0181 #	no
BO	The host country and China belong to a regional organization	H3a	+	0.2968 *	0.2636 *	yes
TA	Bilateral trade agreements between the host country and China	H3b	+	2.0305 **	2.0787 **	yes
IA	Investment protection agreements between the host country and China	H3c	+	−0.3302 *	−0.4354 **	contrast
TAT	Taxation agreements or treaties between the host country and China	H3d	+	−0.2766 #	−0.2117 #	no
FA	China provided economic or technical aid to the host country	H3e	+	0.506 **	0.5658 **	yes
OP	Ownership of property of firm (central enterprises or not)	H4	+	0.4794 **	0.4779 **	yes

Note: * $p < 0.05$; ** $p < 0.01$; # $p > 0.05$.

As for hypotheses related to institutional distance, H2a was well confirmed by the significant negative coefficient of *GLD*. This suggests that Chinese contractors tend to choose host countries with less formal institutional distance to China. However, the insignificant coefficient of *CD* reveals that cultural distance does not influence Chinese contractors' IMS, and so does not support H2b.

More positively, three of the five hypotheses concerning country link—H3a, H3b, H3e—are confirmed. The significant positive coefficients of *BO*, *TA*, and *FA* mean that these three types of linkages between the two countries do increase the probability that contractors will enter the host country: regional trade or economic organizations, bilateral trade agreements, and foreign aid coming from China. On the other hand, the negative coefficient of IA is significant at the 0.05 level. This shows bilateral investment agreements reduce the possibility of Chinese contractors' IMS and refutes hypothesis H3c. The coefficient of *TAT* is not significant, and thus hypothesis H3d is not supported.

The hypothesis on the property ownership of firms, H4, was also confirmed. The significantly positive coefficient of *OP* indicates that central enterprises are more active than local enterprises in the international contractor market.

6. Findings and Discussion

In summary, five of the ten hypotheses are confirmed. This shows that the Chinese contractor IMS conforms to a range of theoretical expectations that derive from an institutional-based view of international construction management. At the same time, however, two hypotheses refute theoretical expectations, as predicted by institutional theory. While a range of firm behavioral patterns is here shown to endorse an institutional theory view of international construction, the fact that two reasonable predictions have not panned out should give international management theorists some pause. Moreover, three of the hypotheses were simply unconfirmed. That again is a reason to rethink the impact institutions have on international construction activity, specifically in regard to Chinese contractors. This study can therefore be expected to provoke and reignite discussion on the explanatory power of institutional theory.

Statistical analysis results show that Chinese contractors prefer international markets with lower formal institutional quality. This finding supports certain earlier research which concludes that Chinese contractors tend to enter countries with high country risk [18]. Such high-risk markets are generally characterized as having low institutional quality. In turn, low institutional quality is associated with high costs and scheduling overruns, quality issues, and other difficulties. In fact, certain studies have previously asserted that Chinese enterprises behave irrationally with regard to IMS [16,49]. By contrast, this study offers an explanation of this phenomenon by way of taking an institutional distance perspective. Chinese contractors' preference for host countries offering closer institutional distances results in market entry choices that preference those countries with lower formal institutional quality. Consider that China's GL score is -0.83, which is nearly a standard deviation below the average value of the other sampled countries. The institutional quality of a country may have different impacts on contractors coming from different countries. For contractors who are accustomed to so-called 'low institutional quality', possibly higher institutional quality confers a greater 'liability of foreignness' that more than offsets operational efficiency.

Additionally, it appears that Chinese contractors' IMS is insensitive to the entry barriers of the host market. The reason for this result may lie in the measurement of entry restriction which reflects not an absolute prohibition of entry, but rather a threshold. Therefore, Chinese contractors can overcome this entry barrier by adjusting their entry mode. For example, joint-venture configurations with local partners can be used when foreign contracting is not permitted.

Chinese contractors' IMS is not sensitive to cultural distance. This contradicts the theoretical hypothesis and refutes an abundance of existing research [18]. The reason may lie in the fact that 15 independent variables were used in each model in this study, while only 7 factors were considered in the study undertaken by Chen. The correlation between variables can be expected to weaken some effects as the number of variables employed rises. Incidentally, the control variable FS is not significant, which is also inconsistent with Chen's findings. The explanation may be similar, since FS exhibits a strong correlation with OP and MNE, while China's central enterprises are usually large, capital sound, and well-resourced in the multinational context.

As for institutional links, Chinese contractors' IMS is insensitive to bilateral taxation agreements, especially bilateral investment protection agreements, which do show significant unanticipated negative effects. Possibly this is because bilateral investment protection agreements and taxation treaties differ from country to country and are dynamic over time. Consequently, their positive or negative impacts are specific, conditional, and fluid. For instance, in the 1980s, China signed investment protection agreements with most developed countries, with most of these treaties being initiated by developed countries in order to protect their investments in China. By the 1990s, however, China began to seek out investment protection agreements with developing countries, this time in order to protect its investments abroad [51].

7. Conclusions and Limitations

Institutional factors constitute an indispensable consideration in a contractor's international market entry strategy [27]. Yet, the role of the institutional factors on contractors' IMS decision-making has hitherto not been comprehensively assessed. To address this gap, this study comprehensively reviews institutional factors affecting contractors' IMS and makes assumptions and empirical analyses on the effects of 10 specific institutional factors at different levels. The following conclusions can be drawn:

(1) The results show that 7 of the 10 institutional factors have a significant impact on Chinese contractors' IMS. These factors cover all four categories in the empirical research, which manifests that the IMS of contractors is affected by institutions from different levels. It is necessary to consider institutional factors comprehensively in IMS decision-making research and practice.

(2) All the hypotheses of this study are based on universal theories. The five hypotheses confirmed include: the contractor's IMS is negatively affected by the institutional distance and positively affected by the link between home and host countries (bilateral trade agreements, regional organization, foreign aid) and the ownership property of central enterprises. Although the empirical evidence takes Chinese contractors as the sample, these conclusions have important reference value for the IMS practice of global contractors, the development of the IMS decision-making model by academic researchers, and even the policymaking adopted by governments to promote domestic contractors to go abroad.

(3) It is interesting to find that the institutional quality of the host country and bilateral investment agreements play a significant role in Chinese contractors' IMS, but are contrary to the hypotheses. The reason for this phenomenon lies in the current situation of China's institutional quality and the history of bilateral investment agreements. For international contractors from other countries, the role of these two institutional factors may be different due to different home country backgrounds. This reminds scholars and managers that specific historical and practical backgrounds must be weighed when applying institutional factors in IMS.

This study fills an overlooked gap regarding the role multi-dimensional institutional factors play in contractors' IMS. Moreover, it enriches the input information that lends support to IMS decision-making. The research results can be utilized by stakeholders, managers, government, and interested parties. However, there are still some limitations in this study that need to be settled in future research.

First, this study only discusses the impact of institutional factors on the IMS of construction contractors at a broader level. Future research can also be subdivided on the basis of detailed data, such as studying the similarities and differences of the effects of institutional factors in different engineering fields such as civil engineering, bridge construction, road construction, and high-speed railway construction.

Second, the empirical part of this study is based on historical data, but the global institutional environment and market have changed dramatically with COVID-19. According to institutional change theory, institutions are often developing in a gradual process and substantive changes often take a long time to accumulate if outbreaks do not happen. In basing a study on panel data, or comparing data before and post COVID-19, more enlightening findings are expected to be explored.

Finally, this study discusses respective roles under the assumption that all institutional factors are independent. However, institutional factors may interact in practice. Under the premise of interaction, the comprehensive role of institutional factors on contractor IMS needs further discussion.

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Review

Organizational Aspects and Practices for Enhancing Organizational Project Management Maturity

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Abstract: An organization's performance in a project is determined by its ability to implement project management knowledge and practices. This ability reflects the organization's level of project management maturity (PMM). PMM is premised on the belief that the higher the PMM level, the higher the ability to successfully deliver a project. With this in mind, the current paper aims to determine the type of organizational aspects and practices that could influence the success of PMM implementation in organizations. For this purpose, a systematic literature review (SLR) was performed on 23 articles published between 2011 and 2021 that studied PMM. The findings showed that most articles stressed organizational culture and integration with strategic organizational initiatives. Among all the studied industries, the information technology industry stood out. Content analysis was used for analyzing data, which were thematized using ATLAS.ti. Ten sub-themes emerged, with six sub-themes under organizational aspects and four sub-themes under organizational practices. These sub-themes, which were intertwined with the implementation and growth of PMM in organizations, positively impact project delivery performance. Based on this, several future research opportunities were proposed.

Keywords: project management maturity; project management maturity models; strategic initiatives; organizational culture; project complexity; integration mechanism; project management office; stakeholder differences; systematic literature review

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1. Introduction

Most organizations use projects to achieve their strategic business objectives [1], and the success of each project is critical for fulfilling organizational objectives. Accordingly, project management has become an important strategic discipline for organizations to follow to deliver successful projects [2]. However, despite the global advancements seen in project management, the success rate of organizational projects has been stagnant [3]. Evidence has shown that successful projects are strongly correlated to the organization's project management capability; when an organization's project management ability is high, its success rate increases. Project Management Maturity (PMM) is an important tool for organizations to determine their project management capabilities.

As an indicator of an organization's ability to perform certain tasks, PMM is used to make continuous improvements [4,5]. Its model, the Project Management Maturity Model (PMMM), is a systematic framework used to assess and evaluate the organization's current ability level [6]. PMM works on the premise that the higher the organization's project management maturity, the higher the organization's ability to successfully deliver a project [7].

Continuous improvements form the foundation of the relationship between organizational performance, project management, and project management maturity [5]. PMM and its models are one of the strategic improvement initiatives to increase the project success rate. While projects are critical to an organization's sustainability [1], project management processes and practices are common in organizations, particularly in large and complex projects [3]. On the other hand, organizations rely on successful projects to achieve their intended business objectives. However, only capable and effective project management leads to a better chance of delivering a successful project [7]. Therefore, organizations adopt PMM as a strategic improvement initiative to increase their project management effectiveness and deliver a successful project.

Despite the many available models, the objectives and construct of the PMMM are the same as its predecessor, Capability Management Maturity Integration (CMMI). CMMI was developed by the Software Engineering Institute in the late 1980s. It aimed to increase the success rate of information technology (IT) projects [8] but was widely used in other services, including project management, risk management, and personnel management [9]. The success and popularity of the CMMI led to the existence of more than 30 models in the market today [10,11].

As shown in Appendix A, the development of the PMMMs was based on a similar objective: to assess the organization's project management competence and capability and "to classify it along with a number of maturity levels" [8]. Another similarity is that the PMMMs were built on two-dimensional structures [12]. The first dimension focuses on the level of maturity, while the second focuses on the critical aspects of the project management knowledge area [13]. Two levels of maturity exist: the continuous level and the discreet level. The former consists of common language, common processes, singular methodology, benchmarking, and continuous improvements [14]. The latter comprises step-like levels of maturity [15]. The models are diverse. One established model is Kerzner's Project Management Maturity Model (KPM3 Model). It is often used at the continuous level to assess organizational maturity [16]. Another established model is the PM Solution, PMMM.

While the PMMM uses a discrete five-step-like maturity progression, the other two models adopt knowledge areas from the Project Management Body of Knowledge (PMBoK) issued by the Project Management Institute (PMI) [17]. This serves as a basis for the focus areas of the assessment. The PMM is a critical framework used in project management to enhance an organization's project management maturity and, hence, its project delivery performance.

Some organizations use the PMMM to assess, evaluate, and directly define the maturity of their area of interest. Such organizations also can quantify their ability to manage their projects successfully. The PMM describes the organization's development processes to reach a desired future state [11]. Based on these promising benefits of the PMM, a continuous study of the PMM, and its associated models, is needed to uncover what organizations need to consider when adopting PMM. This knowledge could hasten the implementation process, allowing organizations to execute their projects more successfully.

The organization's level of project management maturity is determined by the "availability or degree of occurrence of single aspects of the project management structures" [8]. This concept assumes that a higher PMM level leads to better project management performance, increasing the success rate [18].

Current organizations adopting the PMM and its PMMMs expect to gain benefits and improve their project delivery. These benefits include the successful implementation of the PMM, improvements in their project delivery, and an improved organizational reputation [19]. Previous studies [19] have found that an organization's reputation is built on consistently delivering successful projects, thereby achieving its intended business goals, such as increasing shareholder value. Other studies [20] have found that mature organizations have a significantly better performance when compared to immature organizations in terms of the ability to effectively fulfill customers' needs. Other studies [21] have observed that one strategic way for organizations to improve would be to develop a close relationship with the PMM constructs. This may be costly in terms of resources, commitment, investments in software and licenses, consultant fees, and expenses for training, but there are significant benefits to be gained [22].

Previous studies suggest that PMM and its associated constructs lack a theoretical foundation, and most of the existing models were developed based on the continuous improvement concept [23]. As shown in Appendix A, the three examples of models demonstrate their relevance for contingency theory (CT) and dynamic capability. The CMMI and PM solution, which use PMMM's elements and constructs, demonstrate a strong ability, which needs to be extended based on the organization's "best practice, and its ability to integrate and reconfigure internal and external competencies" [24]. KPM3 was developed based on its critical success factors. As suggested by CT [25], the alignment of these elements with the project environment may lead to it fitting within the organizational aspects and practices, thus leading to an improved performance. This preliminary analysis suggests that existing models were developed based on multiple theories. This SLR may confirm this finding.

Studies have noted that low-level project management maturity was significantly related to poor project performance [26]. Previous global surveys conducted by industry researchers, such as the PMI and PricewaterhouseCoopers (PwC), have shown a lack in key focus areas. For instance, scope management contributed to poor project performance. The PMI survey also noted that low levels of project management maturity contributed to an average of 9.9% of dollars wasted for every billion dollars invested in development projects [1]. The highest occurrence was detected in projects implemented in Australia, where 13.9% of the cost was wasted for every billion dollars that were invested. The survey further indicated that the main reason for this was the inaccuracy of the gathered requirements. This illustrates low-level project management maturity, leading to poor project performance. A survey conducted by PwC found that high levels of poor project performance resulted from low levels of project management maturity. This was due to the project's failure to establish a proper project management methodology [27]. According to Kerzner Project Management Maturity Model (KPM3), the inability to identify a project management methodology is categorized as "common language", forming level one out of five maturity levels. At level one, organizations merely have a "good understanding of the basic knowledge of project management" [16]. Based on previous studies, it has been noted that successful implementation of the PMM increases organizational capabilities regarding project delivery, leading to organizational success [28].

Although PMM and its model have progressed since their inception in the late 1980s, the number of publications has decreased since 2014 [29]. PMM and its models, according to Pells [29], have become a "hard sell" in the industry. One of the reasons for this is that executives are unwilling to be assessed and evaluated, and to make their organization's results public, particularly to existing and potential clients.

Another reason for this decline is a lack of flexibility and practical methodology. Previous articles have brought attention to the ongoing problem of PMM and its models. Many previous researchers have identified PMM and its models as having ongoing issues, such as a lack of flexibility [30], a lack of practical methodology [31], and a lack of knowledge about the critical aspects of maturity assessments [22]. Backlund [22] indicated that the lack of empirical research in this area resulted in a lack of knowledge about which aspects are critical.

Research Questions

This SLR aims to uncover the critical organizational aspects and practices to assess and evaluate project management maturity level. The findings from this SLR may assist PMM model developers in improving existing models to become more flexible in their implementation. This knowledge would benefit organizations aiming to implement PMM as part of a larger initiative to successfully enhance their project delivery. The outcome can contribute to the effective implementation of PMM. The research questions are as follows:

1. What organizational aspects could influence the implementation of PMM in organizations?
2. What organizational practices could influence the success of PMM implementation?

This SLR may develop the maturity of the body of knowledge regarding project management if it successfully answers the above research questions. Based on the ideal concept of project management maturity, as suggested by Albrecht and Spang [23], this SLR offers the most critical organizational aspects and practices when assessing maturity. Organizational aspects and practices can broaden contingency theory (CT) to achieve fit conditions between the project management system and the project environments. In practice, this SLR may contribute in two ways. First, it can provide a reference for PMM model developers to improve existing models and make them more practical and flexible. Second, it can enable practitioners to identify existing organizational aspects and practices to determine whether the organization is ready to adopt and implement the PMM model. These actions have the potential to restore PMM value.

2. Methods

This paper employed a systematic literature review (SLR) as a research method to learn about the aspects and practices with the potential to enhance organizational project management maturity. The SLR was fortified by a bibliographic analysis that provides a holistic view of the necessary information about PMM. The SLR reveals the breadth and theoretical background of the examined topic [32]. Previous studies have proven SLR's success in answering research questions in various fields of study [32–34]. This success is because the previous studies strictly followed the SLR's established protocol [35,36]. This SLR follows a similar method. SLR could uncover more areas of the PMM, and the finer details of how it can successfully be implemented.

2.1. Study Design

The SLR was conducted following the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) statement. PRISMA is a published standard method, applied to reviews [33,35,36]. Before qualitative synthesis and content analysis, PRISMA was used to identify, screen, and assess the eligibility of the articles [37].

2.2. Eligibility Criteria

The SLR applied in this work only considered studies that fulfilled the following criteria: publications between 2011 and 2021, articles published in English, and a focus on project management maturity. Table 1 further illustrates the inclusion and exclusion criteria.

Table 1. The inclusion and exclusion criteria.

Criterion	Inclusion	Exclusion
Timeline	Articles published between 2011 and 2021	Any publication before 2011
Literature type	Journal (research paper)	Review paper, book, lecture, and conference
Language	Articles published in English	Non-English
Subject area	Project management maturity	Not project management maturity

2.3. Information Sources

Two databases, Scopus and ProQuest, were searched from August to September 2021. Although this was sufficient [38], Google Scholar [33] was also added to manually search for articles included in citations. Scopus has become a preferred source of information due to its robustness and broad coverage of journals in various fields of study [33,39]. Based on its website, Scopus covers 1814 journals focused on project management. Fisher and Newig [40] completed their SLR on the subject of sustainability transition using Scopus as a single database. This SLR adapts the approach, based on previous successful studies that used Scopus as their primary information database.

2.4. Search

Table 2 shows the search string that was developed and used [36]. It encompasses "project management maturity," which was developed from the SLR's main topic. A total of 741 records were successfully retrieved from both databases. These records and abstracts were imported into Endnote version 20 for systematic archiving, storage, and document management [28].

Table 2. Search strings.

Database	Search String
Scopus	(TITLE-ABS-KEY ("project management maturity model") AND ALL ("project management maturity model"))
ProQuest	ti("project management maturity model") OR ab("project management maturity model") OR ft("project management maturity model")

2.5. Study Selection

Records were retrieved and screened to reduce the number of articles to a manageable size [36]. These were screened, and 51 duplicate articles [39] were removed using the 'Remove Duplicate' function in Endnote version 20's reference manager. The remaining 690 articles were further filtered using the inclusion and exclusion criteria listed in Table 2 [39,41], and the number of articles was reduced to 141.

A full-text review was performed of the 141 articles [33], and 19 articles were found to be suitable for data extraction and further analysis. Only articles that were specific to PMM, with original research data, were included. Consequently, 122 records were eliminated. These were not original research papers; they lacked empirical data, and the PMM models were discussed as a passing reference. Four articles were manually added from the reference search.

2.6. Risk of Bias across Studies

Evaluating the risk of bias is necessary to ensure the accuracy of the analysis, and this was assessed based on publication bias, selective reporting within studies, and conflicts of interest [35].

2.7. Data Extraction

The lead author reviewed all 23 articles, and the list of themes and sub-themes was iteratively generated. Themes encompassing Year of Publication, Authors, Country of Conducted Study, Objectives, Study Design, Sector, Participant's Characteristics, Data Collection and Analysis Methods, Main Results, Future Studies, and Authors' Conclusions were included using ATLAS.ti [42].

2.8. Primary Data Analysis

A qualitative content analysis approach [43] employed a quantitatively oriented aggregation technique to synthesize the qualitative and survey studies. From these studies, a descriptive finding was applied. The most important criterion for this SLR was that the findings were descriptive and they addressed the same subject [33], which concerns the adoption of the PMM and its associated models.

ATLAS.ti. was used to extract the findings, study implications, and future research. An inductive approach was applied to the first few articles [44] to develop the codes. In contrast, a deductive approach [45] was used in the remaining articles to extract the data for the coding process.

The commonality of these codes was then classified and reported as the sub-themes [33,39,42,46]. These were further classified into predetermined themes based on the research questions. Two reviewers reviewed the appropriateness of the proposed sub-themes. The consensus was used to resolve any disagreements. As a result, the main findings of this SLR were developed from the main and sub-themes. The 'frequency effect sizes' were used to present the magnitude of each finding [33]. This was calculated by dividing the number of articles citing a particular theme by the total number of articles (23).

3. Results

3.1. Study Selection

Following quality assessment, 23 articles were identified for analysis, as shown in Figure 1.

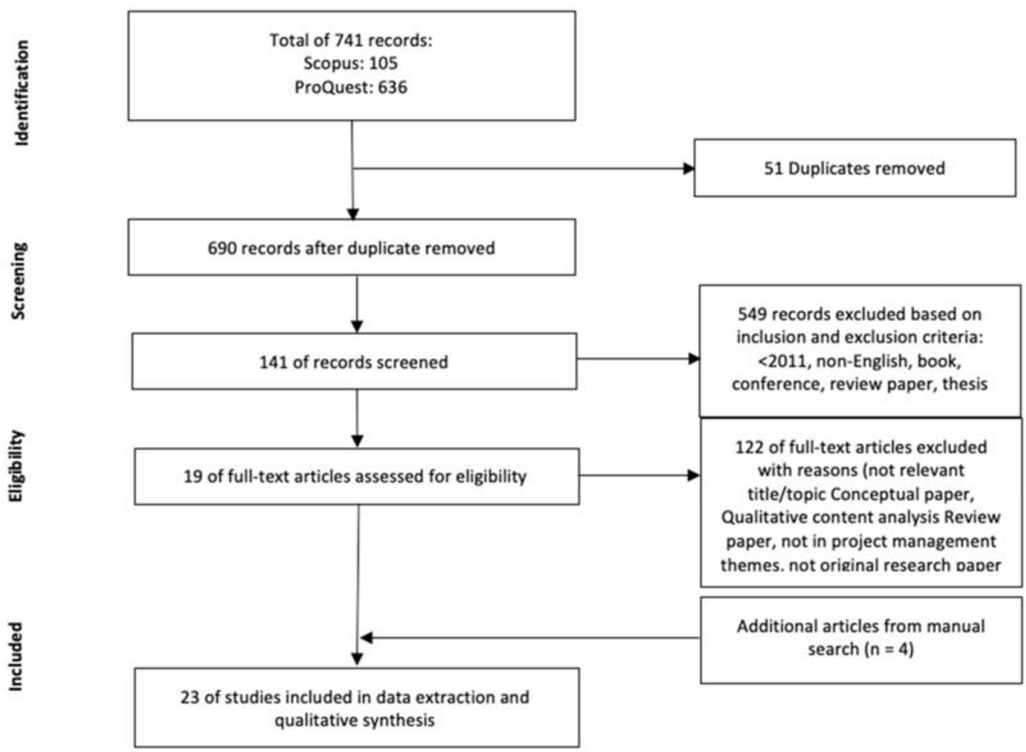

Figure 1. Study workflow [35]. A total of 741 records were identified. After screening, 141 full-text articles were assessed for eligibility. Ultimately, 23 articles were included.

3.2. Study Characteristics

It appears that quantitative studies were more common, with the highest number of such studies being conducted in 2014, amounting to four studies (Figure 2). Qualitative and mixed methods were consistently used between 2012 and 2018, with mixed methods being more consistently applied [34] to gather richer information. No qualitative studies were noted from 2019 to date.

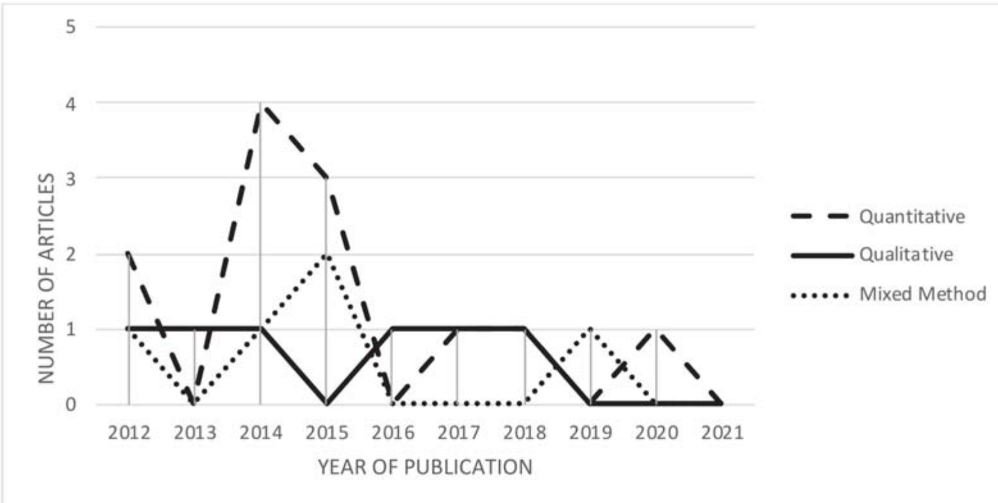

Figure 2. Distribution of methods applied (2012–2021).

Most articles on PMM were published between 2012 and 2020, with the highest number being noted in 2014, totaling six articles (Figure 3). This can be attributed to the Special Issue for project management maturity publications offered by the *International Journal of Managing Projects in Business* [47]. Four articles were published in 2012, five were published in 2015, and only one was published in 2013, 2016, 2019, and 2020. For 2017 and 2018, two articles were published, respectively. There were no publications for 2011 and 2021.

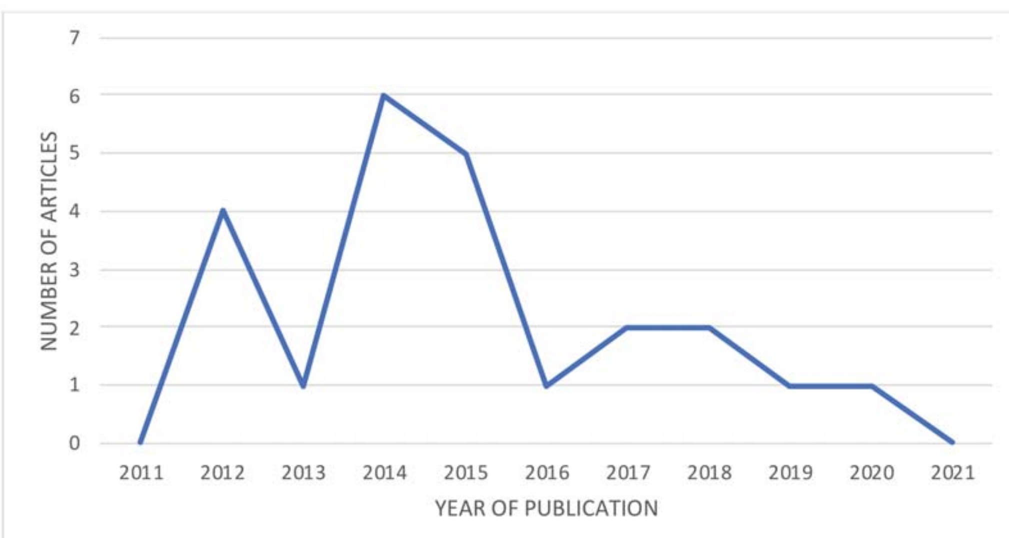

Figure 3. Year of publication.

A total of 23 articles were selected from 16 journals, with the highest number of articles being found in the *International Journal of Managing Projects in Business*, totaling six articles. This was attributed to the Special Issue published in 2014. Three additional articles were selected from the *Applied Mechanics and Material* journal. The remaining journals contributed only one article each (Figure 4).

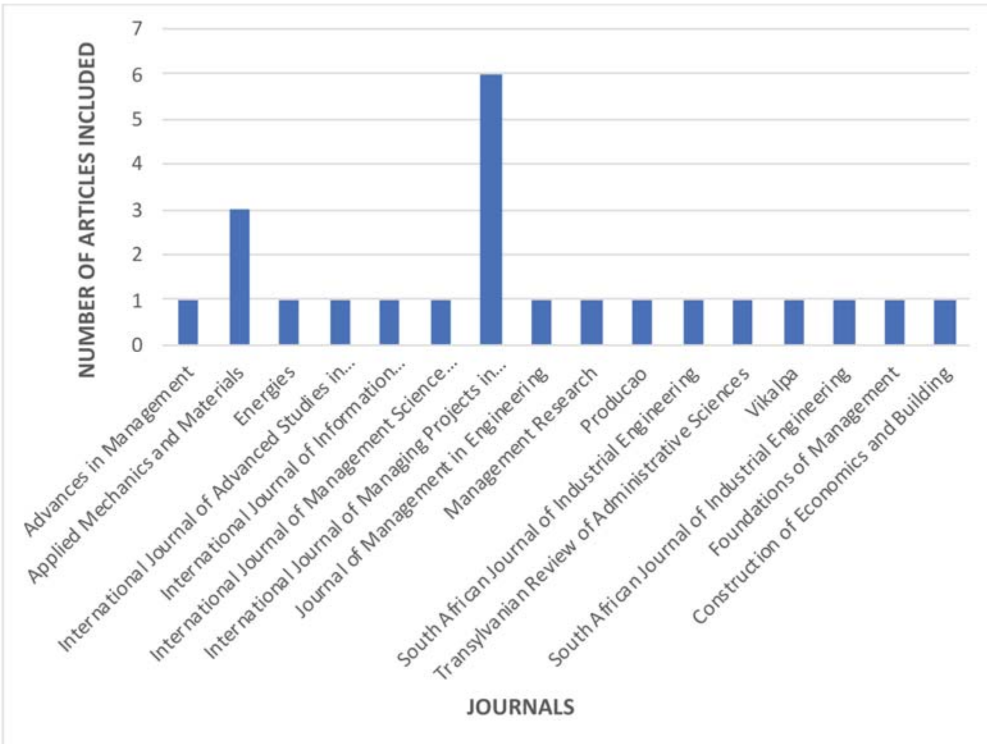

Figure 4. Journals of publication.

3.3. Risk of Bias across Studies

In this SLR, no studies were excluded due to the possibility of bias. There was also no mention of the researcher's influence on the studies. Overall, the quality of the survey studies was moderate, with the majority providing justifications for the research questions and samples. A few, however, omitted sample size. Most qualitative studies demonstrate a clear link between the research methods and questions, data-collection methods, data representation, and data interpretation.

3.4. Research Design Used by Previous Studies

All the research methods used to address the research questions and objectives in all the articles were reviewed. Mixed methods were less applied to study the PMM and its associated models, particularly in the earlier years. Mixed methods were mainly used to include more participants, leading to larger amount of data, including statistical data and selective interviews. These offered a more in-depth look at the data, thus providing more substantial implications and richer descriptive terms [48]. Table 3 illustrates the information regarding the articles included in this review.

Table 3. Study characteristics.

Author(s)	Study Design	Sector	Type of Participant	No of Participant
[30]	Mixed methods	Private—Engineering Companies	Project Manager	15 qualitative 13 quantitative
[23]	Qualitative	Private—Automotive and Energy	Project Manager, Head of Department	6 (2 interviews per case organization
[22]	Mixed methods	Private—Engineering and Construction (Mining)	Top Management, Project Manager Project Coordinator Managers	6 interviews 67 respondents, survey 9 respondents, visit and interview
[20]	Quantitative	Private—Information Technology	Project professional	51 respondents
[49]	Quantitative	Private—Information Technology	Project Manager	16 firms
[50]	Qualitative	Private—7 Multi organizations	Professional	90 respondents
[51]	Qualitative	Private—Automotive	Managers	14 respondents
[52]	Qualitative	Private—Manufacturing	Engineering laboratory	Not applicable
[53]	Qualitative	Private—Facility Construction	Head of Department	Not mentioned
[34]	Mixed methods	Private—Information Technology PM Consultancy	Senior IT Project Manager	18 interviews 190 survey respondents
[54]	Quantitative	Public—Government Agencies	Project Manager PMO staff	128 respondents
[50]	Mixed methods	Private—Information Technology	Project Manager Engineer Director IS IT Manager	41 respondents
[55]	Quantitative	Private—Energy	Project management practitioner	75 respondents from 75 organizations
[56]	Mixed methods	Public—Education	Course developer Instructional designer Sponsor Subject matter expert Unit/dept. head	10 members from two universities
[57]	Quantitative	Private—Facility Construction	Excellent project manager High-level business executive	238 respondents
[58]	Quantitative	Public Agency	Project manager Team member	65 respondents
[59]	Quantitative	Private—Multiple	Project manager	78 respondents
[60]	Quantitative	Public– Government agencies	Secondary data	NA
[61]	Qualitative	Public Agency	Archival data	NA
[31]	Qualitative	Private—Information Technology (Infra)	CEO Program manager Project manager	From 1 organization
[62]	Quantitative	Private—Construction Engineering Petrochemical Mining	Project professional	225 respondents
[28]	Quantitative	Private and Public—Local/regional business Government/county office	Manager of small service business	66 respondents
[63]	Quantitative	Private—Facility Construction	Practitioner from 18 companies	Not mentioned

3.5. Main Findings

Themes and subthemes were developed based on thematic analysis. The lead author extracted a statement or piece of data that responded to two research questions. This process entails a detailed analysis of 23 articles using ATLAS. ti software. The lead author created meaningful categories via the coding method "according to the nature of the data" [39]. The lead author drafted a list of sub-themes based on a similar category. The lead author then divided these sub-themes into two main themes, derived from two research questions. This first draft was then further reviewed by two authors to check for relevancy between themes, sub-themes, and data. Multiple authors refined the draft through a collaborative review process.

Two themes emerged from the conducted analysis: organizational aspects and organizational practices, which influence the PMM implementation. A total of 10 sub-themes were further developed (Table 4).

Table 4. Main themes and sub-themes that influence organizational PMM.

Themes	No. of Studies (%)	Studies
Organizational aspects influence PMM		
Organization culture	6 (26)	[22,39,43,52,58,64]
Stakeholders' differences and priorities	5 (22)	[22,51,52,58,59]
Mature organization structure	4 (17)	[22,43,45,59]
Project complexity	4 (17)	[22,25,43,51]
Motivation	2 (9)	[22,56]
Pre-requisite for the next maturity level	2 (9)	[42,50]
Organizational practices influence PMM		
Integration with organization strategic initiative	9 (39)	[25,39,43,46,51,53,56,58,59]
Adopting PM reference	8 (35)	[20,22,50,51,56–59]
The establishment of Project Management Office	3 (13)	[49,51,56]
The use of project management software tools	2 (9)	[51,59]

3.6. Organizational Aspects Influencing Organizational Project Management Maturity

A variety of aspects determine the success of the PMM implementation in an organization. They include organizational culture, stakeholders' differences and priorities, matured organizational structure, project complexity, motivation, and prerequisites for the next level of maturity.

3.6.1. Organization Culture

According to previous research, the proper alignment of organizational culture with PMM improves project performance [34]. Organizations with adaptability cultures [56] and clan-type cultures [59] are likely to influence the PMM implementation, which leads to successful projects [62]. Although organizational culture significantly impacts project performance, previous research has not emphasized this [22]. As shown in Table 4, the SLR noted that organizational culture constituted 26% of PMM, suggesting its influential aspects regarding the adoption and implementation progress of PMM in organizations. One study [56] also revealed a positive relationship between PMM and organizational culture. Organizations with high adaptability cultures can quickly adopt and implement PMM in their projects. This finding is particularly true in the educational sector. Since the environment in each sector differs, this finding could not be generalized to other industries. Nevertheless, previous studies have revealed that clan culture is positively correlated with organizations' business performance, significantly impacting project performance. Organizational culture sets the foundation for determining the success of any integration initiatives. As shown in Table 5, this SLR revealed that organizational culture is critical to the organization's decision to adopt and implement PMM as part of its strategic initiatives in improving project performance. Thus, organizational culture is one of the most common organizational aspects influencing the implementation of PMM.

Table 5. Relationship between sub-themes with research questions and relevant theories.

Themes	Themes Relation to Research Questions	Contribution to Theory
Organizational aspects influence PMM		
Organization culture	High adaptability culture makes it easy to adopt PMM	Broaden CT: Organizational culture influences organizational flexibility to adopt initiatives for improvement
Stakeholders' differences and priorities	Stakeholders prioritize project deliverables rather than the enhancement of PMM	Broaden stakeholder theory (ST): Organization to balance and prioritize different stakeholders' expectations
Mature organization structure	A mature structure provides an ideal environment to adopt PMM	Broaden CT: Organizational structure affects the way the organization communicates and distributes its authority
Project complexity	Project complexity changes organizations' focus on the initiative to adopt PMM.	Broaden CT: Project complexity determined the effort made to achieve the intended fit condition.
Motivation	Major changes in an organization could disrupt motivation for the implementation of PMM.	Broaden dynamic capability: Motivation is a cluster of activities to build a strong organizational capability.
Pre-requisite for the next maturity level	Fulfil key processes, provide a better foundation to implement PMM	Broaden dynamic capability: Existing organizational practices are signature practices, building strong organizational capability.
Organizational practices influence PMM		
Integration with organization strategic initiative	PMM could be more beneficial when integrated with other existing strategic initiatives	Broaden dynamic capability: Core process in building strong organizational capability.
Adopting PM reference	Organization with existing PM systems could accelerate the PMM adoption process	Broaden dynamic capability: Practice building strong organizational capability.
The establishment of the Project Management Office (PMO)	The existence of PMO drives the implementation of PMM	Broaden Dynamic capability: Coordinating PMO is a coordinating function, one of the core processes in dynamic capability.
The use of project management software tools	Investing in PM software tools and training increases organizational maturity in managing projects	Broaden dynamic capability: Practice building strong organizational capability.

3.6.2. Stakeholders' Differences and Priority

From Table 4, 22% of previous articles widely discuss how stakeholders' differences and priorities could influence the implementation of PMM in an organization [22,55,56,63]. Previous studies also revealed that different groups of people involved in other projects require high competencies and skills to manage their differences. This demand is even more critical when projects have higher value and more significant investments, particularly those related to national interest or global agenda, such as environmental projects. In this regard, such projects need project managers who can deal with the different interests of the various parties. As shown in Table 5, stakeholders who are likely to prioritize may be concerned about the technical deliverables and need for timely project delivery. However, they have less interest in improving organizational project management. As project management maturity improvement is not part of the project deliverables, these stakeholders' differences and priorities can alter the initiatives to adopt and implement PMM.

3.6.3. Matured Organization Structure

As shown in Table 4, 17% of previous articles suggest that a mature organization structure is likely to succeed when pursuing any improvement initiative. PMM levels are influenced by the maturity of the organization's structure. Large organizations, according to the studies, have a more mature structure, leading to higher levels of PMM [50]. Large organizations also have a functional [63], standardized, and formalized project management structure. This study found that respondents rate their project management's efficiency using these mature structures. Backlund and Sundqvist [22] also discovered that a mature organizational structure has more flexibility, allowing it to bring in more personnel when needed to successfully complete the project. Respondents tend to perceive high maturity due to the organizational structure's maturity. The literature also indicated that the current state of an organization's structure could determine its PMM implementation. However, not all existing organizational structures provide an ideal environment for the adoption and progression of PMM. This SLR noted that large and complex organizations were more prone to having formalized and standardized structures. As shown in Table 5, this sub-theme answers the research question, as mature organizational structures are ideal for the adoption and improvement of PMM.

3.6.4. Project Complexity

As shown in Table 4, this SLR found that 17% of previous articles recognized that project complexity could disrupt organizational improvement initiatives, such as PMM development [22,23,28,55]. Issues and problems in processing organizational improvement initiatives appear when project complexity increases. The type of project can also determine the complexity of the project. In energy projects, for example, the complexity of a project can increase due to the multiple activities that need to be completed simultaneously. Accordingly, the condition of energy projects becomes vulnerable to these changes [55].

Nonetheless, a well-defined project goal and method could reduce complexity [22,28]. It takes time before benefits the benefits of implementing PMM can be realized. Moreover, the progress of PMM implementation tends to occur at a steady pace. Progress could be disrupted when the project becomes more complex and more challenging. The cause of this disruption could be the type of project or the various activities involved in the project. Some projects take several years to complete. These projects are exposed to many changes, such as market price [55] and politics [61], increasing the project's complexity. Table 5 shows project complexity to be one of the organizational aspects for which high project complexity leads to more effort being required for the organizations to manage the projects. This causes organizations to deviate from their main focus and priorities when implementing PMM. Previous studies [55] have noted that this project complexity could impede the progress of organizational PMM.

3.6.5. Motivation

Another aspect of ensuring a continuous organizational improvement initiative is motivation. Improving the maturity of the organization's project management takes time; it is a long-term, ongoing effort. Previous research has found that the lack of commitment from both employees and management representatives was one of the reasons why many organizations have abandoned their improvement initiatives [22]. This lack of motivation could be due to major changes occurring in the organization, such as political changes, acculturation, and merger processes [61]. These changes could disrupt and alter the initiatives' process. To implement PMM, organizations should take time to enhance the improvement process, including their human resources. To balance the momentum and the progress, organizations need highly committed staff and management. The success of PMM, just like other improvement initiatives pursued by organizations, depends on people's commitment. This commitment, however, could decline due to changes in the organizational structure caused by external factors. Table 4 shows that the successful implementation of PMM requires high commitment from all parties in the organization.

3.6.6. Prerequisite for the Next Maturity Level

Previous studies suggest that the current maturity level of organizational project management is critical in determining the implementation progress for PMM. A certain level of project management practices is an essential prerequisite for organizations, serving as a foundation for the adoption and implementation of PMM. Previous studies have proposed that organizations should have an existing project management process as part of their organizational practices [64]. In addition, organizations should fulfill key process areas, such as project management, knowledge management, and competitive intelligence [30]. As shown in Table 4, this sub-theme provides a solid foundation for the successful adoption and implementation of PMM, thus answering the research question.

Eleven articles (48%) analyzed by this SLR mentioned six organizational aspects that could determine the success and progress of PMM implementation. Before implementing PMM, organizations should assess each of the six aspects to ensure that they are aligned with the implementation. Table 4 shows that the organizational structure constituted 26% of the total, while other organizational aspects, such as motivation and prerequisites, constituted only 9%. Thus, future research could explore these areas in more depth.

3.7. Organizational Practices Influence Project Management Maturity

The progress of PMM implementation is reliant on organizational practices. Table 4 shows four major organizational practices that influence the progress of PMM implementation. These are: PMM integration with existing organizational strategic initiatives, the adoption of PM references, establishing a project management office (PMO), and PM software tools.

3.7.1. Integration with Existing Organization Strategic Initiatives

Organizations need to adopt one or more of the strategic management initiatives to remain competitive. Common initiatives include benefit management [55], environmental sustainability [28], knowledge management [34], and the PMM framework [65]. The implementation of PMM can be integrated with other strategic management initiatives, enabling organizations to achieve greater project successes [28,55]. This could be carried out integrating organizational resources allocation, realizing organizational goals, and organizational performance management. To materialize their organizational goals, the actual results of their project business must be integrated with PMM [23]. This would make PMM more valuable, as it can be "too rigid" when focusing on project management improvements [31]. Thus, coordination between PMM and other strategic initiatives needs to be enhanced. The successful coordination between PMM and other strategic management, particularly in mega-projects, could help organizations improve their maturity level [57]. Regardless of project size, well-established organizations tend to standardize the use of strategic initiatives when supporting their PMM improvement [63]. In brief, this SLR suggests that PMM is not only suitable for project management but also for organizational improvements. Nonetheless, previous studies suggest the need an important move to standardize all the requirements for the integration of multiple strategic management initiatives, including PMM [31]. Langston and Ghanbaripour [31] also found that a customized PMM based on the PDCA concept could help project management implement organizational strategies, which leads to project success. It was proposed that organizations use PMM models to align various strategic management policies to optimize organizational performance. Proper alignment between PMM implementation and other existing organizational strategic management policies could improve projects and business performance [34].

However, not all forms of strategic management have a positive impact on PMM. Some drastic strategic management changes could have a negative effect on PMM implementation. For example, mergers and acculturation ((M&A) could have a positive or negative impact on PMM implementation in organizations [51]. In this case, the impact of M&A on PMM would depend on how the acquiree and acquirer "moderate the culture differences" [51]. Articles discussing the integration of PMM and strategic management constituted 39% of the total articles in this SLR. This intensity suggests that there has been extensive research on the integration of PMM and strategic management. Previous studies also revealed that the successful integration of PMM with other strategic management initiatives could lead to greater project success. However, drastic strategic management initiatives may negatively impede PMM's implementation progress.

3.7.2. Adoption of PM Reference

As shown in Table 4, 35% of the articles heavily discussed the adoption of the PM reference and the PMM models; it was thus deduced that this practice had a significant impact on improving organizational project management maturity. The PM reference and PMM models both served as a significant tool [64] and a valuable practice [31], ensuring the continuous improvement in organizational PMM. Previous studies have also noted the benefits gained from such a practice. This makes it a feasible approach, and it is supported by multiple organizations, including stakeholders [31]. Although some organizations benefitted from meeting project specifications and stakeholders' requirements [20,23], previous studies show that the adoption and application of the PM reference in IT project led to a positive performance, fulfilling project requirements and stakeholders' demands.

As the project management knowledge advances, there has been an increase in PM references and PMM models. This gives organizations a broader choice when selecting the best model to suit their projects. However, having too many PM references and PMM models can also be "problematic for PM practitioners" [22]. Nevertheless, previous studies have shortlisted the most common PM reference, and the PMM models that organizations adopt. The PMBoK was widely used as a reference and CMMI as a maturity model [20]. Capability Maturity Model Integration (CMMI) was developed in the late 1980s for IT projects and successfully improved these projects. Since then, CMMI has gained popularity, serving as a major reference for other PMM models available on the market today.

Apart from having an established PM reference, an organization may also use a self-developed PM system and maturity model. An earlier survey revealed that most organizations used their self-developed PM system and maturity model, positively impacting their project performance [27]. These organizations successfully increased their project success rate over time. Adopting an established PM reference and model or using a self-developed PM and model has a similar impact [23]. The most important concern is the characteristics of the established and self-developed PM reference and maturity model.

Previous studies noted that the project management knowledge area is important for the PM reference and maturity model. The self-developed PM reference must embrace all the core functions [62] or all 13 project management knowledge areas [63], as suggested by PMBoK. The core functions include integration management, scope management, time management, cost management, and human resource management. All have a positive impact on project outcomes [62]. The omission of these core functions, such as project planning knowledge, could result in a poor project outcome [55]. The Slovenian public project administration study found that public projects could not optimize its benefits due to the lack of human resource management and project planning methods [61]. With the number of PM models available on the market increasing, PM practitioners may have difficulties identifying the most suitable model for their organization [22]. However, with sufficient training, PM practitioners will be able to select the PM reference and maturity model that is appropriate for their organizations [60]. Previous studies also reiterated that training [66] is one of the critical success factors. This means that all levels in the organization need to be trained in project management, because adequate training is the foundation for PMM implementation [66]. Several organizations in Argentina, Brazil, and Chile noted that financial investment in personnel training in project management had a positive and significant relationship with project success or failure. Thus, financial investment in training and capacity building should be prioritized when adopting and implementing PMM.

3.7.3. The Establishment of Project Management Office

This SLR detected a significant difference in the maturity level between organizations that practiced project management office (PMO) and organizations that do not have PMO. Previous studies found that organizations with an active PMO played a role in institutionalizing effective project management methodology, recruitment, and training of project personnel. They also had a higher project management maturity level, leading to higher project success rates [27]. A total of 13% of the articles in this SLR stated that the establishment of the PMO in organizations is a critical practice that can drive organizational PMM implementation and improvement. These articles revealed several examples of the PMO's function, which contributed to PMM. The PMO, as an independent function in the organization, consists of professional staff with the ability to perform strategic functions, such as communication management [54]. For organizations with multiple ongoing projects, the PMO centralizes the information obtained from each project; it can also manage reporting for the stakeholders. One of the most intensive studies looking at the effect of the PMO function on organizational PMM was conducted by Khalema, van Waveren, and Chan [54]. They divided the PMO functions into three levels: strategic level, tactical, and operational. At the strategic level, the PMO can effectively ensure that each project in the organization is aligned with the organizational strategic objectives. It also supports the organization's growth, and can provide effective and efficient knowledge management within the organization. PMO integrates the project initiatives and coordinates multiple projects to ensure knowledge-sharing across the projects. It further standardizes the quality of the project deliverables. At the operational level, the PMO is responsible for project evaluation. It develops the project evaluation process; it stages reviews, from business to technical reviews to feasibility reviews, and it ensures that all projects are conducted efficiently.

This SLR also indicates that the PMO must be equipped with full authorization and the ability to function well. It should be driven by an experienced professional. This type of PMO has been described by an earlier survey as a "front office" PMO role (PwC), constituting only a small portion of the total. At the same time, most of the respondents reported that the PMO, which functioned as a "back office" or coordinator between projects, was more effective. This was able to collect more information and report the progress to stakeholders. However, earlier studies suggested a strong relationship between establishing "front office" PMO and a higher maturity level for organizational project management [15].

One example illustrated how a government ministry's office used the PMO to manage its public projects. The ministry had to deal with various projects of long durations, large budgets, and many participants in energy development projects. Some of these projects were formed under a coalition of two governments. A government project office (GPO) was thus developed to manage and coordinate such projects effectively. The GPO had a similar role to the "front office" PMO [61]. It served as a centralized unit at the state level, providing the methodologies and system support to the ministry.

This strategic function had a positive relationship with the PMO because poor project-monitoring systems had resulted from underdeveloped PMOs. According to Mihic and Petrovic [55], the PMO must be matured and fully established to drive efficient implementations of its organizational strategy. This SLR thus concludes that PMOs must have the ability to play a strategic role to improve organizational PMM and the efficiency and effectiveness of the processes related to materializing business objectives. For this to occur, the PMO should be managed by experienced professionals, who understand project management and the organizations' overall process, including its culture and economic means. Investments depend on the PMO's abilities, based on how organizations conduct the projects (multiple projects and if the organization is based on projects or a project-based-organization) [67].

3.7.4. The Use of Project Management Software Tools

Project outcomes are influenced by project management software tools [63], such as MS Project, Primavera, and CA Clarity [55], which are mainly used by construction organizations. Mihic and Petrovic [55] pointed out that poor project outcomes were caused by poor skills and inadequate training in project management software tools. This means that organizations need to invest in project management software and staff training to improve their project outcomes.

Integrating PMM with existing organizational strategic management, adopting a PM reference and its maturity models, creating a PMO, and using appropriate project management software tools are beneficial to the development of an organizational PMM, particularly organizational performance.

4. Discussion and Conclusions

Organizational aspects and practices are significant elements of project management maturity. This paper has presented a systematic literature review of previous studies examining organizational aspects and practices that could influence the implementation of PMM. The authors analyzed 23 articles supported by ATLAS. ti. The authors answered two research questions and thematically described the findings.

As shown in Table 4, this SLR identifies six organizational aspects that influenced PMM implementation:

(a) Organizational culture;
(b) Stakeholders' differences and priorities;
(c) Matured organizational structure;
(d) Project complexity;
(e) Motivation;
(f) Prerequisites for the next maturity level.

From the SLR, it can be deduced that organizational culture plays a significant role in determining the organization's motivation to adopt and nurture PMM's progress and implementation. Organizations with high-adaptability cultures tend to accept and quickly realize the benefits of implementing PMM. However, it should be noted that a high-adaptability culture was only observed in the educational sector. The aspect of motivation as a prerequisite for the next maturity level had less coverage in previous studies, although it had a significant function in successful PMM implementation. Motivation is crucial for ensuring the consistent commitment of the respective parties. This ensures that PMM is not abandoned halfway through its implementation. Identifying prerequisites for organizations to reach a higher maturity level is important because they serve as a solid foundation, setting organizations on the right track. They also allow for organizations to accelerate their PMM implementation. All six organizational aspects are essential.

As shown in Table 4, this SLR also identifies four organizational practices that could lead to the successful adoption and implementation of PMM:

(a) PMM integration with existing organizational strategic initiatives;
(b) The adoption of a PM reference;

(c) The establishment of the PMO;

(d) The use of PM software tools.

The above six organizational aspects and four practices could fill the gap in PMM, as identified by [22]. These organizational aspects and practices can be used when assessing organizational project management maturity. Practitioners should consider these aspects and practices to improve PMM and organizational performance.

Previous studies have criticized PMM and its associated models for lacking practicality [22,30,31] and a theoretical foundation [49]. This SLR has identified six critical organizational aspects to enhance the maturity of organizational project management, thus providing a foundation for PMM improvements. Table 5 illustrates how these aspects address the research question and broadens three related theories.

CT emphasizes the fit between the organizational aspects and the external environment [25]. From Table 5, a mature culture and structure provide ideal conditions for the organization to undertake any improvement initiatives. Meanwhile, project complexity is an external condition that challenges an organization's abilities. This SLR demonstrated that a mature organization structure and a high adaptability organization culture allow for an organization to adapt to project complexity. Therefore, these enable the organization to achieve suitable conditions. This finding broadens CT, in which a mature structure and high-adaptability organization culture ensure that the organization is highly flexible, and can adapt to the external environment, offering it higher chance of achieving suitable conditions and leading to a more successful performance.

Earlier studies linked project management with stakeholder theory (ST), focusing on how stakeholders strongly influence the project [68]. ST suggests that organizations must have soft skills to balance and prioritize stakeholders' requirements. Table 5 shows that stakeholders' differences and priorities could deter organizational improvement initiatives. This SLR broadens ST, where multiple stakeholders prioritize project deliverables that benefit them rather than organizational enhancement.

Another two organizational aspects, motivation, and prerequisites for the next maturity level, are related to the dynamic capability framework, an alternative to the Resource-Based View (RBV) [24]. According to Shuen et al. [24], compared to RBV, a dynamic capability framework is more suited to explaining organizational capabilities in a dynamic market environment. As shown in Table 5, motivation and prerequisites to the next level maturity level are two features of the organization that develop strong organization capabilities. These are existing organizational aspects that provide an advantage to the organization when realizing improvement initiatives.

From Table 5, the four most common practices are critical to enhancing organizational project management maturity. The integration of PMM with existing strategic initiatives is an effective practice that increases the success of its implementation. This success increases project management maturity, thus increasing the ability to deliver a successful project. Meanwhile, adopting an established PM reference further accelerates the performance of PMM. The PM reference will introduce organizations to similar knowledge areas, which are elements of most PMM models. Thus, adopting established PM references is critical to enhancing project management maturity. An organization with a PMO seems to be more organized, with a clear drive to continuously improve organizational project management maturity. PMO functions as a facilitator who plans, introduce and selects appropriate project management practices that suit the organization. Lastly, investing in project management software tools is a valuable practice that could increase the effectiveness of organization project management when carrying out their work, including sharing project information such as project schedules. According to Shuen et al. [24], these four practices are core processes and practices that build a strong organizational capability. In addition, to answer the research question, these four practices also broaden dynamic capability.

What is novel about this paper is that the constructs to enhance organizational project management maturity derive from common organizational aspects and practices. Based on this finding, model developers may improve and customize existing models to make them more flexible and practical for organizations to adopt and implement. Instead of suggesting unnecessary new aspects and practices, this enhanced version should optimize existing organizational aspects and practices. This is in line with Albrecht and Spang's [23] concept of ideal maturity, in which the PMM model should be flexible and customizable to achieve the ideal maturity level for the organization. Similarly, CT emphasizes the fit between organizational aspects, practices, and project environments. This SLR broadens CT by identifying critical organizational aspects and practices to achieve a suitable condition that improves the organizational project performance. The finding also broadens dynamic ability, as organizational aspects and practices are identified as core processes and practices when building strong organization capabilities. This SLR suggests that the development and improvement of PMM and its models should be guided by multiple theoretical foundations, such as CT, ST, and dynamic capability.

Two limitations of this SLR should be highlighted for future improvement. The first is the limitations regarding the articles. This SLR was limited to articles published between 2011 and 2021 to explore the most recent common themes in project management maturity [32]. Second, this SLR did not consider any contemporary business models' management as a theoretical research foundation. Even though the PMM concept and earlier models were developed based on the idea of a continuous improvement management approach, it is worth revisiting this to find its relevance.

5. Implications for Future Research and Practice

This paper identifies the critical organizational aspects and practices that model developers can employ to improve the existing models. Based on this finding, a model developer may simplify the model by refocusing the elements and constructs of the existing model. This finding also fills a research gap identified by [22] by recommending aspects that should be considered when assessing organizational maturity. The implementation of PMM and its model could become more practical and focused, saving time and effort in the organization. Therefore, PMM adoption and implementation may not be seen as a burden to organizations in the future. In future studies, researchers could analyze articles published after 2021 to include more aspects, for example, the understanding of PMM and its success rate, and why such research was conducted. The future of PMM and its models could also be further pursued, including a search for alternatives to PMM. This SLR recognizes the emergence of the need to alleviate PMM's function as part of existing strategic initiatives in the organization. More research needs to be conducted to observe how PMM and its associated models can be used as a strategic integration mechanism between project management and the strategic management initiatives of an organization.

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Appendix A. Existing PMM Models and Relevant Theories

Author of the References	Elements Considered	Maturity Levels	Relevant Theory
Qin et al. (2017)	CMMI as introduced by SEI Four main elements: • Key practices; • Key process areas; • Maturity levels; and • Generic processes.	Level 1: Initial Process Level 2: Structured Process and Standard Level 3: Organisational Standards and Institutionalized Process Level 4: Managed Process Level 5: Optimizing Process	The foundation of CMMI can be explained by Dynamic capabilities (Shuen et al., 2014) Dynamic capabilities suggest that a strong capabilities are built on best practices and ability to integrate, and reconfigure internal and external competencies to address rapidly changes market.
Kerzner (2019)	Kerzner Project Management Model, KPM3 Based on critical success factors: • Corporate understanding of PM; • Executive commitment to PM; • Organisational adaptability; • Project manager selection criteria; • Project manager's leadership style; and • Commitment to planning and control	Level 1: Common Language Level 2: Common Processes Level 3: Singular Methodology Level 4: Benchmarking Level 5: Continuous Improvement	The foundation of KPM3 is another example of model that fit into Contingency Theory (Donaldson, 2001). KPM3 based on critical success factors and those factors needs to be aligned with to the project environment in order to achieve the most ideal capability, or fit condition.
Crawford (2001)	PM Solutions PMMM Project Management Maturity Model designed based on all nine of the PMBOK areas of knowledge.	Level 1: Initial Process Level 2: Structured Process and Standard Level 3: Organisational Standards and Institutionalized Process Level 4: Managed Process Level 5: Optimizing Process	The core process in strong capability is demonstrate in this model, thus the foundation of this model is relevant to Dynamic capability.

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Application of Integrated Project Delivery (IPD) in the Middle East: Implementation and Challenges

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Abstract: The Integrated Project Delivery method (IPD) is a contractual framework that features enhanced collaboration, risk and reward sharing under a single contract among the major project parties. This delivery method is gaining popularity in the US and other parts of the world, due to its proven results in efficient risk and cost sharing. Despite that, no significant investigations have been made to address the adaptability of the Middle East construction sector to the IPD delivery system. The objective of this research is to investigate the level of preparedness Middle Eastern markets have for adoption of the IPD delivery system. First, a thorough literature review was carried out to identify common barriers and enablers of applying IPD in construction. Second, a survey was carried out to assess and rank such barriers and enablers as they specifically apply to the Middle East construction sector. Third, through structured interviews with contract experts, strategies and guidelines were devised to be used by Middle East owners, consultants, and contractors who have the intention to implement the IPD delivery method in their projects. Finally, a thorough comparison was made between two major Middle Eastern countries, Egypt and the Kingdom of Saudi Arabia (KSA), in terms of IPD application. The findings reveal that the main barriers to implementing IPD stem from cultural resistance to the new system and lack of knowledge about it. The subsequent strategies outlined by the research are expected to help the construction industry in the Middle East gain more depth of knowledge about the benefits and application of IPD.

Keywords: Integrated Project Delivery; Middle East; construction

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1. Introduction

Project delivery methods are important factors affecting the coordination, collaboration, qualitative and quantitative progress update, performance, overall duration, and cost of construction projects [1,2]. Some examples of traditional project delivery methods are: (1) Design-Bid-Build (DBB), where the client prepares separate contractual agreements with different entities for the design, consultancy and construction of a project; (2) Design Build (DB), where the client arranges one contractual agreement with an entity responsible for the construction of the project and for the design, which is executed inside the organization itself, or by a certain subcontractor which the entity will be responsible for; (3) Construction Manager at Risk (CMAR); where the Construction Manager (CM) is committed to deliver the project within a Guaranteed Maximum Price (GMP), and several other delivery methods. All these traditional approaches have effectively dominated the construction project delivery system for decades, but these approaches have disadvantages that need to be tackled [3–5]. Examples of these traditional system disadvantages are illustrated in the following, Table 1.

Table 1. Examples of traditional project delivery systems' disadvantages.

Definition	Illustration	Effect	Source
Separation Hierarchies	Large number of different contracts are arranged between the owner, main contractor, project management, consultant, subcontractors, etc.	• Each stakeholder attempts to optimize his or her own profit, resources, and progress with minor consideration to other stakeholders' interests. • Non-collaborative medium is created inside the project's environment.	[6]
Risk Transfer	Each party tries to transfer risk to the counterparty, rather than introducing methods to mitigate the risk itself.	• Conflicts arise and lots of negotiations take place with no solutions. • Deliverables are not easily defined and there is misconduct in some product responsibilities.	[7]
Interconnected Deliverables	Construction projects' outcomes are very interconnected and have different dependencies among involved stakeholders.	• Each single contract of different stakeholders does not completely contain all the required interconnected tasks. • Increase in the number of contract addendums and amending agreements to cover interconnected objectives.	[8]

The examples shown in the previous table were selected based on their evidenced direct impacts on the construction market in the Middle East; this market is immense in terms of investments, labor and durations, and these examples represent important challenges in the construction project's delivery process. Also, through the literature review, these examples presented the highest probability of occurrence in the construction markets of Middle Eastern countries.

To tackle the problems and risks associated with traditional delivery methods, researchers and practitioners have introduced the Integrated Project Delivery (IPD) method as a sufficient, collaborative, and strong delivery system. IPD develops an organization-based methodology for the collaboration of different stakeholders within the project from the initial stages and maintains this interconnected environment through the different subsequent stages of a project [9]. This system benefits the overall interest of the project, in terms of productivity, coordination, duration, and cost [10].

The American Institute of Architects (AIA) defines IPD as "*a project delivery approach that integrates people, systems, business structures, and practices into a process that collaboratively harnesses the talents and insights of all project participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction*" [11]. This definition describes the strong dependency of IPD on collaboration and teamwork between all the different parties of a project. According to [12], the IPD type of contract can be similar in classification to Project Alliancing contracts, since both aim to achieve the same target of creating a collaborative, integrated environment between the different project entities and encourage coordination between the parties eventually delivering the project. Pertti L. [13] provided a detailed comparison between Project Partnering, Project Alliancing and IPD types of contracts in a relational parametric base. The differences are subtle, and they all share the same ideological basis of strong collaboration and interconnected targets among parties.

The compensation method for allocating gain/pain ratios across project participants, according to [14], is the most significant feature of implementing the IPD approach. The IPD method necessitates a collaborative contracting relationship, which motivates key team members to meet project goals. As a result, all parties should agree to multi-agreements to determine the appropriate compensation percentage for the project. The integration of BIM with IPD, according to [15], can improve overall outcomes of the design and construction processes because it is linked to numerous characteristics, such as cost/profit, schedule, safety, productivity, and relationships. Qiqi L. [16] offered extensive models for material, equipment, and labor cash outflows using 5D BIM capabilities; however, the delivery strategy features were not examined. A comprehensive literature review is performed to investigate the most up-to-date BIM tools and capabilities in terms of schedule (4D BIM) and expense (5D BIM). Several techniques for leveraging BIM to produce dependable cash flow procedures have been published in the literature, as well as IPD's cost structure approach to effective BIM project delivery. A real-life case study is conducted to verify the validity and application of the suggested framework. Due to the fact that IPD is based on project participants sharing risk and rewards, it necessitates custom cash flow curves for the type of payment involved.

According to [17], applying IPD can improve construction project delivery timelines by decreasing waste through better planning and shared risk/rewards. As a result, optimizing 4D BIM can help reduce costs, while also improving overall efficiency of the construction process. According to [18], 4D BIM is a dynamic presentation of a design that considers time parameters, making it easier to understand than old techniques. Also, according to [19], multiparty agreement, early engagement of all parties, and shared risk and benefit are some of the elements that distinguish the utilizing of IPD in BIM projects. Furthermore, according to [20], BIM has improved the efficiency of the construction process, by facilitating collaboration among a diverse group of project participants at various stages, including design and construction. As a result, thorough decision-making must be considered early in the design process [21].

IPD has been proven to be a successful delivery method. Projects contracted through the IPD arrangement perform significantly better than those under DBB or DB agreements, because the IPD procurement strategy provides a model that allows all project participants to be involved from the conceptualization stage and evaluates the compensation approach in accordance with accountable participants [22]. According to [23], an alliancing agreement can reduce the risk of sharing information throughout project stages, because the risk management process's succession is normally dependent on data availability, and IPD enables this data by gathering all project participants at an early stage. Furthermore, according to [24], IPD has three limbs. Limb 1, reimbursement of project costs, in which project cost estimation must be examined utilizing an open book pricing scheme, requires that all projected expenditures to be incurred during the project implementation stages be included in this limb. Limb 2 represents all participants' overhead costs as well as the profit at risk proportion. Limb 3 represents profit at risk ratios, as well as cost savings.

Based on the completed literature review, and previous research cited in this study, the authors derived the following advantages and limitations of IPD contract implementation, represented in Table 2. These analysis points are based on studies conducted in different regions [5,7,8,11,13,14,16,22].

From Table 2, it appears that the limitations of IPD can be overcome through having strong experts, a detailed approach, and a completed contract based on trust between parties. This type of contract has been used in different projects worldwide and showed significant success and profit. Also, the advantages of using this type of contract are massive in terms of costs, risks, progress and duration.

Despite the success of IPD in the USA, Canada, Asia and Europe, the implementation of IPD in the Middle East is still fragile and weak. According to [25], implementation of the IPD concept has increased significantly in the last decade, despite its short introductory period; the highest trends appear in the United States, followed by Europe, then China and Iran. The objective of this research is to analyze Middle Eastern markets' preparedness to adopt IPD delivery, by exploring the different barriers of applying such a delivery method in Middle Eastern countries, comparing the results with other countries which are implementing IPD, and later proposing practices to overcome such barriers.

Table 2. Concise advantages and limitations of the IPD contract.

Characteristic	Description
Advantages	**Shared risk:** All the project parties are involved under the same contract with shared revenue and risks.
	Minimum variation orders: Project parties are involved in the early stages of the project, share information and progress together.
	Minimum variation orders: Project parties are involved in the early stages of the project, share information and progress together.
	Lower cost: Less variation orders and RFI lead to decreasing cost and better schedule.
	Improved project profit: The single contract can optimize the profit for all involved parties.
	Better communication: Different project parties can communicate better because all of them share the same objective.
	Optimize materials' use and time: Since everyone's profit depends on the project's overall success, everyone has an incentive to find the most efficient way to complete the task.
Limitations	**Large capital investment:** Project parties, such as owner, consultant, and contractor, need to have nearly equal capital investment in the project to accept sharing the risks.
	Required expertise: All parties need to have employees who understand different aspects of the project.
	Balanced metrics: The single contract approach requires balanced metrics for design, construction, cost, schedule, etc. to meet goals.
	Conclusive insurance: IPD contracts require substantial insurance, since all the risks are shared between the project parties.

2. Literature Review

In 2007, the American Institute of Architects (AIA) introduced the first comprehensive complete definition for the Integrated Project Delivery (IPD) contract, with the main objective of presenting all the stakeholders of a project in an integrated state, serving the overall interest of the project and its parties. This type of contract aims to use all the involved parties' expertise and construction knowledge in a multi-disciplinary contract that guarantees their fair participation in the project's income and risks [11]. There are different contracts that were written to support this method of project delivery. Especially prevalent in the USA is the AIA E202 contract. However, because of the existence of various conditions in the construction industry, such as different rules, permissions and agreements, these types of contracts were normally added, in the past, as an addendum or attachment to the project contract and conditions [26]. This was because the IPD type of contract required changes on the contractual level and agreements on the behavioral level to be integrated in the project's main contract and conditions [27].

According to the National Association of State Facilities Administrators [28], the following main principles of the IPD contract type are classified into *Contractual Principles* written in the project's agreements: Liability waivers between key participants, Fiscal transparency between key participants, Early involvement of key participants, Intensified design, Key participants bound together as equals, Shared financial risk and Reward based on project outcome, Jointly developed project target criteria, and Collaborative decision-making. The *Behavioral Principles* required for the overall interest of the project are choice-based principles, such as the following: Mutual respect and trust, Willingness to collaborate, and Open communication. Finally, the following *Catalysts* principles are necessary for facilitating IPD implementation and optimizing contract results: multi-party agreement, Building information modeling, Lean design and construction, and Co-location of team.

As mentioned before, the Contractual principles are bonded by the law and cannot be broken. These principles aim to distribute the project's risks and income mutually between all parties involved, which improves integration and builds a trust-based work environment [29]. The Behavioral principles entail rules for the integration of parties and their communication. They attempt to improve the overall attitude of the participants and their negotiation and communication skills, which are very important factors affecting performance and effectiveness of different teams [30]. The Structural principles refer to process/system management; they define the rules that are needed to facilitate joint decisions and responsibilities. For example, team flexibility is needed in these cases, because negotiation and convincing require persuasive open minds for the right approach and decisions [30]. The final principles, the Technology principles refer to available delivery systems which have critical impact on project progress. The different use of Information Communication Technology (ICT) can increase the integration level, which improves progress and facilitates information sharing [31].

While motivation is one of the most important factors in IPD implementation, this depends on trust, respect, good leadership, strong team participation and valid work relations [32]. Trust is the main engine driving coordination between the different project stakeholders, and it requires time and multi-level cooperation to be achieved [33].

The barriers facing the implementation of IPD delivery can be classified into four categories according to [34]. These categories are modified to run alongside the four categories of IPD principles: Contractual, Behavioral, Structural and Technological. The modified **contractual** category encompasses lack of "IPD" insurance cover products, building without Guarantee Maximum Prices (GMP), contracts formed not tested, lack of new legal framework/ collaboration model, risk allocation mechanism, professional responsibility and licensing, challenge in selecting compensation /incentive structure, and dispute resolution. The modified **behavioral** category includes resistance to change, lack of confidence in project team, lack of IPD awareness, organization culture, business risk (return in investment), new approach taking time, and difficulty in measuring benefits. The modified **structural** category covers front-end investment, project characteristics, work process, formation of entity for "Real" IPD, scheduling issues, surrendering command and control, different criteria for procurement, and risk issues. Finally, the modified **technological** category concerns IT infrastructure, data protocol and copyright, lack of authority to restructure AEC procurement to enable an IPD model with advance technologies, and interoperability.

These four categories represent 27 factors from the literature affecting the adaptation of the IPD contract.

According to [34], the contractual barriers are those having a direct impact on the Contractual principles of the IPD contract. These problems affect the contractual bond between the parties and cause lack of liability in the multi-level contract. For example, the lack of an insurance cover plan decreases trust of stakeholders in the IPD contract, which negatively affects trust in the Risk/Reward distribution agreement among the different parties. Behavioral barriers represent the Cultural and Environmental factors which appear clearly in the behavioral acts of different parties in the construction field. This challenge appears in personal resistance to change, for example. People tend to depend on the types of contracts that they trust and refuse to change. Structural barriers are problems that center on opposing collaborative relations between members of different organizations and those inside the same organization. These barriers define the problems that may occur inside construction organization management and inside the system operating implementation of the IPD contract. Finally, the technological barriers are problems facing information sharing and gaining of information through the project life cycle. This information is strongly required for collaboration of different project trades and parties. As an example, [35] showed that the copyright of drawings, details and their processing protocols is essential to guarantee and protect the trust and liability of different project stakeholders in the IPD contract.

3. Research Methodology

This research is based on a quantitative approach where a questionnaire was completed by conducting interviews with managerial levels in different construction firms in the Middle East. Owners, consultants, and contractors having different construction backgrounds were interviewed. Owners are concerned with investment and financial aspects, such as how much they need to spend, and project revenue. Consultants are mainly concerned with process safety, applicability, and durability. Finally, contractors are concerned with the costs of the project, duration, required resources, and logistical implementation aspects. These different backgrounds and experiences allow evaluation of IPD implementation and restraints from different points of view and assessment of how each entity sees the outcomes and process's barriers. The questionnaire was divided into two sets, each set having 14 question points to be answered. In the first set, the manager interviewed was asked to answer the questions based on the following point of view: "In your opinion and experience in the construction market, how do you rate the following challenges/barriers of implementing IPD contracting in the Middle East? In other words, how easy/difficult do you believe it will be for the market to overcome these barriers?". While in the second set, the manager should adopt the following different point of view: "In your company specifically, how willing is your company to overcome barriers to implementing the IPD contracting method?". The reason for creating these two different approaches of answering the questions is to identify how each individual classifies the willingness of his/her company and of other companies in the application of IPD, rating the IPD contract's constraints and recognizing the capabilities and resources of different companies that are needed for such contract implementation. The selected 14 question points about the implementation and constraints in each set were based on the previous literature review, overall study of the Middle East market and how each point is relevant, and the questions have a strong relation to the dynamic nature of the construction industry in the Middle East. The 14 question points are illustrated, with their proposed approach to overcoming barriers, in the following, Table 3. The answer to each point can be one of the following: Very difficult to overcome, Difficult to overcome, very easy to overcome and Easy to overcome.

Table 3. Question points included in the questionnaire.

	Question Point	Significance (Proposed Approach to Overcome)
1	Resistance to Change	The parties involved need to have the tendency to change and experience new systems.
2	Risk Assignment	The process of determining the risks that each party will take responsibility for in the project.
3	Relative Capital Investment	The difference in capital head of the Owner, Consultant and Contractor can cause problems in agreements and risk sharing.
4	Contractual Legal Aspect	The IPD system imposes value-driven selection criteria, and this cannot ensure the lowest bidder and it also requires general agreement on One Single Contract.
5	Future Orientation	Individuals needs to engage in future-oriented behaviors, such as delaying illumination, planning, and investing in the future.
6	Team Orientation	Teams need to be built effectively with implementation of a common purpose, or goal, among team members.
7	Participation	Leadership and managers need to involve others in making and implementing decisions (trusting relations between different parties).
8	In-Group Collectivism	Individuals need to express (and should express) pride, loyalty and cohesiveness to their organizations or parties.
9	Self-Protective approach	Individuals need to feel safe and secure in their organization.
10	Implementation of strict rules, policies, and regulations	Which lead to an individual becoming change averse.
11	Selecting compensation and incentive structure	Which depends on the unique characteristics of the project and its participants.
12	Technological BIM-based Aspects	Subcontractor does not have enough expertise with such technology, thus struggles to coordinate with the rest of the parties.
13	Expert Contract administrators	Experienced and willing to do the Integrated Project Delivery Approach.
14	Early Contractor Involvement	Early involvement in the design stage for constructability reviews. This means signing the contract with the contractor before the designs are complete.

4. Results and Discussions

The results shown here are for the initial sample of 18 large-scale construction firms in Egypt and the Kingdom of Saudi Arabia (KSA) as representative countries of the Middle East (six representing contractors, six representing consultants, and six representing owners). The selection criteria were based on the reachability of highly professional managers and individuals, then the data was collected and analyzed using an iteration approach; each time the results were discussed and analyzed till the final overall results were concluded. The construction markets in Egypt and Saudi Arabia are massive because of ongoing development efforts in these two countries, according to several research. The current construction revolution that Egypt and the KSA are going through makes them strongly representative of the construction market in the Middle East. For example, Egypt is building its new capital and KSA is building hotels for the many tourists it receives each year. The companies represent a significant percentage of these markets where the authors are targeting a larger sample size as the study moves further.

At first glance, the sample size might not seem sufficient to draw reasonable conclusions. However, with further investigation and justification, the number of companies sampled is considered sufficient. The fact that the majority of construction professionals in the Middle East are unaware of IPD dictated the difficulty in selection of experts and companies to feed the research. The research team selected only top tier contract administrators (with experience of 20 plus years), representing the top firms in the regions, for the research to ensure reliable results. Also, only those with prior knowledge of partnering agreements were chosen. Even taking these factors into account, the research team had to explain in depth the concepts and philosophies of IPD to the participants and had to answer several questions asked by the participants about IPD before asking them to answer the survey questions. Within the discussions with the respondents, the research team had to ask them hidden questions (a sort of hidden oral test) to make sure they truly understood IPD. The answers of those who did not seem to grasp the concepts of IPD were not taken into consideration. Many hours were spent in finding, contacting, training, and interviewing the 18 experts about IPD.

4.1. Barriers to Implementing IPD in the Middle East

Table 4 shows a percentile scale ranking of the experts' opinions in each of the question points with respect to two different viewpoints: the Middle East Market and the Interviewee's Company. It gives an overall understanding of the difficulty of these constraints to the construction industry in the Middle East.

For comparison between the different sets throughout this study, a statistical comparison approach was used in the F-test, which is used to compare variance and standard deviation of two different samples, and the *t*-test, which is used to test whether there is a significant statistical difference between the two means of the studied samples or not [36]. These tests are easy to use and can show significant results. The implementation steps and result options are shown in Figure 1. The calculated probability (*p*-value) of the two tests is the factor determining the significant difference, where a value of less than 0.05 means that there is a statistically significant difference between the responses.

As shown in Table 5, the questionnaire points of analysis can be divided into two categories: those with the same results in both viewpoints and those with different results in each of the two viewpoints, depending on the F and *t*-tests (*p*-Value) described in the above section. This can provide insights for comparative analysis between the two viewpoints and how to connect each of them together to encourage and facilitate the implementation of an IPD contract.

Table 4. Percentile scale ranking of the expert opinions.

		The Respondents' Views of the Middle Eastern Market				The Respondents' Views of their Own Companies			
	Barriers	**Very Difficult to Overcome (1)**	**Difficult to Overcome (2)**	**Easy to Overcome (3)**	**Very Easy to Overcome (4)**	**Very Difficult to Overcome (1)**	**Difficult to Overcome (2)**	**Easy to Overcome (3)**	**Very Easy to Overcome (4)**
1	**Resistance to Change**	33%	61%	6%	0%	17%	72%	11%	0%
2	**Risk Assignment**	33%	28%	39%	0%	6%	44%	33%	17%
3	**Relative Capital Investments**	22%	44%	11%	22%	17%	50%	6%	28%
4	**Contractual Leg. Aspect**	28%	56%	6%	11%	11%	72%	11%	6%
5	**Future Orientation**	6%	50%	17%	28%	6%	39%	28%	28%
6	**Team Orientation**	28%	44%	11%	17%	17%	44%	22%	17%
7	**Participation**	11%	33%	17%	39%	11%	33%	11%	44%
8	**In-Group Collectivism**	17%	44%	22%	17%	6%	61%	17%	17%
9	**Self-Protective approach**	17%	28%	39%	17%	6%	50%	22%	22%
10	**Implementation of strict rules and regulations**	17%	33%	28%	22%	11%	50%	11%	28%
11	**Selecting compensation and incentive structure**	22%	44%	17%	17%	11%	28%	22%	39%
12	**Technological BIM based Aspects**	22%	11%	28%	39%	11%	39%	22%	28%
13	**Expert Contract administrators**	11%	28%	22%	39%	11%	39%	22%	28%
14	**Early Contractor's Involvement**	11%	44%	22%	22%	6%	72%	6%	17%

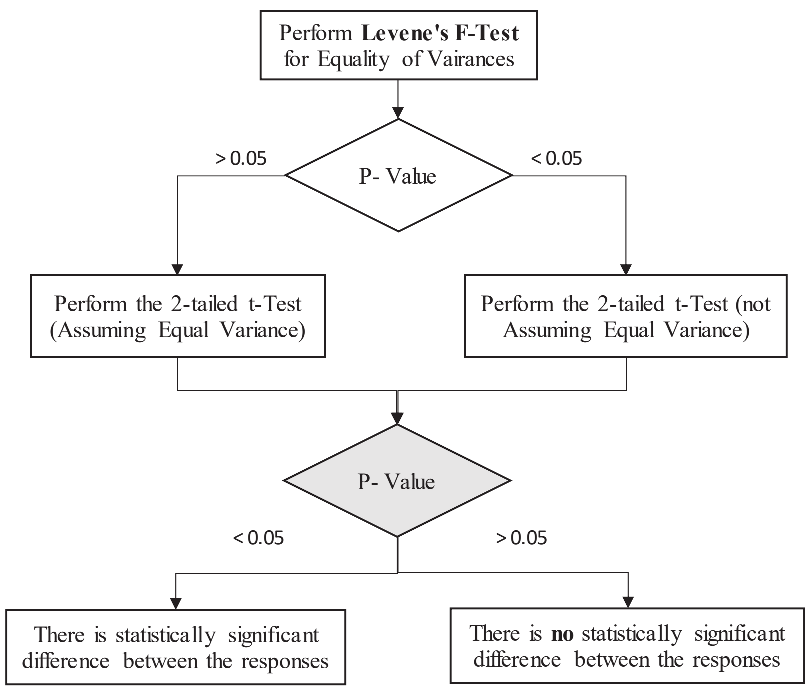

Figure 1. Procedure used to test and compare responses.

Table 5. Summarizing the Analysis results into two Categories.

	Barriers to Implementing IPD	The Respondents' View of the Middle Eastern Market		The Respondents' View of their Own Company		*t*-Test (*p*-Value)	Statistically Significant Difference?
		Avg.	Std. Dev.	Avg.	Std. Dev.		
1	Resistance to Change	1.83	0.50	1.78	0.63	0.78	FALSE
2	Risk Assignment	2.28	1.15	3.11	1.15	0.04	TRUE
3	Relative Capital Investments	2.17	0.69	2.22	0.79	0.83	FALSE
4	Contractual Legal Aspect	2.00	0.75	2.06	0.70	0.82	FALSE
5	Future Orientation	2.50	0.76	2.67	0.82	0.54	FALSE
6	Team Orientation	2.28	0.80	2.33	1.00	0.86	FALSE
7	Participation	2.50	0.76	2.33	0.67	0.50	FALSE
8	In-Group Collectivism	2.44	0.90	2.28	0.56	0.52	FALSE
9	Self-Protective approach	2.56	1.01	2.50	0.60	0.85	FALSE
10	Implementation of strict rules, policies, and regulations	2.67	1.11	2.56	0.83	0.74	FALSE
11	Selecting compensation and incentive structure	2.11	0.74	2.72	0.80	0.03	TRUE
12	Technological BIM-based Aspects	3.22	1.13	2.44	0.96	0.04	TRUE
13	Expert Contract administrators	2.56	0.83	2.56	0.96	1.00	FALSE
14	Early Contractor Involvement	2.56	0.83	2.22	0.53	0.17	FALSE

The points with different results in each viewpoint indicate that there is a lack of communication between different construction firms and this loss in communication increases the difficulty of implementing an IPD contract. Events and conferences bringing together people from different firms provide opportunities to share different opinions, capabilities, and methods to facilitate the implementation of new innovative approaches, like the IPD contract. For example, most experts in this research believe that the "Selecting compensation and incentive structure" constraint is Difficult to overcome in the Middle East market. However, the same experts see that the same "Selecting compensation and incentive structure" constraint is Easy to overcome inside their specific companies. This means that there is a strong capability to overcome this constraint and all that is missing is strong communication and collaboration channels between the different companies, and effective arrangements between them for the sharing of different relevant information, knowledge, and competencies for the implementation of IPD contracts. One constraint that opposes this view of opinions is the "Self-Protective approach", which shows that, despite this being an easy obstacle to overcome, different construction companies' strict hierarchy policies can make individuals afraid to express themselves more openly. Another opposing constraint is "Technological BIM-based Aspects", showing that the technology and experience are available but the intent to try is low, and the "Expert Contract administrators" constraint shows that companies need to hire employees with different scientific knowledge to the traditional, who are willing to implement new techniques in their work. Finally, most of the experts see that the constraint of "Risk assignment" is very difficult to overcome in the Middle East construction market but can be less difficult to overcome inside each interviewee's specific company.

This analysis of the points indicated the following results in each viewpoint and their significance when calculating the overall highest percentage in each viewpoint: 39% of the opinions see that the constraints of implementing IPD contracts are Difficult to overcome in the Middle East Market, while 50% of the same opinions see that these constraints are Difficult to overcome inside their specific companies. This 11% difference shows that there is a strong potential to overcome the constraints affecting IPDs if companies are willing to accept changes and new techniques inside their organizations. This analysis draws the important conclusion that the Middle East construction market is willing to accept new techniques like IPD, but the key to such change is inside the construction companies' policies and their preparedness to take positive risk.

Figure 2 represents a comparison between each of the experts' opinions in the constraints facing the implementation of IPD in the Middle Eastern market (Set 01) and their opinions of the constraints of IPD in their specific companies (Set 02). The numerical rating was (1) Very Difficult to overcome, (2) Difficult to overcome, (3) Easy to overcome and (4) Very Easy to overcome. It appears that the points presenting the experts' opinions in the Middle Eastern market are smoother, with small fluctuations, which indicates consistency and agreement in the different opinions. The experts' perspectives of the Middle Eastern Market's conditions are consistent, while the points presenting the experts' opinions in their specific companies have larger fluctuations and disturbances in their results, which reflects the big gaps in communication between these companies. The gaps in communication call for the establishing of a stronger communication channel and sharing of information through conferences, discussion meetings and technological sharing aspects, to have a comprehensive opinion about IPD implementation in the Middle East, and how to use each company's resources and knowledge to serve this goal.

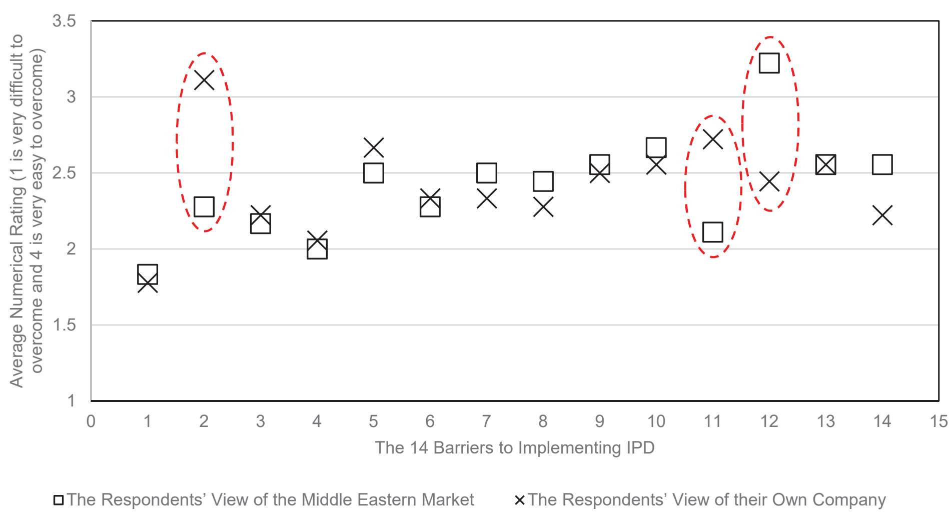

Figure 2. Comparison Chart between the experts' opinions in the Egyptian Market vs. opinions in their specific companies.

4.2. Comparison between the Egyptian and Saudi Arabian Construction Markets

A thorough comparison between the Egyptian market and the Saudi Arabian market was conducted using the statistical F-test and *t*-test. This analysis represents the factors with significant difference between the two markets, which are two of the biggest construction markets in the Middle East.

From the analysis, there is a higher percentage similarity between the two markets. However, there are factors with significant statistical difference, which are as follows:

- In Set 01 (The Respondents' View of his/ her country's Market):
    1. Resistance to change: About 89% of the experts' opinions in Egypt believe that this obstacle is difficult to overcome, while 64% in Saudi Arabia believe the same. This shows that there is a better tendency in the Saudi Arabian market to accept change if it benefits the objectives of the work.

2. Team Orientation: About 43% of the experts' opinions in Egypt believe that this obstacle is difficult to overcome, while 75% in Saudi Arabia believe the same. Opposite to the previous obstacle, this shows a better percentage in the Egyptian market to overcoming this constraint.

- In Set 02 (The Respondents' View of their Own Company):
  1. Selecting compensation and incentive structure: About 50% of the experts' opinions in Egypt believe that this obstacle is easy to overcome, while 45% in Saudi Arabia believe that it is difficult to overcome.
  2. Expert Contracts Administrators: About 60% of the experts' opinions in Egypt believes that this obstacle is Easy to overcome, while 45% in Saudi Arabia believe that it is difficult to overcome. The difference in these two points calls for a window between the two markets to share knowledge and expertise and make the two points of view become closer, so as to overcome these constraints.

4.3. Comparison between the Owners and Contractors of the Middle East's Construction Market

Similar to the previous approach for comparison, the F-test and *t*-test were used to compare owners' and contractors' opinions. The results of the analysis show significant statistical difference between the two parties' points of view in the points highlighted as follows:

- In Set 01 (The Respondents' View of the Middle Eastern Market):
  1. Risk Assignment: About 56% of the owner expert opinions believe that this obstacle is very difficult to overcome, while 44% of the contractors believe that it is very easy to overcome. This large difference between the two types of opinions reflects how much more owners are afraid of the risks and their investments than are contractors. More work needs to be done to convince the owners of the large benefits of using IPD in the construction market.
  2. Relative capital investment: About 67% of the expert opinions regarding owners believe that this obstacle is difficult to overcome, while 67% of the contractors believe that it is easy to overcome. This also presents the owners' tendencies to protect their investments as much as possible.
  3. Future orientation: About 67% of the owner expert opinions believe that this obstacle is difficult to overcome, while 44% of the contractors believe that it is easy to overcome. This could be because of the dynamic nature of contractors' work, making them more capable of preparing for future projects and of implementing different project control techniques.
- In Set 02 (The Respondents' View of their Own Company):
  1. Resistance to change: About 70% of the expert opinions of the owners believe that this obstacle is difficult to overcome, while 56% of the contractors believe that it is very difficult to overcome. This again shows how the construction companies' policies can affect employees' tendency to change.
  2. Future orientation: About 78% of the owner expert opinions believe that this obstacle is difficult to overcome, while 56% of the contractors believe that it is easy to overcome. The increase in percentage in the section regarding the experts' specific companies provides stronger validation that the dynamic nature of contractors' work makes contractors more prepared for the future.
  3. Selecting compensation and incentive structure: About 67% of the owner expert opinions believe that this obstacle is difficult to overcome, while 89% of the contractors believe that it is easy to overcome. Contractors, in general, tend to be more aware of compensation assignment techniques and incentives because most of contractor companies' work is associated with calculating and achieving profit, as well as optimizing incentives.
  4. Experts' contracts administrators: About 56% of the expert opinions of the owners believe that this obstacle is very difficult to overcome, while 78% of

the contractors believes that it is easy to overcome. This could be due to the strong technical processes contracts administrators face inside contractor firms, which provides them with more knowledge and experience, making them more prepared for new techniques like IPD, and increases the trust of managers in these companies.

5. Comparison to Previous Research

Based on this study, the first risk category which is very difficult to overcome is the Risk assignment factor. According to other studies, developed countries, like the United States and Canada, can deal with this factor better due to formalized legal arrangements and contracts that can clearly employ risks. Also, as mentioned before, there is still a lack in literature about the implementation of this type of delivery method in the Middle East. Consequently, comparing these research results in the same region is hard, but the authors hope that this study will open the window and encourage other researchers to further analyze IPD implementation in the Middle East region further and compare different results to the proposed research.

The second risk category which is difficult to overcome is resistance to change. According to [37], overcoming resistance to change is associated with factors like leadership and education, which is currently more available in developed countries, and which can play an important role in the implementation of IPD in the Middle East. Next came Relative Capital investment and contractual legal aspects; these factors are less severe in Western countries, due to better availability. The remaining factors in this category are Future orientation, team orientation, In-Group collectivism, Implementation of strict rules, policies and regulations and Early contractor's involvement which, based on several studies, have the same severity in all the countries trying to implement the IPD approach. These factors can be solved through discussions and presenting the benefits of the IPD method to a range of bodies and different entities.

All the other remaining factors are based on collective subjective data, which means these factors can have a significant impact when implementing the IPD type of contract and should be considered and discussed through the process. These factors depend on different causes that need to be studied and controlled before the assigned construction project is initiated.

6. Conclusions and Summary

This research presented an overview analysis of Implementation of the Integrated Project Delivery (IPD) Contract in the Middle East Market; in particular, its constraints, approaches to overcome these constraints and its benefits. Based on previous analysis, the constraints to IPD contracts implementation in the Middle East are classified into three categories as follows: *Very Difficult to overcome*; Risk assignment, *Difficult to Overcome*; Resistance to change, Relative capital investment, contractual legal aspects, Future orientation, team orientation, In-Group collectivism, Implementation of strict rules, policies and regulations and Early contractor involvement, and *Conflicting viewpoints*; Self-protective approach, selecting compensation and incentive structure, Technological BIM-based aspects and Expert contract administrators.

The proposed approach to apply the viewpoints to the overall Middle Eastern market and the experts' specific companies was valid in distinguishing lack of communication and alignment between different systems in construction companies in the Middle East and the need to reach a suitable solution to this problem. The points with conflicting viewpoints are due to lack of communication and collaboration between the different firms in the Middle East, which can be overcome with the proposed approaches. A comparison between the Egyptian market and the Saudi Arabian market was conducted to highlight the points that need collaboration between the two countries to eliminate the constraints of implementing IPD. Then, a comparison between the contractors and the owners was performed, which reflected their different points of view and how to decrease the gaps between them, by using different approaches that can encourage both parties to implement IPD in their companies.

Based on the conducted survey and research, scientific scholars and researchers should work on overcoming these barriers in the early stages and encourage entities and individuals to become more willing to adapt. Also, construction projects' managerial personnel should understand the positive outcomes of implementing such a project delivery method and, through this understanding, encourage and help their employees to use the method and introduce new potentials to the delivery method's capabilities.

Future studies need to be conducted to identify new methods of encouraging and coaching parties to practice IPD contracts and to clearly define their benefits. Finally, the major constraints facing the implementation of IPD in the Middle Eastern construction market can be overcome by the following guidelines: the parties involved need to adopt a tendency towards change and experiencing of new systems, and value driven selection criteria need to be followed to reach general agreement on a single contract. Different project parties need to engage in future-oriented behaviors, such as delaying illumination, planning, and investing in the future and teams need to be built with implementation of a common purpose or goal among team members. Managers also need to involve others in making and implementing decisions and individuals need to express themselves and their opinions freely without being afraid. Subcontractors need to have expertise in technologies such as Building information modeling (BIM) and different integration systems of construction projects. They also need to develop a suitable process for identifying the price of BIM tools and to solve the problematic setting of standards for sharing data among participants in the BIM process at the start of the project. Finally, there should be early involvement of the contractor in the design stage for constructability reviews.

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The Causal Factors of Elevator Maintenance: A Perspective from Saudi Arabia Healthcare Facility Management

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Abstract: Maintenance is crucial for healthcare facilities in terms of both the continuity of operations and annual costs. Many maintenance issues are associated with design decisions that pave the way for added costs in later lifecycle stages. Some systems, e.g., elevators, are sources of maintenance costs; additionally, elevator outages are significant issues for multi-floor healthcare facilities. Considering the maintainability of elevators from the early design stages helps to highlight potential maintenance issues in later stages. This also assists in mitigating costs by avoiding design decisions that result in future maintenance costs. This research uses the expertise of facility managers who have experience with maintenance issues resulting from design decisions. A list of 35 elevator maintenance issues caused by design flaws is presented in this paper, based on the literature and semi-structured interviews with a representative sample of six healthcare facility management experts. Then, a questionnaire using convenience sampling was conducted with facility management professionals to evaluate and rank the maintenance issues. While 60 professionals responded, only 30 attempted the four-parameter evaluation of all listed maintenance issues. The results of the questionnaire determined elevator car jams, sudden stops, and working space conditions to be the most critical issues faced by facility managers in healthcare facilities. The output of this study can help designers of new healthcare facilities to avoid decisions that result in unwarranted maintenance issues with costly impacts.

Keywords: facility management; construction management; healthcare facilities; design defects; elevator design; FMECA

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1. Introduction

Maintenance plays a vital role in all hospital services and refers to the complicated variety of systems, with various levels of technology, used in hospitals; the potential consequences of the failure of these systems necessitate high availability and functional safety measures [1]. The demand for healthcare services and hospitals is increasing globally, attributable to population growth, population aging, and consumer behavior [2]. Maintenance is essential to hospital performance [3–5]. Furthermore, design-stage problems are considered a more significant source of facility maintenance issues compared to problems in the construction stage [6]. When facility maintenance is not considered sufficiently at the design stage, unforeseen maintenance issues may add a cost parameter to the facility management stage. During the design stage, decisions are usually focused on the initial costs, and this does not reflect the significant impact of these decisions on the later stages [7].

As mentioned, these concerns signify a cost component among buildings' lifecycle costs that can be avoided if maintenance is contemplated sufficiently in the design stage. However, not many owners consider this a priority issue [8,9]. Factors such as cost, longevity, and performance have long been the focus during the design stage, while other factors, including maintainability, have been underrated [10,11]. Al-Hammad et al. cited faulty designs as the reason for maintenance cost escalations [12]. Hence, maintenance problems and faulty designs are related to the level of maintenance input during the design stage. Building maintainability is determined by design selections that address or overlook maintenance concerns at the early stage of design and construction [9]. When maintenance concerns are addressed sufficiently at the design stage, the maintainability of the design is improved, which results in future maintenance cost savings. Feedback from facility management professionals on design-caused maintenance issues is a suitable approach to achieve this maintainability improvement. Designing for building maintainability includes the processes performed to reduce defects and maintenance needs throughout a facility's lifecycle [13]. This issue focuses on the need for a maintainability assessment during the design stages to alleviate the impact of design decisions and predict future maintenance costs. This helps to reduce maintenance by enhancing the maintainability of the design. Therefore, an overall lifecycle cost reduction can be achieved.

Healthcare facilities contain several building service systems that are essential for the continuity of serving their purpose of providing healthcare to the public. The cost component and the annual growth in costs may cause serious concern regarding the continuity of healthcare facilities. In Saudi Arabia, for example, it is projected by the National Committee for Legislation and Standardization of Operation and Maintenance (NCLOM) that the future operation and maintenance of healthcare facilities will grow by an average of 10% annually from 2014 to 2030 if the current rates of growth continue [14]. Investigating the maintainability of healthcare facility service systems during the design stages helps to minimize maintenance needs and can lead to potential maintenance cost reductions. However, it is common to exclude the healthcare facility maintenance perspective while the project is in the design stage because of a lack of communication between the design and maintenance teams [15]. The maintenance of healthcare facilities can be considered with regard to the various systems utilized to run such facilities.

Mechanical, electrical, and plumbing (MEP) service systems in complex projects, such as high-tech, healthcare, and transportation projects, comprise up to 50% of the initial costs [16,17]. Among these mechanical systems, elevators are effective systems that are used in the daily operation of healthcare facilities. Although elevator maintenance is considered a cost, it provides a critical service in terms of the transport of patients. A cross-sectional case review study in Australia on incidents relating to the intra-hospital transfer of critically ill patients found that around 39% of the incidents encountered during transport were equipment-related, and 10% were due to elevator accessibility [18]. Hence, this study focuses on the improvement of elevator maintainability.

2. Literature Review

In previous research on building maintainability (Table 1), elevator systems were investigated; however, the focus was only on commercial buildings. Moreover, multiple studies on building maintainability have been conducted for a number of building types, but few have attempted to investigate elevators. The studies in Table 1 followed different methods of approaching the maintainability of buildings and the assessment thereof, but all of them sought to list and evaluate building defects as part of the various methods adopted to improve maintainability. Until now, there have been insufficient numbers of maintainability studies on elevators in healthcare facilities, despite the heavy usage of elevators in healthcare facilities.

Table 1. Previous research on maintainability.

Authors	Building Type	Location	Elevators Defects	Impact Factors of Defects	Comparison
Siti et al. [19]	General buildings	Singapore	26	Not stated	This study provided a framework for an elevator maintainability evaluation and sought to understand maintainability issues via a questionnaire distributed among practitioners.
Chew et al. [20]	High-rise commercial buildings	Singapore	114	This study analyzed elevators' economic defects, system performance, safety, and comfort impact.	This study focused on commercial buildings, and the impact of defects did not consider healthcare-related building use. It includes defects that occurred during the construction and operation stages.
De Silva et al., 2016 [21]	High-rise Building	Sri Lanka	-	10 risk factors	This study followed a risk-based framework that can measure maintainability by listing. It used an artificial neural network (ANN) tool to forecast maintainability in the early stage of a building. It serves as a decision tool to reduce maintenance costs.
De Silva and Ranasinghe [22]	Condominium	Sri Lanka	-	-	This study followed a risk-based maintainability assessment by investigating defects and problems. Although building service defects were the most serious maintainability issues, this study did not specify the defects of the elevator system.
Hassanain et al., 2014 [23]	Higher education	Saudi Arabia	-	-	This study investigated the defects of the heating, ventilating, air-conditioning, and cooling (HVAC) systems from maintenance professionals' point of view. It presented evaluated maintainability lists built to help designers avoid common maintenance issues.

The elevator systems investigated previously in maintainability studies follow a similar breakdown of elevator components, with some differences (Table 2). For one, Siti et al. [19] presented five main component groups that included various common maintainability issues. The breakdown of components adopted by Chew et al. [20] included a larger breakdown that specified subcomponents. The subcomponents may be present within a single component or in more than one. Another study by Chew and Das [24] listed the main components in a manner that combined the main approaches of the studies of both Siti et al. [19] and Chew et al. [20]. This study adopted a synthesis of the component breakdowns presented in the previous studies.

This research aims to use the experience of healthcare facility management experts in a proper framework that helps to improve elevator maintainability by achieving two objectives. The first objective is identifying a list of elevator maintenance issues caused by their design, and the second is evaluating and ranking the maintenance issues based on their criticality.

During the design stage, the designers can utilize this study's output regarding the maintainability of elevators to enhance the decision-making process. Such a proactive approach eliminates unfavorable design decisions and improves the maintainability of healthcare facility design by reducing the undesirable effects of future maintenance needs.

Table 2. Elevator components.

Siti et al. [19]	Chew et al. [20]	Das and Chew [21]
Traveling performance Machine rooms Hoistway and elevator pit Elevator car Elevator lobby	Components: Machine room Lift hoistway Lift car Lift pit Lift landing Sub-components: controller, governor machine, machine room, traction machine, traction motor, brake assembly, guide rail, wire rope, shaft, car interior, car door, car top, car bottom, door operator, travelling, landing door, lift landing, and smoke detector	Machine room and equipment Lift car Car and lobby door Hoistway Ropes Landing Lift pit

3. Materials and Methods

The objective of this research is to eliminate common building defects from the early stages, before they occur. The following steps (Figure 1) were followed to acquire knowledge from practicing facility managers in healthcare facilities to evaluate a wide array of elevator defects collected from the literature.

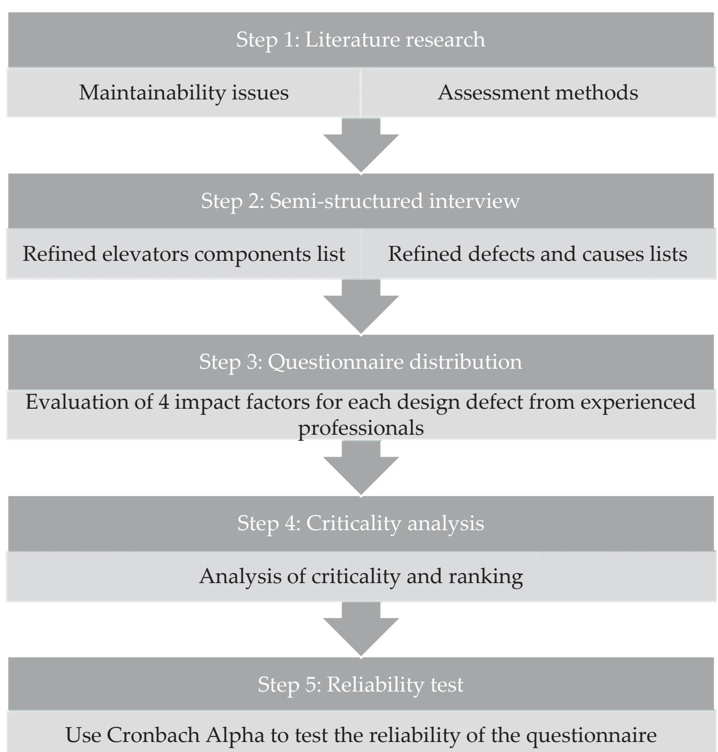

Figure 1. Methodology followed in this research to evaluate critical elevator maintenance issues caused by design.

Step 1. Research was conducted that reviewed the literature regarding elevator maintenance defects and their causes in order to analyze their criticality. Since this study focuses on design-caused maintenance issues, the selection process for defects and causes verified that design decisions regarding the specifics of an elevator component lead to the occurrence of said defects. This included research on the assessment methodology to be utilized. Guided by the maintainability assessment and checklist presented by Das and Chew, four elements were chosen for evaluation in this study for each defect, i.e., hygienic, health, and safety impact; cost impact; performance impact; and defect frequency [24]. These elements added additional factors focused on health and safety in order to respond to the nature of healthcare facilities, compared to the impact factors employed by Das and Chew [24].

Step 2. Semi-structured interviews were conducted with a representative sample of experts in elevator maintenance to collect data on the elements mentioned above and to critique the research content of the literature. A total of 62 elevator maintenance issues were discussed with each expert. The interviews involved discussing each issue in light of two essential elements: the extent to which a defect was design-caused, and healthcare relatedness. There were anomalies in the feedback from the selected 6 participants. To avoid bias or inconsistency, the results from all participants were cross-checked during interviews. This step resulted in a refined list of 35 defects as a final list of maintenance issues caused by design decisions as agreed upon by most interviewees. The targeted interviewees were professionals with a proven record of experience with healthcare facility management. Since some experts may not have dealt with elevator systems directly, experience in elevator maintenance was a prerequisite. Whether in a public or private healthcare facility, the level of experience required of the interviewees was at least 15 years. Table 3 lists the responses collected from the interviewees after cross-checking the literature review data of each elevator defect and its cause.

Step 3. A questionnaire was distributed among facility management experts in Saudi Arabia, asking them to evaluate the list generated in Step 2 based on a 5-point Likert scale. This questionnaire adopted convenience sampling, which is a non-probability sampling technique that selects a sample of participants from a population based on convenient accessibility of the data sources [25]. Failure mode, effects, and criticality analysis (FMECA) was used to reflect upon the perspectives of the interviewees to produce their evaluations. The targeted experts were required to have more than ten years of experience in a public or private healthcare facility. All the respondents had to disclose whether their professional background included elevator maintenance experience in healthcare facilities.

Step 4. Criticality analysis was applied to the results that reflected the most severe design decisions, leading to the determination of the most common elevator maintenance issues.

Step 5. We performed a reliability test on the questionnaire, utilizing Cronbach's alpha (α).

$$\alpha = (k \div (k-1)) \times (1 - ((\sum_{i=1}^{k} \sigma_i^2) \div \sigma_X^2))) \quad (1)$$

where k is the number of test items, σ_i^2 is the variance of a single test item X_i, and σ_X^2 is the variance of the overall test items, X.

Cronbach's alpha is a test reliability evaluation technique, and it is imperative to employ it when using Likert-type scales to ensure internal consistency and reliability [26]. A reliable test requires the alpha coefficient to be very close to 1.0 [26,27].

Table 3. Defects detected in the facility management phase that were caused by design decisions.

Sn	Component	Defect	Causes
1	Elevator general performance	Long waiting time for elevator to come	Design consideration for traffic load is improper
2		Elevator car vibrations	Overloading when counterweight ropes are not perfectly matched, especially if less than three, or poor machine room and hoistway building tightness, which allows dust in
3		Elevator car jams	Limit switch placement is near the governor rope, which causes the car to stop
4	Machine room	Existence of debris and lubricants	Dust from finished or window AC usage or inadequate space and clearance around equipment in the machine room
5		Falling on machines while performing maintenance or being hit by them	Inadequate space in the machine room, hoistway, or pit, or water or lubricant spills forming slippery working surfaces
6		Insufficient lighting level	Inadequate lighting level or short-lamp-life design
7		Poor air quality	No air conditioning or proper ventilation, or high humidity coming from water leaks in the wall or ceiling without proper drainage
8	Controller	Dirt or noise	Not configured for the environment of the area, i.e., cold versus arid environments and weather conditions, and Ingress Protection (IP) rating does not match
9		Voltage mismatch	The voltage of imported controllers may differ under many circumstances, allowing a potential voltage mismatch
10	Traction machine	Dirt and oil on the traction machine	Insufficient accessibility and limited space to allow adequate general cleaning or spillage removal during lubrication
11		Wearing marks on ropes	Selection of the rope is mismatched and improper for long sustainment of friction, and possible tension unevenness or improper sheave geometry and design, allowing fast sheave wear that damages ropes
12		Noise and vibrations	Insufficient specs for traction machine strength, leading to faster inner wearing, or a proper machine bed rubber is unavailable to absorb vibrations and add more durability
13	Speed governor machine	Dirt or noise	High friction due to unsuitable components and rope selection, or inadequate accessibility causing insufficient cleaning for dirt and spillages
14		Sudden stops	Improper selection, sizing, and specifications of the tripping mechanism
15	Elevator car	Maintenance working conditions unsafe	Insufficient clearances, low overhead above, guards unavailable, or lighting is poor or unavailable
16		Noisy traveling cable	Cable selection does not secure proper acoustic performance
17		Darkness or low lighting level	No guard for lights, which may become damaged
18		Poor air quality	Inadequate air conditioning or ventilation
19		Noisy interior	Finished materials for the car have poor acoustical design; low specs are selected; ventilation fan is noisy due to low quality; trapdoor lock design allows minor movement, thus making sounds
20		Car Operating Panel (COP) button not working	Nondurable design for buttons allowing faster damage
21		Damaged flooring	Nondurable flooring materials are selected
22	Hoistway	Noise and vibration	Guide rail specifications are poorly selected, which may lead to denting
23		Dirt and dust	Materials selected to build the hoistway generate dust
24		Poor air quality	Inadequate ventilation inside the hoistway, walls allow for water seepage, no existing waterproofing
25	Roping system	Corroded wires	Rope materials are not rust-resistant and are thus susceptible to corrosion, or poor pulley geometry or grooves causing wires to undergo repetitive bending or excessive friction
26		Rope vibrations	Deep dust accumulations in pulleys

Table 3. *Cont.*

Sn	Component	Defect	Causes
27	Car door	Frequent door closing while users step in	Poor sensing system design, such as single-point photoelectric eyes sensors, that allows such performance
28		Car doors remain open	COP buttons are nondurable and become unable to function properly without intervention and second attempts
29		Noisy doors and abnormal operation	The door roller shoe is poorly designed, and its materials are not adequately selected with rubber lining
30		The front frame (jamb) is rusty or damaged	Poor material selection in terms of durability and corrosion resistance
31	Lobby and Landing	Button damage	Poor material selection for nondurable buttons that cannot withstand heavy use
32		The in-car service switch is jammed/broken	Inadequate design to protect the switch from possible vandalism
33	Lift pit	Wet and dirt issues	Inaccessible pits or limited access for cleaning, or seepage through structural members with no proper waterproofing
34		Poor lighting	The lighting is either not provided by the design or not adequately guarded, or the selected lighting level is insufficient
35		Falling on or being hit by an adjacent machine while performing maintenance	The pit does not include a partition when accommodating more than one car

FMECA Assessment

Since the mitigation of defects is a maintainability approach to reducing maintenance, FMECA was adopted by Das and Chew to analyze building defects and grade defects to enhance the maintainability of buildings [24]. Their work proposed a modified FMECA approach as a defect-grading tool to adopt a more suitable building industry version of the FMECA approach, and the scope of their study included only commercial buildings in Singapore. Their efforts included investigating the suitability of applying classic FMECA to grade commercial building defects, including elevators, which resulted in considering the inability to use the quantitative aspect of FMECA in grading building defects due to several obstacles, i.e., the difficulty of obtaining defect data and the inapplicability of the operating time data for some building systems. Thus, the qualitative data were deemed appropriate for FMECA, and the FMECA risk parameter numbers were measured to produce an overall criticality estimate of a specific defect. This provided a deeper analysis, comparing other studies on building maintenance utilizing relative importance [28] and the relative importance index (RII) [29].

Research in healthcare facility management and maintenance has adopted failure mode and effects analysis (FMEA) to analyze facility failures, which is a similar approach and a subset of FMECA that excludes the criticality analysis and can be considered to be a troubleshooting guide for maintainability [30–32]. Even though FMECA and FMEA originated in other engineering fields, they were introduced for use in buildings [24,33–35].

Using a similar approach, this study adopted a modified FMECA. In light of the work of Das and Chew on building maintainability [24], FMECA provided a suitable tool to analyze the defects presented by this study according to a number of parameters. FMECA focuses on linking each defect with the issues that may cause its occurrence, and it provides a criticality evaluation built on multiple parameters. The parameters of defect impacts were used to grade design-caused defects triggering maintenance issues, conducted by experts in healthcare facility management. In this research, elevator defects were categorized according to a questionnaire regarding ten elevator components, which was sent out to experts. Grouped according to components, the defects differed by focusing only on design-caused defects (Table 4). The grading of defects was then established based on the questionnaire that gathered expert judgment for each defect's frequency and the severity of the impact of the defect occurrence. The impacts of the defects were classified into three impact parameters, i.e., economic, system performance, and comfort. The research presented here added another impact parameter for defects: the hygienic, health, and safety impact, which signified the additional sensitivity to maintenance defects present in healthcare facilities. Although cost was considered among the other factors, evaluation based on expert judgment is merely an indicator. Actual cost analysis may be considered for more accuracy when investigating specific case studies. The parameters to be rated were: A = hygienic, health, and safety impact; B = cost impact; C = performance impact; D = defect frequency. Hence, the formulation of the criticality of defects in this research can be represented as follows, with criticality being represented on a 5-point Likert scale:

$$\mathrm{Sv} = (\mathrm{A} + \mathrm{B} + \mathrm{C}) \div 3 \tag{2}$$

$$\mathrm{Cr} = (\mathrm{Sv} \div 5) \times (\mathrm{D} \div 5) \tag{3}$$

where Sv is severity, and Cr is criticality (Table 4).

Table 4. Questionnaire results for elevator design defect evaluation by facility managers.

Sn	Component	Defect	Number of Responses				Severity (Sv)	Criticality (Cr)	Defect Rank	Avg Component Criticality	Component Rank
			A	B	C	D					
1	Elevator general performance	Long waiting time for elevator to come	27	27	27	27	3.5432	0.4462	10	0.4703	1
2		Elevator car vibrations	27	27	27	27	3.6049	0.4700	4		
3		Elevator car jams	27	27	27	27	3.6296	0.4947	1		
4	Machine room	Existence of debris and lubricants	27	27	27	27	3.2593	0.3959	28	0.4074	3
5		Falling on machines while performing maintenance or being hit by them	27	27	27	27	3.4938	0.4296	17		
6		Insufficient lighting level	27	27	27	27	3.4074	0.3988	26		
7		Poor air quality	27	27	27	27	3.4198	0.4053	25		
8	Controller	Dirt or noise	15	25	25	25	3.4133	0.4260	19	0.4359	2
9		Voltage mismatch	25	25	25	25	3.6667	0.4459	11		
10	Traction machine	Dirt and oil on traction machine	25	25	25	25	3.2400	0.4199	20	0.4124	2
11		Wearing marks on ropes	25	25	25	25	3.1467	0.3877	32		
12		Noise and vibrations	25	25	25	25	3.4000	0.4298	15		
13	Speed governor machine	Dirt or noise	25	25	25	25	3.5067	0.4657	5	0.4701	1
14		Sudden stops	25	25	25	24	3.5733	0.4745	3		

Table 4. *Cont.*

Sn	Component	Defect	Number of Responses				Severity (Sv)	Criticality (Cr)	Defect Rank	Avg Component Criticality	Component Rank
			A	B	C	D					
15	Elevator car	Maintenance working conditions unsafe	25	25	25	25	3.6667	0.4928	2	0.4167	3
16		Noisy traveling cable	25	25	25	25	3.4400	0.3963	27		
17		Darkness or low lighting level	25	25	25	25	3.2667	0.4077	23		
18		Poor air quality	25	25	25	25	3.0667	0.3925	30		
19		Noisy interior	25	25	25	25	3.0400	0.3843	33		
20		Car Operating Panel (COP) button not working	25	25	25	25	3.3733	0.4480	9		
21		Damaged flooring	25	25	25	25	3.2933	0.3952	29		
22	Hoistway	Noise and vibration	25	25	25	25	3.5067	0.4096	22	0.3772	4
23		Dirt and dust	25	25	25	25	3.1600	0.3741	34		
24		Poor air quality	25	25	25	25	3.2933	0.3478	35		
25	Roping system	Corroded wires	25	25	25	25	3.4400	0.4293	18	0.4097	3
26		Rope vibrations	25	25	25	25	3.3867	0.3901	31		
27	Car door	Frequent door closing while users step in	25	25	25	25	3.4267	0.4331	12	0.4387	2
28		Car doors remain open	25	25	25	25	3.5067	0.4601	7		
29		Noisy doors and abnormal operation	25	25	25	25	3.4000	0.4298	15		
30		Front frame (jamb) is rusty or damaged	25	25	25	25	3.3733	0.4318	14		
31	Lobby and landing	Button damage	25	25	25	25	3.2400	0.4510	8	0.4330	2
32		In-car service switch is jammed/broken	25	25	25	25	3.4133	0.4151	21		
33	Lift pit	Wet and dirt issues	25	25	25	25	3.3333	0.4320	13	0.4333	2
34		Poor lighting	25	25	25	25	3.3067	0.4074	24		
35		Falling on or being hit by an adjacent machine while performing maintenance	25	25	25	25	3.4667	0.4604	6		

4. Results

Only 30 responses attempted to answer all the questions in the questionnaire out of the total population of 60 responses. However, all the answers received from the targeted group were considered; these range from as low as 15 respondents to as many as 27 respondents.

Although defects can vary in criticality within each component of an elevator system and when standing alone, the overall criticality of components was ranked based on the average Cr values that comprise the components. The same rankings were assigned to the components where the difference in the criticality values was less than 5%. Table 4 summarizes the questionnaire results, which revealed that the design defects that affect general elevator performance, such as extended waiting times, vibrations, and car jams, were the most critical maintenance issues caused by design decisions. Car jams caused by the placement of limit switches carried the highest criticality with a Cr value of 0.4947.

The causes of the other defects for this component, which came fourth and tenth in rank, mainly stemmed from underestimating the design considerations for traffic load and counterweight ropes, poor machine room layout design, and hoistway building tightness.

Despite the overall rank of the average criticality for elevator components, the second critical elevator defect focused on the causes of unsafe conditions of maintenance activities. With a Cr equal to 0.4928, elevators with a low overhead clearance above the car, poor lighting, or unavailable lighting were ranked the second most critical by experts. From the questionnaire results, the frequency and impact of this defect were the main drivers behind this evaluation. The speed governor component of elevators included two defects, with a Cr of 0.4745 for sudden stops and a Cr of 0.4657 for dirt and noise, and it ranked first alongside the elevator's general performance component. These defects came third and fifth, respectively, in the list of overall defect criticality.

5. Discussion

The results show an inconstant evaluation for defects related to cleanliness. As dirt accumulation impact varies from one component to another, the respondents changed their evaluation of the various cleanliness-related impacts. This can be observed for other defects that have a low Cr for one component while scoring a higher Cr for a different component. For example, air quality ranged from a more serious Cr in machine rooms to a lesser one in the hoistway. This can be explained by the spacious volume of the hoistway compared to the machine rooms, and the fact that the opening and closing of doors allow air movement.

The facility management experts linked the sudden stopping of elevators to the improper selection, sizing, and specifications of the tripping mechanism. Among all the impacts evaluated for the latter defect, sudden stopping affected overall elevator performance more than the other impacts evaluated in this study. On the other hand, dirt or noise in the speed governor component was mainly caused by high friction or inadequate accessibility of the system components.

Maintenance working conditions for elevator car maintenance were evaluated to be the second-highest-ranked critical defect. Most of the facility managers agreed that insufficient design considerations regarding the safety of the technicians while performing maintenance work was significant; such issues include the space surrounding the elevator, machine and tool setup and clearance, safety measures for falling items while working at the top of the elevator car, and low overheads. Falling in the lift pit represented a maintenance issue that experts emphasized. This defect concerns performing maintenance anywhere in the shaft but the elevator car. There is a risk of falling from car doors when performing maintenance. The unavailability of design decisions that lead to safer conditions for performing maintenance in elevators remains an alarming issue. This defect had a Cr value of 0.4604, which was ranked sixth among all defects.

Various types of healthcare facilities likely have various scenarios regarding elevators maintenance. However, this study approached various types of facility management together to simplify the process of designing for maintainability. Moreover, there are several maintenance approaches and processes, including corrective, preventive, risk-based, and condition-based maintenance, and they differ in terms of their impact on maintainability. Since design stage decision impacts on maintainability were the focus of this study, the processes and decisions associated with maintenance stages were beyond the boundaries of this research.

The ranking based on Cr values may be a limitation since Cr values tend to cluster with minute differences. Further studies that incorporate additional parameters would introduce a wider range among the results. Table 5 provides more details for each elevator component according to the results of the questionnaire.

Table 5. Observations on the questionnaire results grouped by components.

Sn	Elevator Component	Notes
1	Elevator general performance	Contains the highest weight of overly critical maintenance issues. The major critical design-caused defect is elevator car jams caused by the limit switch placement in elevators near the governor rope, making the elevator car stop moving.
2	Machine room	Comes tenth among the overall less-critical components. The defects associated with the machine room are pertinent to other systems and mostly focus on accessibility and cleanliness obstacles.
3	Controller	Includes the most critical design-caused defect seen in the area experts worked in, i.e., the voltage mismatch of controllers. Since controllers are mostly imported from abroad, there are frequent cases of voltage mismatch, which could be avoided if additional measures were taken at the design stage.
4	Traction machine	The most critical defect within the traction machine category is the noise and vibrations caused by insufficient specifications for traction machine strength, leading to faster inner wearing. A proper machine bed rubber is unavailable to absorb vibrations and add more durability.
5	Over-speed governor machine	This component comes second among all others for two primary defects, i.e., dirt or noise, caused by high friction due to unsuitable components and rope selection, or is otherwise caused by inadequate accessibility causing insufficient cleaning of dirt and spillages. The second is a sudden stop due to the improper selection, sizing, or specifications of the tripping mechanism.
6	Elevator car	The primary defect that causes maintenance issues is unsafe working conditions caused by a low overhead above the elevator car or poor or unavailable lighting.
7	Hoistway	From inside the hoistway or shafts, host elevators have a moderate critical defect affecting their maintenance. The primary design-caused defects rated for this component are noise and vibration, dirt and dust, and low air quality.
8	Roping system	Corrosion is the primary defect that affects this component caused by non-rust-resistant rope materials, which are thus susceptible to corrosion, poor pulley geometry, or grooves, causing the wire to undergo repetitive bending or excessive friction.
9	Car door	Overall, this component comes third compared to other components. Its primary defect is that the doors may remain open because the car's operating panel (COP) buttons are nondurable and become unable to function appropriately without intervention and second attempts.
10	Lobby and landing	The in-car service switch being jammed or broken is the most critical defect for lobby and landing components. This is caused mostly by inadequate designs to protect the switch from possible vandalism.
11	Lift pit	As a component, this is among the components that are second in criticality. The most critical defect, ranked eleventh among all component defects, is the possibility of falling on or being hit by an adjacent machine while performing maintenance. The reason for this is that some elevator pits do not include a partition when accommodating more than one car.

The main issues related to healthcare facilities that the interviewees emphasized were the stoppage of service in elevators, air quality, and maintenance practices. While stoppage is linked directly to elevator components, the air quality may be associated with another building system. However, the inclusion of air quality is consistent with the hygienic role of elevators in a healthcare facility. The design decisions that handle air passage and circulation through elevator systems affect elevator safety in transporting patients and visitors. Although maintenance practices may not be part of the design stage decisions, the inclusion of maintenance considerations, including safety tools and attachments, accessibility, light availability, and air quality, is important to safe operation.

This paper approached the evaluation of maintainability without detailed cost analyses. The rating of cost impacts by experts was used as the essential reference for the cost of maintenance in a generalized form. Previous studies have approached maintainability assessments in a similar manner. For example, the work of de Silva & Ranasinghe [21] followed a risk analysis approach to evaluate maintainability, which considered expert evaluations of costs of maintenance as a trigger for risk seriousness. Additionally, the work of Das & Chew [24] adopted FMECA, which included a cost parameter evaluated by experts. In the work of Hassanain et al. [23] that ranked HVAC maintenance issues, they listed design-caused maintenance issues and evaluated their seriousness based on expert judgments.

To verify the internal consistency of the Likert-scale questionnaire employed in this study, Cronbach's alpha coefficient was calculated, and the result was 0.9968 (Table 6). Although high alpha coefficient scores are sought, a high score such as this one does not necessarily reflect a higher internal consistency because it is impacted by the length of the test [36].

Table 6. Cronbach's alpha of the questionnaire results.

Number of Questions	Sum of Variances	The Variance of Total Scores	Cronbach's Alpha, α
140	129.35	12,564.74	0.9968

6. Conclusions

This research assessed the criticality of maintenance issues caused by design decisions based on a modified FMECA approach, aiming to improve the maintainability of elevators in healthcare facilities. Data regarding elevator components, defects, and their causes were gathered from the literature to verify the input of facility management experts. The design defects that cause the maintenance issues studied in this paper considered the four aspects of: (1) hygienic, health, and safety concerns; (2) cost; (3) performance; and (4) frequency of occurrences.

The questionnaire outcomes included a list of criticality evaluations by experts regarding the sources of 35 elevator maintenance issues. The general performance of elevators, as represented by waiting time, vibrations, and car jams, presented the most serious maintenance issues. In particular, jamming issues caused by the limit switch placement were evaluated in this study to be a source of the most critical design decisions affecting the maintainability of elevators in healthcare facilities.

Designers of new healthcare facilities will benefit from the approach proposed in this research by having access to the knowledge produced, particularly for elevators in healthcare facilities. The outcomes of this research may aid designers in promoting maintainability for new healthcare facility designs.

One limitation of this research can be described as being due to the limited number of studies on elevator maintainability to compare against, especially in healthcare facilities. Moreover, we focused on experts from one geographical area, which may have yielded different results from those of other areas with different climates and industry practices.

Future research may advance the maintainability of elevators by integrating maintainability-based technical specifications into Building Information Modeling (BIM) software. BIM tools can enable designers to be aware of the impact of their early decisions on the lifecycle maintainability of facilities based on the experience of maintenance professionals. Additionally, future research can address further aspects of elevator maintainability, for example, a detailed engineering study of the defects and maintenance practices for elevators in healthcare facilities. This may alert designers early in the process to the impact of design decisions on future maintenance.

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buildings

Review

Review of Culture in Maintenance Management of Public Buildings in Developing Countries

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Abstract: Studies have shown that culture is one of the significant elements that influence the behavior of doing things the right way, without which there is a hindrance to the attainment of set goals. It has also been stated that culture is essential to maintaining public buildings, which is significant to national development. However, the level of abandonment and deterioration of public buildings is high due to a lack of culture among stakeholders in the maintenance process. Therefore, through a literature review from over 100 recent publications, this study measured culture as a variable that influences effective maintenance management of buildings. This was carried out to enlighten maintenance managers and policymakers within the developing countries regarding the significance of maintenance culture and possible measures for improving the attitude of stakeholders on the maintenance process. It was also carried out to develop a new maintenance focus (behavioral change) for maintenance managers and policymakers, especially in developing countries, to manage the available public buildings and other proposed ones effectively.

Keywords: behavioral change; maintenance culture; maintenance management; public buildings; stakeholders

1. Introduction

Public buildings are building that belongs to a town, state, or organized private sector used by the public. Public buildings can also be any structure owned or leased and principally used by a governmental agency for general business, meetings, and residential purposes [1]. Like any other physical building, public buildings deteriorate at various rates [2]. As noted by Ref [1,3], the rate of its deterioration depends on the attitude of stakeholders (users and maintenance personnel) to the maintenance process and maintained buildings. Providing better maintenance management (MM) for public buildings is important [4]. However, the efficient management of public buildings is dependent on an effective maintenance process [5].

Public buildings, especially in most developing countries, are often inadequately maintained, with evidence of a lack of maintenance and repair [5]. After construction completion, most public buildings used as residential and office buildings have not seen significant care, and this has been observed to cause underutilization of the facilities [6]. The majority of these buildings are dilapidated, while others are abandoned. The lack of maintenance culture among stakeholders (Government, maintenance manager, maintenance personnel, and users) of these public buildings often lead to wastage and reduced lifespan [7]. According to Ref [8], public buildings must be effectively and efficiently managed and maintained through organizational or national maintenance policy that addresses stakeholders' needs to achieve a good maintenance culture. Also, Ref [9] opined that maintenance operations should be innovative and strategically organized for better performance of these buildings. Maintenance stakeholders should have positive behavior developed through good maintenance culture. However, Ref [10] observed that culture endures and evolves through the learning capacity and, consequently, through sharing current knowledge with succeeding generations.

The concept of culture has been perceived differently by various studies. Ref [10] argued that culture is the key that influences the attitude of getting things done the right way, without which there is a hindrance to the attainment of goals. Ref [11] asserts that culture from a working establishment's perspective is put in place when the social relationship among members influences their pattern of thinking, behavior, and belief. On the other hand, maintenance culture is the change in the behavior, mindset, and attitude of the maintenance team towards executing the maintenance activities and operation of an organization the right way without any hindrance to the attainment of maintenance objectives of the organization [12]. Consequently, it is of essence to investigate and understand why there are divergences in maintenance management (MM) research findings. In addition, the adequacy of existing MM theoretical frameworks to be adopted in every clime is also important. This requires testing the MM frameworks developed in developed countries to ascertain if they can be adopted in developing countries. This is imperative, especially from maintenance culture within the maintenance process among the stakeholders. There is a dearth of studies on culture in maintenance, asset management, and facility management, most especially on behavioral issues relating to the maintenance process. The present study has the following objectives:

- To ascertain the relative contribution of the behavioural construct to effective MM of public buildings;
- Understanding culture in MM of public buildings;
- To assess the influence of maintenance culture on the effective MM of public buildings;
- Drawing knowledge from existing studies on methodological issues in maintenance, MM models, and challenges of MM of public buildings in developing countries.

A comprehensive literature review on the MM of public buildings was conducted to achieve this. Research works related to maintenance, MM, and maintenance models were reviewed and analysed comprehensively. The gaps were also identified and discussed. Thus, this paper makes a modest contribution to discussing behavioural issues as a new construct in understanding culture in the MM of public buildings. The study is also important to the MM of public buildings in developing countries toward achieving a more effective MM system.

2. Methodology

It is essential to verify if the existing MM theoretical frameworks proposed by studies in climes of advanced nations differ by presenting gaps that do not capture the peculiarities of the cultural context of developing countries. This is conducted with a direct and deliberate focus on the behavioral construct for MM. Maintenance culture has been included in this present study amid other factors that have already been researched. Thus, it is necessary to understand how an effective MM can be attained and the likely barriers to its attainment in the MM of public buildings. Based on this knowledge, this study adopts a literature review method. This was achieved by efficiently reviewing peer-review journal articles related to MM of public buildings. Journal articles in the asset and facility management industry were initially searched for and selected.

As shown in Figure 1, the search and selection process of the articles comprised two stages. Stage one involved the determination of academic databases. Seven academic databases, namely, Scopus, IOP, Taylor and Francis, Engineering Village, Web of Science, Science Direct, and ASCE Library, were selected for literature search due to their inclusive coverage of quality peer-reviewed journals in the research field of the construction industry most especially in the management of buildings. Stage two is where the literature search process was conducted by inputting the following keywords: ("maintenance" or maintenance management" or "maintenance culture" or "building management" or "maintenance concept" or "maintenance approach") and ("behavioural change" or "stakeholder needs"). The keywords are employed to search in the aforementioned seven academic databases, while the retrieved literature was restricted to journal articles written in English. There were 420 articles initially identified in the preliminary search. However, three hundred and one (301) patents and other invalid articles were removed due to overlapping literature coverage on MM among the seven databases.

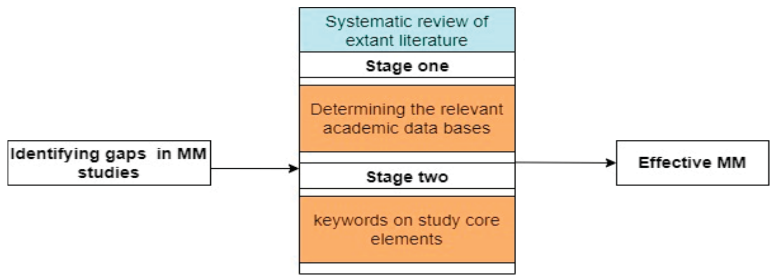

Figure 1. Research methodology adopted for the systematic review.

Consequently, 117 articles directly related to the study were retrieved for further analysis. These 117 articles provide a representative sampling of existing studies on the maintenance management of buildings. The highlight of the systematic review shows the significance of culture in the MM process toward improving the behavior of maintenance personnel and users of maintained public buildings and other assets. The study was limited to the identified databases as they provided sufficient published manuscripts, which were adopted for this study. Also, the study was limited to public buildings to give a context to the approach of maintenance culture in public infrastructure.

3. Maintenance Management Concept

Deterioration and decay of the fabric and the services begin the moment a building is completed and occupied. Hence, there is a requirement to undertake maintenance activities to ensure that the facility performs to an acceptable level [13]. As defined by Ref [14], maintenance is the combination of all technical, management, and administrative engagements during the life cycle to restore or retain it to a state in which it can perform the required function. Ref [15] defined it as the services provided for a structure (building) after completion to replace it to a standard that will make its components stable and serve its required functions without upsetting its functional ability and basic features throughout its entire life span. Ref [16] postulated that maintenance is related to redecoration, repairs, and replacement of a structure and its auxiliary facilities. This is to prevent damage and injuries and increase the economic life's usefulness of the structure while improving its functionality and aesthetics [17]. These definitions show that the essence of maintenance in a building is to meet its required functional performance and the expectation of the users [18]. Thus, maintenance is not just to rectify defects but also to prevent them [19]. However, for the effectiveness of the maintenance process, there is a need to incorporate management concepts into it to facilitate how maintenance is carried out in buildings.

Ref [20] submitted that for MM organizations to sustain their competitiveness, they need to create a value-based maintenance system better than their rivals in the maintenance industry. Ref [21] noticed that maintenance organizations could only have an operational edge over their competitors when deploying a more effective management style to offer superior services to users. Ref [21] postulated that formulating maintenance policies and plans within an organization develops a good management strategy for effective maintenance operations. Ref [22] asserted further that resource management such as humans, components, and materials need to be given good consideration in developing a viable MM team. Ref [23] stated that maintenance operation under viable human resources management would bring together a range of stakeholders' functions to benefit employees and the organization. Hence, Ref [21] submitted that MM of buildings is more proficient when suitability and efficient human resources support maintenance personnel toward effective MM through the best combination of cost, efficiency, and quality of the organization. Ref [24] maintain that MM is not about keeping the buildings only; it involves the management of the organization's resources and the processes it supports, operating within the realm of available resources based on the organization's corporate culture. Ref [25] affirmed that no matter how well-focused an organization might be on its core business, it cannot ignore maintenance issues, especially during maintenance operations.

4. Methodological Issues in the Study of Maintenance Management

Available literature has suggested diverse ways of measuring MM at the organization, industry, and national levels. Also, existing literature informs that there is no generic measurement of MM as the variables of MM have varied according to definitions and concepts as developed by different studies [26–29]. Ref [26,30] measured MMs outcomes using an organization maintenance strategy. Some of the strategic measures that have been used in alignment with the company's business plans include reliability, overall equipment effectiveness, number of maintenance interventions, safety/risk, logistics, and output quality, among others. On the other hand, studies Ref [31] measured MM by productivity measures. Generally, maintenance productivity measures describe the organization-specific need required to attain transparency and uniformity amongst stakeholders, including all employees of the organization. According to Ref [32], it ensures the reduction of overall productivity costs (efficiency). Additionally, it also generates activities and processes that support these objectives. Ref [31] noted that there is a need to consider value created by the maintenance process, resources allocations revising, health safety, and environmental (HSE) issues in measuring maintenance productivity. While management of knowledge, adopting a new operating and maintenance strategy, and changes in organizational management and structure were also significant.

Another point of note with studies on MM is that a considerable number of these measured MM through maintenance re-engineering measures. According to Ref [29], the basic concept of measuring maintenance re-engineering is the continuous improvement of the MM process. Moreover, the maintenance re-engineering measures consider strategies for asset and human resources, monitoring and control of individual assets, maintenance performance measurement system, planning and scheduling of maintenance activities, maintenance tactics, and application of TPM and RCM for continuous improvement [33]. In measuring the maintenance re-engineering, the MM is incorporated with knowledge, intelligence, and analysis, which support maintenance decision-making for the continuous improvement of the MM process [32]. Additionally, studies also measured MM through maintenance performance measures. Accordingly, Ref [34] posited that maintenance performance measures could be viewed along three dimensions these are effectiveness (users' satisfaction), efficiency (resources optimization), and changeability (strategic plan to handle organization changes). Ref [35] states that maintenance performance measures are concerned with the multidisciplinary process of justifying and measuring values through maintenance investment and meeting the organization's stakeholders' requirements based on overall business perceptions. Nonetheless, various issues considered in maintenance performance measures include equipment history, information system, management training, labor productivity, engineering, condition monitoring, work measurement, and incentives [36].

Also, some other studies Ref [37,38] measure MM through value-driven maintenance (VDM) measures. According to Ref [37], the philosophy behind VDM is to understand a delicate balance between the values that improved reliability can bring on the cost of maintenance. More so, Ref [38] asserted that the philosophy behind VDM measures is the alignment of building performance with the organization's corporate strategy and maintenance resources with users' satisfaction. Additionally, VDM measures ensure holistic consideration of MM processes, procedures, practices, and implementation [39]. However, various issues in VDM measures are based on the methodology developed on four value drivers in the maintenance process: resource allocation, asset utilization, cost control, and healthy, safety, and environment [37]. The significance of VDM measures is for optimizing the value derived from the maintenance process at any point in time [37]. As informed by the literature review, there is no generic measurement of MM as the variables of MM have varied according to definitions and concepts as developed by studies. Thus, the next section reviews and discusses previous MM models and theoretical frameworks that inform effective MM systems.

5. Conceptualization of the Maintenance Management Models

Several professionals and studies have defined MM based on how they understand its concept. This, in turn, has influenced the characteristics of the attributes which impacted or determined MM in their respective studies. Among the relative nature of MM is that professionals and scholars use different words to describe similar MM concepts [31,39]. The concepts of MM as described by authors with different terms include maintenance models, maintenance systems; maintenance strategies; maintenance philosophies; maintenance types; maintenance methods, and maintenance techniques. Most literature often describes MM models on the same notion as maintenance studies [29,31,39]. Nevertheless, the variables that determine MM differ from one organization to another and from one nation to another owning to the relative nature of MM studies [27,28]. Although, in most studies, MM is well measured in relation to a particular organization in a specific nation within which the maintenance organization or agency operates [22].

The relative nature of variables that determine MM models changes with time as it shifts from one maintenance set objectives to another within an organization, industry, or nation. This is primarily due to changes in operation strategy, economic positions, changes in management, or gaps observed in existing maintenance concepts [40]. As shown in Table 1, choosing each model from existing concepts for this study is based on their philosophy supported by its specific details. As a conceptual structure, each of the models selected contained various processes (tasks/activities) that can be organized, coordinated, monitored, and managed systematically toward satisfactory completion of maintenance work not only for the maintenance administrators but for users and clients of the building (public) maintained. The different MM models reviewed from extant literature are discussed further (See Table 1).

Table 1. Summary of the core elements from the models reviewed.

Authors	Maintenance Management Core-Elements								
	Organisational Maintenance Policy	Human Resources Management	Monitoring & Supervision	Maintenance strategy	Maintenance Budget	Education & Training	Continuous Improvement	Maintenance Information System	Maintenance Culture
Ref [22]	√	√	√		√		√		
Ref [41]	√	√		√	√			√	
Ref [42]	√			√	√	√	√	√	
Ref [43]	√	√	√		√	√			
Ref [44]	√	√	√	√	√	√	√	√	
Ref [45]	√		√	√		√	√	√	
Ref [46]	√	√	√		√			√	

Source: Author's compilation (2022) as reviewed from the literature.

As presented by Ref [22], the generic MM model suggests the alignment of the MM process with the three levels of business activities: strategic, tactical, and operational. The model is backed by three fundamental pillars of information technology (IT), maintenance, and organizational techniques. The models show that the process will require a maintenance plan and task scheduling at the tactical level. At the operational level, emphasis is more on maintenance tasks executed by the skilled maintenance technician based on scheduled time, correct procedure, and proper tool usage [22]. The strategy-level maintenance information system will be required to document maintenance activities carried out. More so, at the strategy level, data will be necessary to report maintenance activities in the information system [22]. While the data provided through the computer maintenance management system (CMMS) will be transformed into information that would be used to make decisions at the levels of the business activities and prioritize actions [22]. This will allow effective control of assets and proper monitoring and supervision of maintenance processes and operations. The framework identified a set of key techniques that constitute the maintenance technique pillar: reliability-centered maintenance (RCM), total production maintenance (TPM), quantitative tools, and tactical activity-oriented stochastic tools [22].

Ref [41] suggest a maintenance model that contains three simple building blocks. The first block places the MM into the broader business perspective: finance, marketing, and operation. The second block in this MM decision-making level is planning and control, the core element with sub-variables that includes maintenance manager decisions on business functions, performance reporting, and resource management. The importance of training was highlighted to improve the maintenance personnel's knowledge for them to operate in a safe environment [41]. The last block was the third block in this maintenance framework is called the MM toolkit, which is the core element. It consists of statistics that focus on optimizing maintenance resources management. The model posits that effective MM depends on resources, task planning control and scheduling, maintenance information system, and maintenance budget [41].

Moreover, Ref [42] suggests a generic MM model. The proposed framework contains eight blocks in sequence, covering four functions representing the core element, including effectiveness, efficiency, assessment, and continuous improvement. The effectiveness of the framework covers maintenance objectives. It is related to key performance indicators, appropriate maintenance strategy specified, where assets will be prioritized, and a weak point with high impact will be acted upon [42]. The efficiency in the model shows the optimization and design of preventive maintenance plans that include resources schedule and resources [42]. Assessment in the model focuses on maintenance control, execution, monitory and supervision, replacement optimization, and asset life cycle analysis. Whereas improvement in the model focuses on issues relating to continuous improvement by integrating new techniques where applicable [42]. The framework, however, highlighted the significance of incorporating new techniques and engineering tools with management concepts [42].

Similarly, the management process model for maintenance was developed by [43]. The model suggested that a maintenance structure include two management processes [43]. The two management processes include analysis of process effectiveness and process efficiency. The model postulated that an effective management process seeks to identify the most critical problems in maintenance activities and identify their potential solutions [43]. The efficiency management process focuses on identifying suitable procedures for maintenance operations. The model identified eight stages loops for evaluating the MM process towards achieving effectiveness and efficiency. The model specifies that the first stage determines the maintenance structure's current performance, including planning, supervision, and monitory [43]. As identified by the model, the second stage is to analyze the quality and downtime problems achieved through policy deployment and organization [43]. However, the third stage of the model shows that there should be an adequate analysis of a potential solution to maintenance problems through continuous improvement [43]. The model postulated further that there should be an efficient analysis of maintenance procedures which can be achieved through a suitable maintenance approach [43]. The model also identified plan and execution as a stage required for evaluating the MM process, which can be achieved through planning and scheduling. Stage six, seven, and eight of the models emphasize the importance of data collection and implementation actions, data processing, monitory and supervision, and effective information handling procedure [43]. The model clearly shows that all this can be achieved through CMMS, which can be used for proper information gathering, process, and sharing to achieve effective and efficient MM [43].

Additionally, Ref [44] suggests a generic framework for integrating the MM for built and in-use assets. According to the framework for MM effective and efficient, there is a need for five sequential management asset maintenance plans. This model states that maintenance operations management should be based on effective monitoring and supervision for effective and efficient maintenance management [44]. However, the model shows a need to define the required maintenance objectives and develop maintenance information systems and effective maintenance operations [44]. The model also recognized a value-driven management system as vital for an effective MM system [44].

Also, Ref [45] proposes a formal structure model for effective MM. The model starts by identifying maintenance strategies for the asset and associated human resources-related aspects required to produce the needed working culture [45]. The model shows further that the organization gains monitory and control to ensure the functionality of each asset throughout its life cycle. As stated in the model, this can be achieved by implementing a CMMS, a maintenance function measurement system, and planning and scheduling the maintenance activities [45]. The model posits that depending on the value assets represent for the organization, it is accomplished according to various tactics employed on one or more of the following eight tactics: redundancy; run to failure; scheduled overhaul; scheduled replacement; ad-hoc maintenance; preventive maintenance (use-based or either age-based); condition-based maintenance; and redesign if necessary [45]. The model suggests using two highly successful maintenance methods, TPM and RCM, to realize continuous improvement. The model signifies process re-engineering techniques to sustain improvements already achieved at the top level of the maintenance process [45].

Moreover, as Ref [46] suggested, the maintenance model shows that a preventive maintenance program should be in place before advancing to the next level of maintenance activities. The model posits further that before one considers the implementation of RCM and predictive maintenance programs, there should be CMMS implementation with a suitable work order release system, provision of spare parts, and training of maintenance personnel (maintenance resources management system) [46]. The model states further that there is a need to implement total productive maintenance (TPM). The TPM would help guide the necessary maintenance organization structure configuring and applying statistical tools for financial optimization [46]. However, the model signified continuous improvement in maintenance practices to achieve an effective maintenance management system.

Table 1 summarizes the core elements identified from the MM models reviewed above. It showed that all of the models reviewed have core elements such as organizational maintenance policy, human resources management, monitoring and supervision, maintenance strategy, education and training, continuous improvement, and maintenance information system, as indicated by the mark symbol ($\surd$) in Table 1. Also, they have been used by studies such as Ref [29,47,48], among others, to develop different maintenance concepts for effective MM of buildings. However, as indicated further in Table 1, maintenance culture focusing on behavioral issues is an element that has not been addressed by any of the maintenance models analyzed. This clearly shows that maintenance culture as a construct in some existing literature and concepts for effective MM of buildings has been marginalized [49]. According to Ref [49], this might have been why huge and costly projects go into disuse in a short while. Ref [49] emphasized that a culture-based MM system of buildings ensures regular servicing, repairs, and maintenance of working assets or established procedures to guarantee their continuous usefulness. Ref [49] also observed that the inculcation of culture in the maintenance process or concepts could increase the quality of maintenance activities. Ref [50] also posited that maintenance culture is unique for each organization. Therefore, it is important to understand culture as a construct in the MM process, especially in understanding the behavioral aspect of the stakeholders (maintenance personnel and users) of the public buildings.

6. Culture in the Context of Maintenance Management Study

Public buildings are developed to fulfill society and organizations' needs. Ref of [12] postulated that public buildings are critical to an organization or nation's resources. Ref [7] observed that the present maintenance problem in public buildings had become an important agenda for developing countries and pressured their government to manage their public buildings. Ref [51] sustain that public assets, especially public buildings, are not maintained properly due to the nonexistence of a maintenance culture. Hence, developing a maintenance culture based on stakeholders' behavior, environmental needs, values, and cultural beliefs is essential [51].

In this study, maintenance culture is defined as the perception, behavior, value, and underlying norms of a person, group, or society that considers maintenance as a matter that is a priority and practices it in their daily life cycle. Maintenance culture in maintaining public buildings is not easy to develop. It takes time, and it can mostly occur in response to individual (stakeholders) attitudes to changes. Thus, a person, society, or country with a maintenance culture would have a good attitude toward regularly maintaining, protecting, and preserving public buildings. The attitude in this context is the behavior of stakeholders in responding to maintenance work, needs, or damaged components within the building maintained. According to Ref [52], maintenance culture is not universal but can be emulated, derived, or learned by others, making maintenance a natural daily practice. The studies of Ref [53–55] showed that the cultural aspect that is the basis of a maintenance process and operation is often overlooked. Ref [56] stated that the absence of maintenance culture due to behavior issues among stakeholders has led to an increase in management and maintenance costs to repair damaged buildings and their auxiliary facilities. Ref [12] observed further that maintenance problems could be better solved through the behavior change of individuals in the maintenance process of buildings. Ref [53] state that behavior change is essential to improve maintenance work's tenancy, skills, and diligence. Ref [57] observed that a maintenance culture is not easy to develop. This is due to the fact that keeping up a good maintenance culture takes time and occurs in response to changes in the individual [58].

For societies to exist, there must be a cultural exhibition [59]. The fluid operation of society is supported by cultural norms and cultural values that guide people in making choices [59]. However, Ref [60,61] opined that the culture of maintaining and sustaining infrastructures is essential to national development. Ref [61–63] posit that the absence of maintenance culture, especially in the public sector of most developing countries, has been the bane of an infrastructure-driven national development. Ref [64] observed that the development of maintenance culture is one of the significant forces that catalyze the growth of any nation's economic, social, and technological advancement. It has been noted that a paucity of maintenance culture characterizes the MM of public buildings in most developing countries, especially among stakeholders of buildings maintained [56,63]. However, past studies have reiterated the importance of maintenance culture among stakeholders in the MM of public buildings in developing countries [2].

However, studies have differed in views about the specific variables that constitute the determining factors in the development of maintenance culture in the management of buildings. Ref [12] identified effective communication in the MM system; reward systems and recognition; empowerment; motivation; involvement; strategy and work planning; teamwork, good policy system, training and education, and organizational cultures as determining factors in developing a culture-based maintenance model. Nevertheless, there are still challenges in developing culture-based maintenance systems in developing countries [22,65].

6.1. Cultural Challenges in Maintenance Management of Public Buildings in Developing Countries

According to Ref [66], the development of maintenance culture is one of the major forces that catalyze the growth of any nation's economic, social, and technological advancement. Ref [67] postulated that the deterioration level of public buildings in most developing countries poses a great concern for national prosperity and a healthy environment. Ref [66] noted that challenges facing the developing countries' ineffective maintenance culture of their public buildings could be attributed to lack of maintenance policy, lack of professional maintenance practice and ethics, and corruption in the maintenance process. Ref [67] also identified a lack of on-job training, lack of awareness of the importance of maintenance, and usage information on maintained buildings. On the other hand, [63] identified variables such as corruption, leadership challenge; behavioral issues; lack of policy as factors that cause no maintenance culture within an organization.

Existing literature such as Ref [56,68,69] indicated that developing countries lack cultural behavior that ensures effective and efficient functioning of the public buildings and fosters national development. Moreover, provision for adequate care of the hard-earned infrastructure has not gained ground in the consciousness of stakeholders in the country over the years. This is due to the absence of a maintenance culture. For instance, Ref [56] observed that poor maintenance culture had become a widely acknowledged problem in Nigeria. This has made the country prioritize property management and maintenance activities [70]. Ref [71] affirmed that Nigeria has no functional maintenance policy and, therefore, is a dearth of culture toward the maintenance process and the maintained public buildings. Ref [72] indicated that inadequate maintenance culture is peculiar in almost every public building in Nigeria. As posited by Ref [73], this is partly due to the problem of maintenance culture based on societal behavior toward the maintenance process and the maintained buildings. Ref [72] postulated that the leading factors to Nigeria's ineffective MM of public buildings are the declining maintenance culture, corruption in the maintenance process, and lack of political will. Similarly, Ref [69] showed that warranted attention had not been given to maintaining public buildings in Ghana. This has restricted Ghana's development through gaping infrastructural deficit and poor maintenance culture of existing public buildings. This was bolstered by Ref [74] that Ghana continues to invest heavily in new public facilities while the sustainability of the existing ones suffers from poor maintenance culture. Ref [75] opined that Ghanaians have a growing awareness about the lack of maintenance culture in public buildings. Ref [75] stated further that Ghanaians' attitude to public-owned buildings is generally negative, with the common understanding that it is "nobody's property." The study of Ref [76] stated clearly that in Ghana, most of the public buildings accommodating public servants had not seen any significant maintenance since they were constructed. Ref [74] postulated that owing to a lack of maintenance culture, the maintenance of public buildings is awful in Ghana.

In Kenya, Ref [66] observed that public building maintenance had not received much attention since more emphasis was on developing new buildings. Ref [66] further posited that due to non-maintenance culture, a crisis is looming in the building stocks. This is due to the fact that existing private buildings and other public infrastructure are running down and losing their utility value due to a lack of maintenance culture. Moreover, Ref [66] opined that the maintenance policy in Kenya, based on borrowed cultures from the firmly grounded maintenance culture of developed countries, has proven to be environmentally unfit for MM activities in Kenya. Similar problems of maintenance culture are evident in other parts of Africa, as acknowledged in South Africa. Ref [77] study showed that the maintenance problem concerning government buildings in South Africa is not unique. Ref [78] observed that due to several structural factors such as lack of MM culture, maintenance of public buildings could not be adequately addressed. Ref [79] finding on MM of public facilities in South Africa shows that the maintenance of buildings is mainly based on developed countries' maintenance systems. Ref [80] postulated that the inability to meet industry and consumer demands on basic building services is due to ageing caused by the lack of maintenance culture of management of existing buildings. This assertion was buttressed by Ref [81] that since 2005, maintenance of most public buildings has been held up due mainly to a lack of proper maintenance plan and culture. Furthermore, Ref [82] observed little funds were assigned to maintaining existing public buildings while new projects were fully funded. Due to many years of maintenance neglect and the dearth of maintenance culture, existing public buildings are deteriorating. Also, a study carried out by Ref [83] on financing infrastructure maintenance in South Africa concluded that due to years of sub-standard maintenance, majorly due to a lack of maintenance culture, the quality and reliability of most public buildings remain poor.

Thus, in addressing the culture gap in MM of public buildings in developing countries, mainly the behavioral change management theory was engaged in holistically addressing the knowledge gap. The theory covers a broad scope of thought and appears close to containing all of the essential vital skills required for effective management through increased employee loyalty to the organization. It provides a job for life with a strong focus on the well-being of stakeholders that can influence their attitude toward the maintenance process and the maintained buildings.

6.2. Behavioural Change Management Theory

As described by [84], change is the crystallization of new possibilities such as new behavior, policies, methodologies, patterns, products, or market ideas based on institutions' re-conceptualized patterns. Ref [85] summarily describes the change as a simple process. Change is about travelling from the old to the new, leaving yesterday behind for the new tomorrow. Nonetheless, implementing change is incredibly difficult. Most people are reluctant to leave the familiar behind. We are all suspicious about the unfamiliar; we are naturally concerned about how we get from the old to the new, especially if it involves learning something new and risking failure or changing our behavior toward achieving a new ideal. Thus, Ref [86,87] postulated that change management is the organizational movement from the existing plateau toward a desired future state to increase organizational efficiency and effectiveness.

Change management can involve technological developments; transformational relationships, organizational control; organizational structure; organizational culture; organizational locations; balance sheets, and others [88]. Ref [89] stated that change within the organization depends on the degree and nature of transformation within the organization. Therefore, an organization needs to strive to change individuals' rites, rituals, behavior, and values in organizations [90]. However, managing and implementing change can be ambiguous [2,3,90]. Additionally, change management ensures that organizational goals are met properly using organization resources.

From the above literature, it can be deduced that to maintain an effective MM of public buildings, changes, especially behavioral change, are a way of life that the stakeholders must embrace. Conversely, change management in maintenance organizations aim to ensure that the set goals are achieved by effectively managing maintenance personnel and other stakeholders. By better understanding their rites, rituals, behavior, and values within the maintenance organization. This will help the maintenance organization gain a competitive edge over its rivals and meet the needs and expectations of the users of their facility. To better understand the change in the maintenance process, Kotter's change model is discussed below in understanding maintenance culture within an organization.

6.3. Kotter's Model of Change

Kotter's change model explained that changes are a continuous adaptation process to changing conditions and circumstances. The model approach to change also shows that change should be perceived as a continuous, open-ended adaptation process to changing circumstances and situations [91]. Approaches to this model show that maintenance personnel need to be continuously trained and educated not only on their job but also on innovation, technology, techniques, material selection, job behaviors, and values. Also, the model showed that the maintenance organization should develop a maintenance strategy that will create a benchmark for stakeholders required for both the maintenance process and usage of maintained buildings. In achieving the set maintenance goals of an organization, the model advocates eight steps in the change process. The steps in Kotter's model change concerning culture as a variable for effective maintenance management are further described in Table 2.

Table 2. Change concerning culture as a variable for effective MM of buildings using Kotter's 8-step model.

Levels	Kotter's 8-Step Model of Change	Impact in Relation to Effective Maintenance Management Process
Level 1	Increase Urgency	Identify maintenance needs through an early warning system
Level 2	Build Guiding Team	Assembly of the effective maintenance management team
Level 3	Develop the Vision	Set maintenance objectives, development of maintenance policy
Level 4	Communication for Buy-in	Developed the maintenance plan, strategy required and involved the stakeholders.
Level 5	Empower Action	Education and training of maintenance personnel
Level 6	Create Short Term wins	Establishment of benchmark for maintenance operations in terms of quality
Level 7	Don't let up	Consolidate on improvement through continuous improvement
Level 8	Make Change Stick	Institutionalised the new maintenance approach.

7. Implication of the Study

The focus for maintenance organizations is to capture the organization's past, present, and future performance in meeting the organization's maintenance business plans, maintenance objectives, equipment prioritization, cost/benefit analysis, and users' requirements, among others [1,4,6]. Summarily, the main stimulus for undertaking maintenance is to deter deterioration and abandonment in the building maintained [9,15]. The focus on managing the maintenance process and operation is the difficulty experienced in addressing stakeholders' behaviors toward the maintenance process and the preserved buildings [24,29]. Nonetheless, considering the exclusive role of stakeholders of the maintained public buildings, understanding their needs, and the ability to manage any new changes towards improving their behavior within an organization would lead to an effective MM system [53–55]. Conversely, in the behavior of stakeholders in the maintenance process and activities, including usage of the maintained public buildings, there is a likelihood to change when a discontinuity occurs in the management of established rules guiding the direction of the stakeholder's commitment and attitude [53–57].

Therefore, an effective change management system is the key opportunity of involving stakeholders in any changes that might occur in the MM process of buildings to make them change their behavior toward meeting maintenance goals [86–90].

Additionally, previous studies Ref [12,53,57,60] have shown that understanding stakeholders' needs, continuous improvement, and maintenance strategy development are key elements for formulating MM policy for specific industries, organizations, or nations.

Thus, as shown in Figure 2, in developing an effective MM policy, models, or concepts for public buildings in developing countries, the behaviour of stakeholders (maintenance culture) should be matched and considered in designing different maintenance instruments. This will help in improving and addressing the following:

- The crisis of maintenance of public buildings stocks through improved attitude toward maintenance process;
- It will trigger new thinking (political and administrative thinking) in maintenance policy formation;
- Enormous improvement in maintenance performance;
- Improving a healthy living environment with proper social values;
- Reduction in the total maintenance budget of buildings;
- Cautions and continuous adherence to maintenance guidance and regulation;
- Issue of preservation of aesthetics and qualities of maintained public buildings;
- Necessary safety and improve the sanitary level;
- The commitment of stakeholders to the maintenance process and maintaining public buildings.

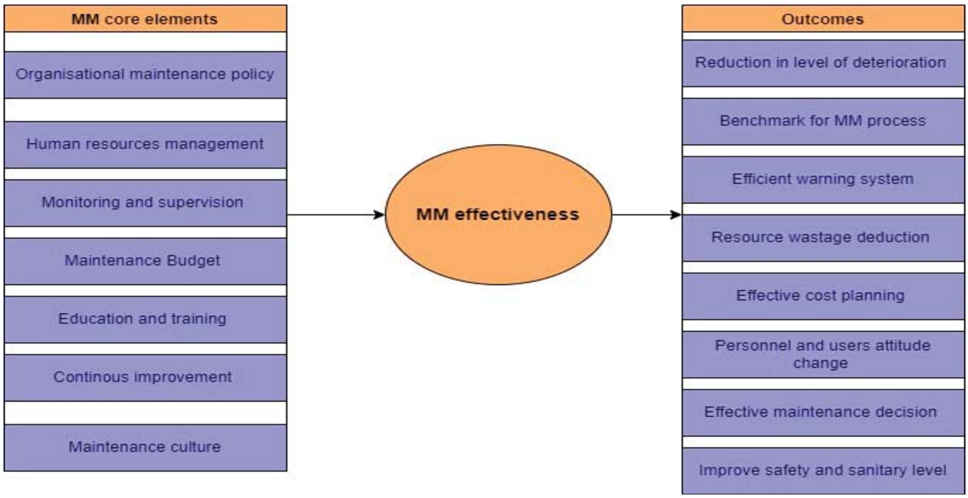

Figure 2. Culture-based maintenance management concept for public buildings.

The study's findings indicate that maintenance focus must be shifted from strategy to behavioural issues (See Figure 3). This is due to the fact that all of the important maintenance strategy attributes such as policy, budget, training, maintenance information system, and others required for effective MM were present in nearly all of the existing maintenance concepts or models. While the problems of deterioration and abandonment still exist in the maintenance management of public buildings. This problem, as observed, is due mainly to the absence of maintenance culture and behavioural change among stakeholders of buildings being maintained. Nevertheless, there is a need to change behaviour, attitude, and mindsets towards maintained building through its usage or maintenance process and operations.

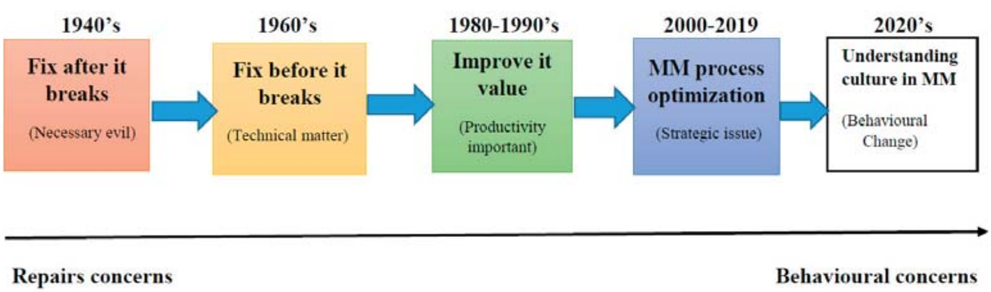

Figure 3. Changing maintenance management focus.

8. Concluding Remarks and Recommendation

The continued deterioration and high decay of public buildings in developing countries are of great concern. This has drawn the attention of policymakers, academics, and other stakeholders involved in these buildings' policymaking, usage, and maintenance. Also, the desperate need to investigate culture-based MM of public buildings is linked to evidence revealing an improved level of building users' well-being, performance, productivity, and health benefits associated with an adequate and effective preventive MM system. This study presents a comprehensive overview of MM studies by focusing on behavioral issues affecting the development of culture-based MM in public buildings. This study provides important information to policymakers, academicians, and maintenance managers on developing a MM system guided by specific issues that can change stakeholders' behavior in the maintenance process and usage of the maintained public buildings. The research finding shows that change in behavior of stakeholders regarding the maintenance process and the maintained public buildings will lead to the following:

- Reduction in the level of deterioration, decay, and abandonment within the public buildings;
- A benchmark for the maintenance process and usage of the public buildings;
- An early warning system for identifying damaged components of the public buildings;
- Use of quality replacement materials for the maintained public buildings;
- Resource wastage and its associated cost and time overrun will be averted in the maintenance process of public buildings.

Based on the literature review, this study concludes that understanding the culture in MM of buildings within developing countries should be centred on behavioural change, especially on the usage and maintenance process of public buildings maintained. This will immensely help developing countries to establish a cultured maintenance system. Also, it will lead to the continuous improvement of the maintenance process toward the development of an effective MM system. The study thus recommends that for a better understanding of the culture in the MM of public buildings in developing countries, the maintenance organisations should be guided by the following:

- There is a need for behavioural change toward the usage of the maintained public buildings;
- Rightful skills should be used for maintenance operations with the public buildings;
- Required tools and environment should be created for an effective maintenance process;
- Effective communication should be developed among stakeholders;
- There is a need to provide a benchmark for maintenance operations;
- There is a need to ensure early servicing and repairs for damaged building components;
- User maintenance guide should be provided within the maintained buildings;
- A standalone maintenance policy/law should be provided for the maintenance of public buildings;
- There is a need for effective decision-making on the maintenance process and operation;
- There should be an early response to damaged components of the public buildings.

Finally, in understanding the place of culture in the maintenance management of public buildings, there is a need to motivate maintenance personnel by meeting their needs and giving recognition to their efforts to improve their behaviour toward the maintenance process. This study adopted a theoretical approach to achieving the set objectives. Hence, further studies can be carried out to apply this study's theoretical positions and findings in typical real-life situations.

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Article

Classification of Key Elements of Construction Project Complexity from the Contractor Perspective

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Abstract: Contractors are facing an increasing degree of complexity in their construction projects. Due to inadequately prepared project plans, they have been suffering significant losses during the execution of construction projects. One of the key disadvantages of such plans is that during the planning process, a construction project is mostly defined as a linear rather than a dynamic and complex process with a high degree of uncertainty. Therefore, a contractor who is in the planning phase of a construction project should consider the impact of the project characteristics on its implementation according to the elements of project complexity. In this research, we therefore first made an overview of the existing research related to the elements of project complexity. Based on the frequency of their occurrence in existing surveys, this paper singled out eight groups of complexity characteristics that contractors should be aware of during construction projects. After that, based on the frequency of occurrence in the existing surveys, fifteen elements of complexity were classified for each project complexity group. The research conducted among construction project managers identified key complexity elements of the construction project from the contractor's perspective. Thereby, the classification of groups with the associated key elements determining the complexity of a construction project from the perspective of the contractor was performed. By properly analyzing the impact of key elements of complexity on project flow during the planning phase, contractors can be more successful when planning the project objectives to be performed.

Keywords: construction project; project complexity; construction project complexity; project management; project success

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1. Introduction

The success of contractor organizations in the construction sector, which mostly operates as a project-oriented, depends on the success of individual projects. In the case of construction projects, success is measured on the basis of the results achieving the project objectives related to cost, time, quality, safety, and environmental conservation [1]. Understanding and properly dealing with project complexity is the key determinant of success, especially in project-oriented organizations [2]. The literature dealing with complexity defines uncertainty as one of its essential determinants [3,4], and, going along with it, the risks of the project and the consequences that they can cause. Successful completion of a project depends significantly on the number of activated risks in the project that cause deviations from the planned results and project goals, which are set in advance.

Problems during projects that cause cost and deadline overruns have been a common hurdle that researchers have dealt with for years [5]. Among the reasons why projects fail are their increasing complexity [3] or underestimations of the complexity of the project during the planning phase [6]. In practice, the contractor for the construction project during the planning phase, while defining the budget and time required to execute the project, views the project as being a proper and predictable process. However, a more detailed analysis of practical examples leads to the conclusion that construction projects are non-linear and dynamic, i.e., complex processes that often exist on the border of chaos. Therefore, in order to influence the results and success of the project, the contractor should consider the project as a complex and unpredictable process when developing the plan.

One feature of unsuccessful projects is a delayed response to a problem that occurs during the execution of the project, while a feature of successful projects is the prediction of such problems [7]. Each project that the contractor performs has different variable and immutable characteristics and requires a different approach to management and execution. When planning a construction project with a contractor, it is necessary to analyze and determine the project's degree of complexity. The degree of project complexity is an indicator of the impact of the project characteristics on the activation of the risk in the project and therefore the impact of these complexity characteristics on the goals and success of the project as well. To determine the degree of project complexity, it is first necessary to define the term complexity of the project from a contractor perspective and the elements that affect its degree.

Although project complexity is not clearly defined [3,8–11], it is recognized as one of the critical characteristics of a project that determines the appropriate actions that will result in the success of the project [12]. It is widely accepted that the complexity of the project affects the results of execution and possibly results in the success of the project [13–16]. Baccarini [12] stated that project complexity helps to determine the requirements in terms of the planning, coordination, and control of the project; makes it difficult to clearly identify and define the objectives of the project; and plays a major role in selecting the appropriate organizational structure, selecting project inputs, and selecting the appropriate procurement arrangement for the project. As a determinant of the project, complexity significantly affects the project objectives related to time, costs, and quality. Based on the need to create a realistic plan for the execution of the project with indicators through which the successfulness of the project is monitored, Wood and Gidado [17] found that the degree of project complexity should be identified at the earliest stage of the project.

Measuring the complexity of construction projects is different for investors, designers, contractors, project managers, and site managers [18]. In previous surveys determining the complexity of a construction project, the elements that make up complexity, and how to measure it, the research was generally carried out for projects, IT projects, and construction projects. These surveys were mainly conducted from the point of view of investors.

In their work [11], Luo et al. analyzed the previous research related to the complexity of construction projects in detail and state in their conclusions that future research should address elements of project complexity from the perspectives of different participants in the construction project, the connection between complexity and project success, and how to increase complexity over the course of the project. Although research related to the complexity of construction projects has intensified over the last twenty years, a review of the literature found that there are no significant complexity studies that focus on the perspectives of contractors. As investors are increasingly using forms of contracting that transfer risks to the contractor, contractors encounter a greater degree of project complexity than investors [19].

The main objective of this paper is to identify groups of complexity and the key elements of the complexity in construction projects from the perspective of the contractor. Project complexity groups were determined based on a review of the literature and the frequency of occurrence in existing surveys and complexity models. Key elements of complexity were identified based on the literature review, as well as their frequency of occurrence in existing surveys and research conducted among construction project managers with contractors. In this way, a classification of groups of complexity and the key elements of project complexity is obtained and can be viewed from the perspective of the contractor. This paper presents the literature related to complexity, with special reference to the definition of project complexity and the complexity of construction projects. After that, the elements of project complexity are identified and summarized from the perspective of the contractor, and the research methodology is presented. The research question for project managers which was included in investigation on project complexity was: Which element of complexity do you consider most important from the contractor's perspective? When we ask how managers perceive project complexity elements, we do not ask only in a specific case of a given project but rather in a more general manner. In other words, the question concerns the mental model, not the assessment in a single case. The results of the research show the degrees of importance of key elements of complexity within the different groups of complexity. Based on the results of the research, a classification of the complexity groups with the associated key elements of complexity was determined from the perspective of the contractor on the construction project. A discussion and guidelines for future research are provided, along with conclusions.

2. Literature Review

2.1. Project Complexity Theory

Project Complexity Management is becoming an important segment of project management that is crucial for the success of projects [20,21]. It is important to understand the link between project success and different project conditions, and it represents an intervention variable for successful project implementation [22,23].

The beginnings of the application of complexity theory in project management are related to works by Morris [24], Bennet and Fine [25], Bubshait and Selen [26], Bennet and Cropper [27], Gidado [28], Wozniak [29], and Baccarini [12]. All of these studies were mainly devoted to illuminating the notion of complexity in general, both in terms of projects and its impact on project objectives, though to a lesser extent.

When talking about complexity, its unpredictability (the degree that needs to be determined) depends on the interdependence and dynamic interaction between the system and individual elements of the system itself. In order to prevent a project's unpredictability from growing and creating additional problems, it is necessary to define the degree of complexity as soon as possible. In this way, the possibility of unpredictability (risk activation) is reduced, and the chances of the project being successful are increased.

From the point of view of complexity theory, each project is complex [30]. The claim that we often hear from those participating in different projects is that their project is complex from the point of view of complexity theory, but this is not a clear determinant. All of the authors above stated that the participants believe that their projects have a high degree of complexity and that because of insufficient knowledge of this theory, they reach for such definitions. Thus, every project, even the smallest, has complexity as its basic determinant; the degree of this complexity changes depending on its characteristics. The idea is that project complexity is applicable to all projects, regardless of their size.

Processing the complexity of the project is one of the most important but also the most controversial topics in project management. It is considered controversial because most standards, as well as researchers in the field of project management, have a different view on project complexity. Through a large number of surveys, there is still no consensus on how to define an unambiguous concept and measurement system to determine project complexity [31]. In the last few decades, complexity theory has been used in various fields, such as physics, astronomy, finance, biology, geology, chemistry, and meteorology [32,33].

2.2. Definition of the Project Complexity

The problems with complexity begin with the very notion of complexity [34]. Given that this is a multidimensional concept, providing an unambiguous definition of project complexity is still impossible. The most frequently quoted researchers are more concerned with the question of what complex systems are not than with what they actually are. In general, complexity refers to the difficulty of understanding certain phenomena in a given context or environment. In more specific terms, its use denotes a complex interaction between parts of a system. Complexity is defined in different ways across different groups of disciplines and in relation to different systems. However, as already stated, there is still no consensus on the exact definition of complexity [33,35–43]. A detailed review of the literature finds a large number of definitions of complexity. Sinha et al. [44] found that there is not a single concept of complexity that can adequately encompass the intuitive notion of what complexity should mean. The first definitions of complexity were encountered in the 1950s and 1960s. However, it was only over the past thirty years that the number of authors studying what constitutes the notion of complexity increased. Baccarini [12] created one of the foundational works related to project complexity and found that overall project complexity does not exist and that we need to determine different types of complexity when we talk about project complexity. Complexity theory provides a general definition of complex systems for certain fields and analyzes the interaction of individual elements of complexity within those fields (e.g., the financial market field, IT sector field, construction field, biology field, etc.).

By reviewing complexity research, it can be established that it deals with elements that affect the degree of complexity, the impact of complexity on the project, and methods for measuring and managing complexity during the project [45,46]. A significant number of surveys address the elements of complexity as determinants of complexity and show the disaggregated structures of the notion of complexity itself. Complexity elements are arranged into groups of complexities, while individual authors determine the elements of complexity as independent indicators of the overall complexity of the project.

2.3. Complexity of the Construction Project

The notion of complexity is often used when talking about construction projects. Construction projects consist of a large number of elements, and their implementation requires a large number of participants and a large number of resources, as well as various techniques for their management. With their characteristics, construction projects match our general understanding of something that is significantly complex.

Project complexity is one of several concepts that represent the irregular behaviour of the project, but in the field of construction, this concept is of utmost importance [47,48]. As a scientific discipline, complexity is an emerging topic, but it is also a critical topic in the field of construction project management [21]. Construction projects are immutably complex and have been progressively becoming more complex since World War II [12]. In fact, construction processes can be considered to be some of the most complex ventures across all industries [49]. Today, the construction industry has experienced speedy progress in projects of rising size and complexity [43]. Large scales, sophisticated technical processes, long lead times, huge numbers of people involved, diverse geographic locations and high-performance pressures make these projects more complex than ever [50].

Although complexity is a widespread term that can be associated with any subject, there is still a lack of published literature in the field of complexity in construction. Thus, construction projects are often described as complex, but there is no universally accepted definition of complexity in the construction industry [17]. When it comes to complexity, it is most often analyzed from the theoretical or abstract perspectives, while the practical applications of complexity theory are very small. A large number of authors have noted the difficulty of applying theory in practice in relation to complexity theory [51–55].

The construction industry has shown great difficulty in dealing with the increased complexity of major construction projects [56]. Bertelsen [38] explained that the general view of construction projects is such that they are considered to be a regulated and linear phenomenon that can be organized, planned, and managed in a proper manner. Frequent examples of failure to complete construction projects on time and within the established plans has led to a reconsideration of how accurate such a general view of construction is and has forced us to consider whether construction projects are as predictable as we consider them to be. A more detailed processing of examples from practice led to the conclusion that construction projects are essentially non-linear, complex, and dynamic processes that often exist on the border of chaos. Therefore, he concluded that the perception that projects are regular and linear by nature is a crucial mistake that could impair the success of the project, and project management must consider the project as a complex and dynamic process with non-linear characteristics.

Continuous requirements related to the speed of construction; cost and quality control; workplace safety and dispute avoidance, as well as the technological progress; economic liberalization and globalization; environmental issues; and fragmentation of the construction industry have led to a significant increase in the complexity of construction processes. Regardless of how their relationship was conceptualized in the literature, it is clear that complexity and uncertainty have substantial impacts on project performance. Today, complexity has reached a level where construction project managers have to consider its impact on the success of the project with great care [28]. It is a common opinion that the reason for poor results lies in the planning process and that construction processes are significantly more complex for a large number of reasons [12,57,58]. Most believe that the main reason for the failure of a construction project is poor project management. The critics are partly right. However, they are correct not in the way that they think they are. In order to properly manage a project, it is important to understand the nature of the project. From the above, it can be concluded that we do not know enough about the nature of the construction projects that project managers try to manage in the right way.

The complexity of construction projects significantly influences various aspects of the project results [18]. Many empirical studies in the field of construction have found that complexity affects project duration, cost, and quality [43,59–65]. It is widely accepted that the complexity of a project should be something that can be measured objectively for the purposes of continuous feedback, which would help control the project implementation process [12,66–70]. A systemic analysis of the complexity of construction projects is a crucial element in decision making used by project managers and in the successful implementation of complex construction projects [11]. Complexity is crucial for project resource management, and finding ways to manage complexity can affect the improvement of project results [70]. Leung [70] stated that it is necessary to define a quantitative method for measuring the complexity of construction projects.

2.4. Project Complexity from Contractor Perspective

Contractors are the main actors concerned with project management performance and need to manage their perceived project complexity [71]. When we talk about the complexity of a construction project, it is important to emphasize that it can be viewed from the different perspectives of the participants involved in the construction project. A significant degree of project complexity for the investor does not necessarily mean the same or similar degree of project complexity for other participants who are involved in its execution. It is necessary to specifically analyze the complexity for each of the participants in the construction project from their individual perspective. Previous research has mainly dealt with the analysis of complexity from the perspective of investors, but in accordance with the research of Lu et al. [10], it is necessary to investigate and define complexity from the different perspectives of the participants who are involved in the project. This paper analyzed complexity from the perspective of the contractor, and it determined the classification of the groups for the associated key elements of complexity. In this way, a basis for future research, which requires the establishment of a framework for evaluating the elements of complexity in contractors, was created. The creation of such a framework will provide the contractor with an adequate tool to analyze the impact of the project features on the activation of the risk and on the success of the project.

It is also important to emphasize that, for the different participants involved in the construction project, the complexity of the construction project needs to be defined at the different stages of the project. It is known that the construction project begins at different stages for different participants, but it is also necessary that each project participant define the degree of project complexity from their own perspective as soon as possible, immediately after he/she becomes involved in the project's implementation. From the investor perspective, complexity should be defined immediately, as soon as the initial project realization planning starts—that is, in the project design phase. In the planning and design phase, it is mainly the designers and the supervising engineer who are involved in the project. At this stage of the project, it is necessary to determine the degree of project complexity from their perspectives, and thus influence the reduction in the overall complexity of the project by influencing the complexity related to the designer and the supervising engineer. Complexity from the perspective of the contractor—the subject of the research in this paper—should be analyzed upon the beginning of the contractor's involvement in the project. The contractor is included in the project during the execution stage. The inclusion of the contractor in the project also means the inclusion of other participants related to the execution of the work, i.e., subcontractors, suppliers of different resources, etc.

Although there have been a number of surveys of the complexity of construction projects over the last thirty years, surveys on the complexity of projects from the contractor's perspective are very rare. Today, given the methods of contracting, as well as the fact that the contractor employs the vast majority of the resources required for the project, the state of construction is such that most of a construction project's complexity is transferred to the contractor. Therefore, for the overall success of the construction project, it is necessary to analyze complexity as a significant determinant of the project from the perspective of the contractor. From the contractor's perspective, the project represents a subproject of the entire project, as seen from the investor's perspective. From the contractor's perspective, the success of the project can affect the success of the complete project. However, the success of the project from the contractor's perspective does not necessarily mean the success of the entire project, nor the opposite.

The present research is based on previous research and compares project complexity for the different participants involved in the construction project. In their 2012 research, Xia and Chan concluded that measuring project complexity is different for investors, designers, project managers, and contractors. In his research, Gidado [28] deals with project complexity in relation to time and money as the most important indicators (according to him) of how a construction project is managed by contractors. According to him, the situation of the contractor in relation to the other participants in the project is much more complex. The conclusion is that the degree of complexity to which the contractor is exposed is greater than the degree of complexity to which the other participants involved in the construction project are exposed. Brockmann and Girmscheid [46] state that contractors on large construction projects respond to the overall complexity, as well as the complexity of individual tasks by dividing them into smaller elements along their sections of functioning, and in this way, they can manage them more or less successfully. Contractors employ large amounts of resources, have less impact on the environment than investors, use state-of-the-art scientific and technological know-how, and combine different methods in the workflow. The contractor's situation is much more complex than the situation of the other participants involved in the construction project [28].

Taking into account the phases of construction projects, the largest number of interactions between the participants and the project elements occur in the project execution phase. At this stage, the project has the most participants, it correlates with the environment the most, and has the most financial flows present. Therefore, it is clear that this phase of the construction project is one in which the complexity of the project should receive special attention. All of this was confirmed by Winchur [72], who, through his research, came to the conclusion that the complexity of a construction project is the greatest at the stage in which the work is executed. The contractor largely controls the processes and has the most influence on the project at the work execution stage, and, therefore, the complexity of the project at this stage is of the greatest importance for him/her.

Information on project complexity can make it easier for contractors to make management decisions during the procurement process, to set project objectives and manage risks, and to determine project personnel [18]. When taking over project management from the contractor, each project manager's primary interest is the complexity of the project, which is set for execution, and he/she seeks answers to the questions related to the characteristics that make up the complexity of the project.

Before defining the bid for work execution, contractors generally do not have adequate information about the project because they are only provided with data related to the estimated value of the work, the deadline for execution, and project documentation, and they are sometimes warned about special construction conditions through a tour of the construction site with the investor. Therefore, for a more successful project implementation, it would be very important that the contractor be able to determine the degree of project complexity from the available or possibly additional information based on the complexity model before defining the bid price. Thus, the contractor could influence and increase the chances his project has of success as a sub-project of the main project by looking at it from the investor's perspective. However, by increasing the success of performance in this way, the contractor can also greatly influence the increase in the investor's success in performance, as well as the success of all of the other participants involved in the execution of work on the construction project. Therefore, it is very important for the investor to provide the potential contractor with input data of the highest quality, which will then enable the contractor to determine the degree of project complexity as accurately as possible. Once the complexities of the construction project are better understood, it could enable the project management team to apply a proactive and front-end planning approach in the initiation phase in order to better manage scope changes in the delivery of the project, eventually improving the project performance [73]. Studies have shown that project complexity has an impact on the project performance but detailed studies on direct impacts are missing [11,74].

Traditional research related to project complexity focuses on components and elements of project complexity [21]. In accordance with all of the above, in order to define the classification of groups comprising the key elements associated with complexity from the perspective of the contractor, it is important to first analyze and systematize potential groups of complexity and elements of project complexity. The classification of groups and key elements of complexity for the contractor is the first step in analyzing the impact of a project's characteristics on the activation of risks and the success of the project.

2.5. Review and Identification of Elements of Complexity from the Contractor's Perspective

With the purpose of identifying the elements of complexity from the perspective of the contractor, a detailed review of the literature was conducted. The literature review was carried out in three steps. First, the search was performed based on the following keywords: project complexity, construction project complexity, complexity from contractor perspective, complexity, and project success. The first step of the search was performed in six databases, namely Science direct, ASCE Library, Taylor & Francis Online, Emerald insight, Academic Search Complete (EBSCO), and Google Scholar. The first step singled out 92 articles. The criterion for selecting the articles for the analysis was that the articles deal, either partly or completely, with the analysis of project complexity. In addition to searching the databases, in the second step, a search was performed in journals dealing with topics related to the field of research, namely: *Construction Management and Economics*, the *International Journal of Project Management*, the *Journal of Construction Engineering and Management*, the *Project Management Journal,* and the *Journal of Construction Engineering and Management*. The second step singled out an additional 34 articles. When searching the databases and journals, time filters were not included. In addition to the articles in the third step, two books and six PhD theses that were in the relevant fields of research were included.

By reviewing the literature in accordance with the above-stated methodology, a total of 37 articles defining the project complexity model were extracted. These 37 articles identified 267 different associated elements of complexity. For the purposes of the research, an analysis of these models was conducted. There is a large diversity of models of project complexity and complexity elements. This diversity can be illustrated by the variety of selected dimensions in the different models [75]. As stated, the key role in defining the complexity of a project is the fact that it needs to be defined from the different perspectives of the participants involved in the project. Accordingly, when reviewing the literature and the elements of complexity, the existing elements of complexity and groups of complexity were structured to best suit the contractor's perceptions.

The literature review identified eight indicators that will be defined in the research as groups of project complexity based on the frequency of their occurrence in existing research. Through the reviewed literature, it was found that certain groups of complexity in certain studies also appear as elements of complexity in complexity models. When analyzing the frequency of occurrence of these complexity groups, these occurrences were also taken into account.

It is important to emphasize that when structuring groups of complexity and elements of complexity, different names related to the same characteristics of the project were linked. Thus, more credible data based on the frequency of occurrence of individual groups and elements of complexity as real characteristics of the project were obtained. The analysis of the research determined the frequency of occurrence for individual groups of complexity elements, which were determined to be components of the complexity framework from the contractor's perspective. All of this was determined on the basis of an analysis of previously conducted research, the applicability of parts of existing models, and interviews with construction project managers with years of experience. Reviewing the complexity groups with the goal of defining the framework identified eight complexity groups, namely the complexity of the project scope, organizational complexity, operational and technological complexity, the complexity of the project environment, complexity related to resources on the project, legal and socio-political complexity, and communication and economic complexity. Below is an overview of the frequency of their occurrence in previous surveys (Table 1).

Table 1. Project complexity groups—occurrence frequency in existing surveys.

Complexity Groups	Frequency of Occurrence
Scope complexity	75.67%
Organizational complexity	59.46%
Operational and technological complexity	56.76%
Environment complexity	40.54%
Complexity related to resources on the project	37.84%
Legal and socio political complexity	27.03%
Communication complexity	16.22%
Economic complexity	18.92%

After a review of the literature, the elements of complexity were classified into groups of complexities based on previous research. Some of the elements of complexity that related to the same project characteristics, but that had different names in the existing research, were merged into a unique element of complexity to obtain more credible results. After that, the analysis of the frequency at which the elements of complexity occurred in previous surveys began.

Since the previous surveys did not consider complexity from the perspective of the contractor, the need to add elements of complexity to certain groups of complexity and elements that were not represented in the previous surveys arose. These elements were considered to be a significant contributor to the adequate definition of the framework and the classification of key elements of complexity from the perspective of the contractor.

The review of existing research dealing with elements of complexity identified several elements of complexity that were allocated to groups of complexity by means of analysis. The complexity group related to operational and technological complexity includes 26 elements of complexity; scope complexity includes 29 elements; organizational complexity includes 31 elements; complexity related to resource use during the project includes 22 elements; legal and socio-political complexity includes 19 elements; economic complexity includes 17 elements; communication complexity includes 17 elements; and environment complexity includes 21 elements of complexity. The remaining elements (36) could not be classified into one of the identified groups of project complexity from the contractor's perspective. The analysis of the frequency of occurrence of certain elements of complexity was then initiated. Based on these results as well as through the addition of additional elements of complexity, which are characteristic of the contractor, 15 elements of complexity were defined for each group of complexity of the project to be used in further research after conducting interviews with project managers with significant experience (Table 2).

Table 2. Project complexity groups with associated complexity elements.

Project Complexity Groups with Associated Complexity Elements	Frequency of Occurrence	Project Complexity Groups with Associated Complexity Elements	Frequency of Occurrence
OPERATIONAL AND TECHNOLOGICAL COMPLEXITY		**LEGAL AND SOCIO-POLITICAL COMPLEXITY**	
Incompleteness of the project documentation	2.70%	Political impact of the project	8.11%
Incorrect project documentation	2.70%	Local legislation	13.51%
Technological competence	18.91%	Cultural diversity of participants	13.51%
Technological diversity	13.51%	Contract type	2.70%
Usage of complex technologies	16.22%	Culture of claims	2.70%
Requirements of preparatory work	5.40%	Investors on the project from a different country	2.70%
Change of technology during the execution of works	2.70%	Local experience	5.40%
Presence of transport system near the construction site	2.70%	Number of contracts	2.70%
Energy Requirements	5.40%	Changes in legislation during the execution of the project	2.70%
Insufficient project data	2.70%	Changing of the policies over the course of the project	5.40%
Quality Requirements	13.51%	Holding elections over the course of project execution	2.70%
Inadequate bill of work expenses	5.40%	Workforce fluctuations	5.40%
Function of the structure being built	2.70%	Preparedness of the local community for the project	5.40%
Lack of quality management tools	2.70%	Interest of the local community in the project	5.40%
Technology that is unknown to the Investor	10.81%	Political and social instabilities	5.40%
SCOPE COMPLEXITY		**ECONOMIC COMPLEXITY**	
Duration of the project	27.02%	Project Financing	13.51%
Project value	16.22%	Change in prices in the course of the project	8.11%
Number of activities in the project	27.03%	Poor contractual price	0.00%
Number of Critical Activities	8.11%	Accuracy of the statistical office data, on the situation	0.00%
Activity overlap	29.73%	Funding from various sources	5.40%
Overlap of Critical Activities	8.11%	Currency of cost calculation	5.40%
Overlap of the project phases	8.11%	Availability of cost data for specific	8.11%
Number of Cost Significant Items	5.40%	Change in the investor's budget	13.51%
Cost Significant Items on Critical Path	0.00%	Economic stability of the investor	10.81%

Table 2. *Cont.*

Project Complexity Groups with Associated Complexity Elements	Frequency of Occurrence	Project Complexity Groups with Associated Complexity Elements	Frequency of Occurrence
Interconnectedness of activities from different stages	8.11%	Financial condition of the contractor	5.40%
Changes in the scope of the project over the course of execution	5.40%	Payment deadlines	5.40%
Quantity of additional works	8.11%	Number of variations in the project	5.40%
Amount of activities with a long duration	8.11%	Existence of a minimum chargeable amount	2.70%
Size of the project in terms of funds	8.11%	Changes in the global economy	2.70%
Variety of project scope	13.51%	The existence of advance payment	0.00%
ORGANIZATIONAL COMPLEXITY		**COMMUNICATION COMPLEXITY**	
Number of investors	5.40%	Communication within the project team	8.10%
Number of hierarchical levels in the project team	10.81%	Communication between the project manager and the project team	10.81%
Significance of the project for the parent organization	8.11%	Relationship between the project manager and the parent organization	8.11%
Number of construction site locations	10.81%	Large amount of information on the project	8.10%
Number of subcontractors	5.40%	Communication with the supervising engineer	0.00%
Number of suppliers	16.22%	Communication with the investor	5.40%
The influence of the supervising engineer	10.81%	Procedures during the project	16.21%
Subcontractor work on the critical path	0.00%	Communication with subcontractors	8.11%
Subcontractor work overlapping	0.00%	Communication with suppliers	5.40%
Size of the project team	10.81%	Capacity of the project team to transfer the information	5.40%
Multiple contractors on the project	8.10%	Diversity of participant communication cultures	8.11%
The importance of the project for the investor	5.40%	Interdependence of the established procedures	8.11%
Coordination of participants	16.22%	Inconsistency of procedures	5.40%
Changes of the project team members during the progress	5.40%	Meetings	0.00%
Interconnectedness of participants	21.62%	Concealment of information between participants	10.81%
COMPLEXITY RELATED TO RESOURCES ON THE PROJECT		**ENVIRONMENT COMPLEXITY**	
Resource Quantity	18.92%	Dependence on the environment	10.81%
Diversity of material resources	8.11%	Local climatic conditions	13.51%
Diversity of the workforce	5.40%	Geological conditions	8.11%
Availability of material resources	18.92%	Geographical location of the participants	2.70%
Availability of a skilled workforce	18.92%	Hydrological and hydrogeological conditions	2.70%
Equipment availability	10.81%	Stability of the environment	5.40%
The variety in equipment	10.81%	Extreme weather conditions	5.40%
The experience of the project manager acquired on similar projects	16.22%	Construction site in a public environment	5.40%
Experience of the project team acquired on similar projects	16.22%	Interaction between the technological system and the environment	5.40%

Table 2. *Cont.*

Project Complexity Groups with Associated Complexity Elements	Frequency of Occurrence	Project Complexity Groups with Associated Complexity Elements	Frequency of Occurrence
Oscillations in the number of available human resources	8.11%	Groundwater protection zone	2.70%
Changes in the project manager in the course of execution	21.62%	Construction site in contaminated environment	2.70%
Smaller quantities of different material resources	5.40%	Construction site in the historical core	2.70%
Larger quantities of equal material resources	5.40%	Incorrectly planned geological conditions	2.70%
Resource Delivery	8.11%	Construction site in traffic	0.00%
Oscillations in the necessary equipment for the execution of works	5.40%	Frequent variability in weather conditions	8.11%

When it comes to operational and technological complexity, it should be noted that in a significant number of surveys, operational and technological complexity are separated. Bearing in mind how connected they are at the work execution stage, in this case, they represent a single group of elements of complexity. The complexity of the project scope as a group of complexities appears, as stated above, most often in the existing research, from all groups of elements of complexity. This can be concluded if we consider that the two terms that are used have the same meaning, namely, the complexity of the project scope and the complexity of the task. For this complexity group, in addition to those determined by the literature review, the element of Cost Significant Items on the Critical Path has been included as an element characteristic of the contractor that can significantly affect the course of the project. As a group of complexities, organizational complexity was recognized at the very beginning of the process of defining and exploring the notion of complexity. Through analyzing the existing research, it can be concluded that there is virtually no research dealing with elements of complexity at any level without addressing a group or element of complexity related to the organization of the project. The contractor mainly uses the project resources during its implementation. Accordingly, the analysis of existing research indicates the existence of adequately defined elements of complexity for this complexity group by looking at them from the perspective of the contractor. The current state of the construction market results in resources, which can have a very large impact on its results from the perspective of the contractor. In the existing research, elements related to the quantity and diversity of resources, namely, labour and force, as well as elements related to the contractor's project manager, appear the most often. For this group of complexities based on research from existing research, 13 elements of complexity were distinguished based on the frequency of occurrence, while 2 other elements of complexity that are characteristic for the contractor were included, namely, Subcontractor Work on a Critical Path and Subcontractor Overlap. Legal and socio-political complexity was analyzed to a lesser extent in the existing research. This complexity represents an additional challenge for providing a quality definition for the associated elements of complexity. They were analyzed by looking at legislation and contracting on the project. These elements, at the work execution stage, have a greater impact on the implementation of the project from the contractor's perspective than from the investor's perspective. During the beginning of the realization of the project as well as when work on the project is being executed, the contractor can encounter various challenges related to the legislation but also related to the social aspects that surround the project being executed. The complexity group related to economic indicators was found in existing surveys the least, along with communication complexity. Nevertheless, the financial stability of the project is a key determinant of its implementation from any perspective. Any significant irregularity in this area may not only affect the success of the project but may also lead to its suspension or the total interruption of its implementation. The review of existing research dealing with elements of complexity highlights Project Financing, as well as possible Budget Changes and Investor Economic Stability and Contractor Financial Status as the most important elements. Bearing in mind the insufficient processing of economic complexity and taking into account the economic complexity from the perspective of the contractor, the elements of complexity that will be used in further research are included in the elements of complexity related to the Poor Contract Price of Works, the accuracy of data of the Statistical Office on the state of the market, and the existence of advanced payment. Communication complexity plays a very important role in a complex system such as a construction project. As a complexity group, it is necessary for it, to be part of the complexity framework from the contractor's perspective. Communication complexity contains a large amount of information circulating about the project, as well as a large number of interactions with other participants involved in the project, along with the local community. Communication complexity, similar to economic complexity, is not significantly analyzed in the existing research. One of its forms can be found in 16% of the research that deals with elements of complexity in some way. Among the existing elements of complexity that are highlighted in the table below, elements related to the procedures on the project, as well as communication within the project team itself, are particularly prominent. As the communication complexity was not sufficiently analyzed in the existing research, and considering its importance for complexity from the perspective of the contractor, the inclusion of additional elements of complexity was performed, namely the inclusion of elements related to meetings, as well as communication with the supervising engineer. The environment of the project can influence its execution significantly, and, as a determinant of the project, has a great influence on the degree of complexity from the perspective of the contractor. In existing surveys of complexity, the environment of a project appeared in a significant number of surveys as one of the determinants of project implementation. By analyzing the frequency at which the elements related to the project environment occurred, as well as their applicability from the perspective of the contractor, 14 elements were singled out. The most common elements related to the environment were the Environmental Dependence of the project and the Local Climate Conditions of the project being executed. In addition to the fourteen elements singled out from the existing research, the element related to the Construction Site under traffic was included as an element of project complexity from the perspective of the contractor, which will be a part of the research for defining the model of the complexity for a specific construction project from the perspective of the contractor.

By examining the elements of complexity separated into groups of complexity, it can be established that for each complexity group, there are elements that stand out with regard to their presence in the existing research. The most common elements in the existing research are the overlap of activities, the project duration, and the number of activities on the project. All of these elements belong to the group of project scope complexity elements. In continuation of the present work based on the results of the pre-existing research, key elements of complexity for each complexity group are distinguished, and in this way, a classification of groups and the associated elements of complexity of the construction project was created from the perspective of the contractor. It is important to emphasize that the frequency of occurrence in the existing research has no impact on the present research or on the final definition of the key elements of complexity from the perspective of the contractor.

3. Research Methodology

The research presented in this paper was based on the need to determine how a project's characteristics affect the success of the construction project from the perspective of the contractor. Complexity characteristics do not all have the same impact on the success of a project [10,76], so it is important to understand and quantify the aggregated weight of each complexity element and its impact on the overall level of project complexity.

The theoretical framework of this research is explained in the previous section. In order to increase the performance of the project, the contractor should timely identify the characteristics of the project that, as elements of complexity, affect the success of the project. The research consists of collecting data through a review of the literature made in the previous section, sending questionnaires and collecting answers to the questionnaire given by the project managers who work in organizations which are contractors on construction projects. After that, the analysis of the received data was performed, on the basis of which the results of the research will be presented. The analysis and the presentation of the research results were made on the basis of mathematical data processing and the application of the mean value of the obtained results.

To collect the necessary data to conduct this project, based on the determined input data, the focus group method was applied and consisted of 41 experts who provided answers to the questions asked. In order to determine the final form of the research, the research was first analyzed with five members of the focus group with the most experience as the contractor project managers. While defining the questionnaire in the initial interviews about the research itself, detailed interviews about the content of the questionnaire were conducted with five members of the focus group. Through initial discussions and an analysis of the prepared questionnaire, the number of complexity elements per group was reduced from 15 to 10.

The project managers considered that it was possible to reduce the number of complexity elements that would be addressed by the research immediately at the beginning of the survey. In addition, they considered that conducting extensive research with a large number of complexity elements with common characteristics would create a number of ambiguities when providing answers to the questions asked and would significantly affect the increase the scope of the overall research. Bearing in mind that the focus group consisted of representatives of contracting organizations with extensive experience, their suggestions were accepted. In this way, the key elements of complexity from the contractor's perspective had largely been identified already. The reduction in the number of complexity elements was mainly carried out by linking similar and easily connectable complexity elements into one common complexity element encompassing a slightly wider area based on the experiences of five members of the narrower focus group to conduct the research in a more efficient manner. In cases where linking alone was not sufficient to reduce the number of complexity elements to ten per group, the expulsion of those complexity elements whose appearance was less frequent compared to others was initiated by looking at the review of previous research, and some of the complexity elements that were found to be less suited to the perspective of the contractor were expelled through initial discussions with members of the focus group. In this way, the complexity groups containing other associated elements of complexity could be defined.

In the continuation of the research, it was necessary to determine the importance of the influence of individual elements of complexity on the degree of complexity of each complexity group and thus on the overall degree of complexity of the project. By determining the intensity of this impact, the classification of complexity groups and key elements of complexity from the perspective of the contractor could be determined.

In addition to the aforementioned five representatives of the focus group, the survey was sent to fifty-four more addresses, and we received answers from thirty-six of those addresses. A total of 18 respondents did not provide a response to the questionnaire. Of those eighteen non-responders, nine declared that the research presented here is a complex task that would take them a long time to complete and that they are currently unable to send a response. Three respondents stated that they were not sure if they could provide adequate answers to the above questions and that they would not submit their answers. No feedback was ever received from the remaining six addresses to which the questionnaires were sent. Nevertheless, the 41 responses that were received provided a significant sample that could adequately define the answers to the questions.

It is important to emphasize that more than half (53%) of the respondents who participated in the survey were working in at least two countries; this confirms them as having the necessary international experience, which can add relevance to the results of the survey (Table 3). It is possible that the diversity of the market could influence the different complexity elements and the overall measure of complexity. In addition, more than 80% of respondents had worked for two or more construction companies throughout their working life. This data indicates that the respondents have the necessary experience in different companies or systems to realistically assess the impact of the complexity of the project on the contractor without taking into account the characteristics of the system of only one organization. In addition, companies of different sizes—i.e., different number of workers—are represented in the survey. Based on this data, it is possible to analyze the results obtained by the research with regard to this indicator and to identify differences in the definition of key elements of complexity with regard to the size of the company.

Table 3. Characteristics of the responders.

Characteristic		Number of Respondents
Sex	Female	37
	Male	4
Age	<30	0
	30–40	28
	41–50	10
	51–60	2
	>60	1
Qualifications	NSS	0
	Secondary school	0
	University degree	28
	Master's degree in science	12
	Doctor of Science	1
Years of experience in managing exection of construction works	5–10	21
	11–20	13
	21–30	4
	More than 30	3
Number of states in which the respondent worked	1	20
	2	12
	3	4
	4	2
	5 and more	3
Number of the construction companies where the respondent worked	1	8
	2	11
	3	9
	4	4
	5 and more	9
Number of workers in the respondents company	0–50	4
	51–100	7
	101–250	5
	251–500	8
	More than 30	17

4. Research Results

In the conducted research, the levels of importance of the individual elements of complexity for construction projects were defined from the perspectives of the contractors for each of the complexity groups based on the submitted answers. For the previously defined lists of complexity elements for each complexity group, the degree of importance of their impact on each group of complexity elements and on the overall complexity of the project was offered from the perspectives of the contractors. During the period of time in which the replies to the questionnaire were being sent back, there were no significant questions or ambiguities regarding the nature of the project, which represents a particular element of complexity that is part of the present research. The degree of importance was determined by the respondents by providing answers on a Likert scale of importance that ranged from 5 to 1. On the scale of importance determining the impact, 5 represents the largest possible impact, and number 1 represents the smallest possible impact that an element could have on the degree of complexity of the group. The impact with an intensity of 4 on the Likert scale represents a large impact on the degree of complexity of the group, 3 represents a medium impact, and 2 represents a low impact of elements of complexity on the degree of complexity of the group.

By analyzing the data obtained from the questionnaire responses and by creating a ranking of importance with regard to the mean value of the received responses, we were able to obtain the data presented below.

The elements are arranged based on level of importance with regard to the mean value of all 41 responses submitted over the course of the research.

When talking about the elements of operational and technological complexity, the elements that stand out are the ones related to how technology changes when work is being executed, as well as the incompleteness and inaccuracy of the project documentation. The least important elements of an operational and technological complexity group are Quality Control and Quality Requirements and Function of the structure being built (Table 4).

Table 4. Degrees of importance of elements of operational and technological complexity.

Operational and Technological Complexity Group	Mean Value	Rankings
Change in technology intended for the execution of works during the execution of works	3.9756	1.
Incomplete and inaccurate project documentation	3.8537	2.
Technology intended for the execution of work	3.7805	3.
Inadequate bill of work expenses	3.7317	4.
Presence of transport system near the construction site	3.3902	5.
Requirements of preparatory work	2.7073	6.
Technology which is unknown to the Investor	2.7073	7.
Energy Requirements	2.6098	8.
Quality Control and Quality Requirements	2.5366	9.
Function of the structure being built	2.5366	10.

Through the analysis of the results of the examination on the importance of individual elements of complexity in the group of complexities related to the scope of the project, it can again be concluded that the element with the greatest possibility of variability has the most significant impact on the project. Changes in the scope of the project during the period of time in which work is being conducted thus have a mean value of importance that amounts to 4.1220. The characteristics of the project that, according to the respondents, can play a significant role in the degree of complexity of this complexity group, are the number and the overlap of critical activities, as well as the number and the overlap of activities on the project. The overlap of project phases represents the least important element of complexity out of all the isolated elements from the complexity group related to the scope of the project (Table 5).

Table 5. Degrees of importance of elements of scope complexity.

Scope Complexity Group	Mean Value	Rankings
Changes in the scope of the project over the course of execution	4.1220	1.
Number and overlap of Critical Activities	4.0000	2.
Number and overlap of activities on the project	3.8537	3.
Quantity of additional works	3.7805	4.
Variety of project scope	3.6585	5.
Number of Cost Significant Items and Cost Significant Items on a Critical Path	3.5366	6.
Project value	3.2927	7.
Size of the project in terms of funds	3.2195	8.
Duration of the project	3.1951	9.
Overlap of project phases and the interconnectedness of activities from different project phases	3.1220	10.

Organizational complexity as a determinant of complexity has been present from the very beginning of complexity theory. Regardless of what has been stated above, it does not necessarily represent the most important groups of complexities from the contractor's perspective.

The number of construction site locations itself, as well as the number of investors participating in the project, has the least important impact on the degree of complexity when talking about the organizational complexity of the project. The number of site locations and the number of investors represent the characteristics of the project that are known to the contractor since the contractor's inclusion in the project and their impact of those elements on the project can be properly planned without the significant changes being initiated while work is being completed. The least important elements of an organizational complexity group in accordance with survey results are the number of construction site locations and the number of investors (Table 6).

Table 6. Degrees of importance of elements of organizational complexity.

Organizational Complexity Group	Mean Value	Rankings
The importance of the project for the investor	4.0732	1.
The influence of the supervising engineer	4.0244	2.
Significance of the project for the company	3.8780	3.
Subcontractor works on the critical path	3.8537	4.
Coordination of participants	3.8049	5.
Multiple contractors on the project	3.4878	6.
Number of subcontractors and suppliers	3.1463	7.
Number of hierarchical levels in the project team	3.0976	8.
Number of construction site locations	2.8049	9.
Number of investors	2.5854	10.

Considering the problems in the construction market, it is expected that the research results show how the diversity of the workforce, as well as its availability, represent the most important element of complexity related to the resources required for the project. What can also be of great importance, in accordance with the results of the research, is the experience that the project manager has working on similar projects. The availability of such a resource significantly facilitates the position of contractors when work is being executed on a project. The number of resources itself represents the least important element of this group of project complexity since it contains the least unknowns, so it can thus be planned and will not change significantly over the course of the project (Table 7).

Table 7. Degrees of importance of resource-related complexity elements.

Complexity Group Related to Resources on the Project	Mean Value	Rankings
Diversity and Availability of Workforce	4.1951	1.
The experience of the project manager acquired on similar projects	4.1220	2.
Workforce fluctuations	3.8049	3.
Experience of the project team acquired on similar projects	3.7561	4.
Oscillations in the number of resources required on the project	3.7317	5.
Change in the project manager over the course of execution	3.5854	6.
Diversity and availability of material resources	3.5122	7.
Diversity and availability of equipment	3.4146	8.
Resource Delivery	3.1707	9.
Resource Quantity	3.0244	10.

Bearing in mind that the execution of construction projects is an undertaking that drives the entire social community, the socio-political and legal elements surrounding the project play a significant role in its success. According to the research results, the political impact on the project is the most important element of the complexity of the project from this group. The least important elements of the legal and socio-political complexity group are the number of contracts and the cultural diversity of participants (Table 8).

Table 8. Degrees of importance of elements of socio-political complexity.

Legal and Socio-Political Complexity Group	Mean Value	Rankings
Political impact on the project	4.0732	1.
Local legislation	4.0000	2.
Local experience	3.9024	3.
Holding elections over the course of project execution	3.8780	4.
Local community	3.1951	5.
Changes in legislation during the execution of the project	3.0488	6.
Contract type	2.7561	7.
Culture of claims	2.7073	8.
Number of contracts	2.5854	9.
Cultural diversity of participants	2.4634	10.

Financing a project of any kind, including a construction project from the perspective of the contractor, represents a significant determinant of the complexity of the project's implementation. The most important elements of the economic complexity group are the financial condition of the contractor and the economic stability of the investor.

The existence of advanced payment and the currency of cost calculations represent the least important elements affecting the economic complexity of the project, especially when taking into account that they are known characteristics of the project from the very beginning and cannot change. What may partly affect the contractor is the currency of cost calculations, especially in certain volatile markets. However, this research mainly covers markets with stable currencies, and this research result is expected (Table 9).

Given its nature, communication complexity, which is mainly characterized by various types of uncertainties, represents a very significant group for the overall complexity of a project.

Table 9. Degrees of importance of elements of economic complexity.

Economic Complexity Group	Mean Value	Rankings
Financial condition of the contractor	4.2439	1.
Economic stability of the investor	4.1463	2.
Project Financing	4.0976	3.
Payment deadlines	3.8780	4.
Number of variations on the project (impact of changes in the financial value of the order)	3.5122	5.
Change in prices over the course of the project (adjustment for changes in	3.3659	6.
Changes in the global economy	3.2195	7.
Availability of cost data for specific activities	3.0244	8.
The existence of advance payment	2.8293	9.
Currency of cost calculation	2.4878	10.

From the contractor's point of view, in accordance with the results of the research, the most important element of complexity relates to communication with the supervising engineer and the investor, as well as concealing information between the participants in the project. When all of these elements of complexity have an adequate impact, they can significantly affect the overall complexity of the project and thus its results and success. For this complexity group, the least important element of complexity is the diversity of communication cultures of the participants involved in the project because the diversity of cultures cannot significantly contribute to the quality of communication itself if some other problem is not present (Table 10).

Table 10. Degrees of importance of elements of communication complexity of the project.

Communication Complexity Group	Mean Value	Rankings
Communication with the supervising engineer and the investor	4.1951	1.
Concealment of information between participants	4.1707	2.
Relationship between the project manager and the parent organization	4.0488	3.
Communication with subcontractors and suppliers	4.0244	4.
Procedures on the project	3.8537	5.
Communication within the project team	3.7073	6.
Large amount of information about the project	3.4390	7.
Capacity of the project team to transfer the information	3.2927	8.
Meetings	3.0488	9.
Diversity of participant communication cultures	3.0244	10.

The results obtained through the test indicate that the inaccuracy of the projected geological conditions, as well as the geological conditions themselves, have the most significant impact on the degree of complexity of this complexity group from the perspective of the contractor. However, the elements with the greatest share of uncertainty in their occurrence and impact on the execution of the project are shown to be the most significant elements of each complexity group. In accordance with the above, the elements that are known and whose impact can be predicted and that are related to the construction site in historical areas or in contaminated and groundwater protection zones have the least impact on the degree of complexity related to the environment of the project being executed. Via proper planning, the contractor can significantly reduce their impact on the complexity and results of the project (Table 11).

Table 11. Degrees of importance of elements of complexity of the project environment.

Environment Complexity Group	Mean Value	Rankings
Incorrectly planned geological conditions	4.2927	1.
Geological conditions	4.1951	2.
Construction site in traffic	4.1220	3.
Local climatic conditions	3.7805	4.
Interaction between the technological system and the environment	3.7317	5.
Construction site in a public environment	3.7073	6.
Hydrological and hydrogeological conditions	3.5122	7.
Construction site in the historical core	3.3902	8.
Construction site in contaminated environment	3.1220	9.
Groundwater protection zone	2.6585	10.

By conducting the present research and by analyzing the results of the degree of influence of a particular element of complexity on a particular group affecting the project, the elements of complexity were ranked according to their level of importance. What is also important is that the research confirmed that the proposed elements of complexity, which were collected through the existing research—as well as from the suggestions of the focus group members with adequate experience in project management and in the execution of projects—formed appropriate elements of project complexity from the perspective of the contractor.

By distinguishing and agreeing on the importance of each element, a classification of complexity groups was created with the associated key elements of complexity from the perspective of the contractor. The research found that the elements of complexity that have uncertainty and dynamism as their basic characteristics have the greatest importance for the degree of complexity in individual groups. From the above, a clear link can be drawn to the previously stated claim that elements of complexity are the drivers of risk during a project.

The established framework consists of eight groups of complexity elements with ten associated complexity elements in each group (Table 12). The established classification represents the first significant result related to groups and elements of complexity from the contractor's perspective. As such, this classification is the basis for analyzing the impact of complexity elements on the activation of risks on the project and consequently on the success of the project from its perspective. Within this framework, the elements of complexity are classified with regard to their importance for the contractor. Depending on the contractor's needs for the project being executed, the contractor may also allocate a smaller number of key elements of complexity to possibly reduce the scope of the analysis of the impact of elements of complexity over the course of the project. Based on this classification and the conducted research, the classifications of key elements of complexity for different types of projects and the values of the projects that are being executed, as well as the types of contracts on the basis of which the construction work on the project is being executed, can also be defined.

Table 12. The classification of groups with associated key complexity elements from the contractor's perspective.

Operational and Technological Complexity Group	Scope Complexity Group	Organizational Complexity Group	Complexity Group Related to Resources on the Project	Legal and Sociopolitical Complexity Group	Economic Complexity Group	Communication Complexity Group	Environment Complexity Group
Change in technology intended for the execution of works during the execution of works	Changes in the scope of the project over the course of execution	The importance of the project for the investor	Diversity and Availability of Workforce	Political impact on the project	Financial condition of the contractor	Communication with the supervising engineer and the investor	Incorrectly planned geological conditions
Incomplete and inaccurate project documentation	Number and overlap of Critical Activities	The influence of the supervising engineer	The experience of the project manager which is acquired on similar projects	Local legislation	Economic stability of the investor	Concealment of information between participants	Geological conditions
Technology intended for the execution of works	Number and overlap of activities on the project	Significance of the project for the company	Workforce fluctuation	Local experience	Project Financing	Relationship between the project manager and the parent organization	Construction site in traffic
Inadequate bill of work expenses	Quantity of additional work	Subcontractor works on the critical road	Experience of the project team acquired on similar projects	Holding elections in the course of project execution	Payment deadlines	Communication with subcontractors and suppliers	Local climatic conditions
Presence of transport system near the construction site	Variety of project scope	Coordination of participants	Oscillations in the number of resources required for the project	Local community	Number of variations on the project	Procedures on the project	Interaction between the technological system and the environment
Requirements of preparatory work	Number of Cost Significant Items and Cost Significant Items on a Critical Path	Multiple contractors on the project	Change in the project manager over the course of execution	Changes in legislation during the execution of the project	Change in prices over the course of the project	Communication within the project team	Construction site in a public environment
Technology unknown to the Investor	Project value	Number of subcontractors and suppliers	Diversity and availability of material resources	Contract type	Changes in the global economy	Large amount of information about the project	Hydrological and hydrogeological conditions
Energy Requirements	Size of the project in terms of funds	Number of hierarchical levels in the project team	Diversity and availability of equipment	Culture of claims	Availability of cost data for specific activities	Capacity of the project team to transfer the information	Construction site in the historical core
Quality Control and Quality Requirements	Duration of the project	Number of construction site locations	Resource Delivery	Number of contracts	The existence of advance payment	Meetings	Construction site in contaminated envi-ronment
Function of the structure being built	Overlap of project phases and the interconnectedness of activities from different project phases	Number of investors	Resource Quantity	Cultural diversity of participants	Currency of cost calculation	Diversity of participant communication cultures	Groundwater protection zone

5. Discussion

In the existing research, the authors mainly established the fact that there are a significant number of defined complexity models with associated elements. The research found that the models of complexity that have been established for construction projects were mostly analyzed from the investor's perspective. Bearing in mind that the existing research found that complexity is different for the individual participants involved in the construction project, this research sought to classify groups of complexity with the associated key elements of complexity from the perspective of the contractor. Given the existing practices in construction, the contractor bears the greatest burden of the complexity of the project and the impact of the complexity of the project on the activation of risk and on the success of the construction project.

The defined classification of complexity consists, as mentioned before, of eight complexity groups with the associated 10 key elements of project complexity for each group.

In operational and technological complexity, there stand out elements of complexity which, as main characteristics, have a significant degree of uncertainty in regard to their appearance during the project being their basic characteristic. With all of the above in mind, the high level of importance that these elements of complexity in the group of operational and technological complexity have is quite logical. The function of the structure being built comes out as the least important element of complexity in a group of organizational and technological complexity. Viewed from the contractor's perspective, this element really cannot play a more significant role in the results of the contractor's project, especially when bearing in mind that for the contractor, operational and technological tasks arise from the project documentation and not from the function of the structure being built.

The increase in the number of activities, as well as the overlap of those activities during the execution of works, significantly increases the degree of complexity related to the scope of the project. This complexity element, as well as the element related to the increasing of a scope of works, can significantly affect the success of the project. Phase overlapping is something that is known to the contractor at the very beginning of the project, and it is a characteristic that he can affect with adequate planning and can reduce its influence on the results and the success of the project.

Through the discussions with the participants of construction projects, which were related to the problems on their projects, they mainly put the emphasis on organization problems. From the point of view of organizational complexity, the most important elements of complexity are the importance of the project for the investor and the influence of the supervising engineer on the organization of the work to be completed during the project. If the project, which is performed by the contractor, represents something crucial for the investor, which often means that it has to be completed before the agreed upon time, then the total complexity of the project in each of the segments increases. In addition, the supervising engineer, the person authorized to manage the project in accordance with his contract with the investor, can significantly influence the atmosphere during the period of time in which work is being executed and can, through his actions, have the most influence on the necessary time, as well as the costs of the contractor.

In today's market, which is characterized by a lack of work force and problems with deliveries and changes in the prices of material resources and equipment, the complexity related to resources plays an important role in the overall complexity of the project from the perspective of the contractor. Significant changes in resource prices are common, which can put the contractor in a situation in which the execution of works is not a profitable task. However, a thing that most significantly affects the area of research related to resources is the growing shortage in the workforce. The market is characterized by a lack of both a trained and educated workforce and workers without any education and experience. Therefore, in this market, there is an increasing tendency to find workforce from Eastern Europe, as well as from Asia, specifically Turkey, India, or Bangladesh. The adaptation of the market to these conditions will be time-consuming and will require significant investment.

The impact of politics depends significantly on the realization of individual construction projects, and it is therefore expected that the political impact plays a significant role on the project's complexity. Local legislation, given the nature of the performing organizations and their operations in different communities, also has a high impact on the success and degree of complexity of a project. If we look at larger construction projects, we can conclude that construction has long been globalized, and it is therefore expected that, if there is cultural diversity among the participants involved in the project, then it will not affect the results of contractors significantly.

The frequent increases in purchase prices that characterize today's market can create significant inconvenience for the contractor when work is being executed. If these price increases are reflected in several major projects that the contractor is carrying out, then it may lead to problems with the contractor's overall financial condition. The results of the research define how the financial condition of the contractor represents the most important element of complexity in this group. If the financial condition of the contractor is not in accordance with the needs of the project, then it is expected that it will cause an increase in the complexity of the execution of the project. In addition to the financial condition of the contractor, the financial condition of the investor is an almost equally important element of complexity. The financial condition of the investor determines the dynamics of payments and can consequently also affect the financial condition of the contractor; the importance of this element of complexity on the overall complexity of the project can be easily deduced from this fact. For the contractor, this can be particularly negative if the key investor, with whom the contractor may have several contracts with at a certain time, is experiencing financial problems. Such a scenario is highly negative for the contractor, and the contractor should therefore endeavour to avoid being dependent on only one or several key investors.

Quality communication at any level reduces the complexity the project and thus affects the increase in success and the decrease in the overall complexity of the project. If the communication during a project leads to distrust between the participants, the consequences can be extremely negative. Deficiencies in communication can occur within the contractor's project team itself, which the contractor can solve on their own within their organization after recognizing them. However, if appropriate communication with the other participants involved in the project is achieved during the project's execution, this can play a major role in simplifying its implementation, thus creating a positive atmosphere and trust and affecting the results and success of the project both from the perspective of the contractor and the overall success of the construction project.

The environment of the project represents an important determinant of its execution. A lack of or the inaccuracy of the data about the environment of the contractor's project will mislead the contractor, as they prepare for certain conditions and not knowing that they will be met with completely different conditions during the execution of the project. The contractor has to reorganize these changes as soon as possible in order to ensure that as little time is lost as possible. Such ventures can generate large amounts of additional costs, both for the contractor and, consequently, the investor.

Related to the existing frameworks of the complexity of construction projects, it is important to point out that the adopted framework of complexity from the perspective of the contractor has almost the same groups of complexity, such as the Nguyen model for Complexity of Transportation projects from 2015 [77]. This framework also confirms the importance of the elements of complexity that the authors have singled out in previous research. It was also confirmed that the elements of complexity are the same for all participants in the project, but do not have the same impact on each of the participants. A more significant comparison of the defined framework of complexity with similar frameworks cannot be made, given that the researchers in the previous period did not deal in more detail with the analysis of complexity from the perspective of contractors.

A defined classification of complexity groups with associated key complexity elements represents a good theoretical basis for the contractor, but it cannot introduce significant benefits for the contractor as a participant in the implementation of the construction project without adequate quantification. Therefore, in future research, it will be necessary to establish a framework for evaluating the key elements of complexity with regard to their impact on the activation of risks and the success of the construction project. By establishing such a framework and putting it into practice, the contractor can influence the proper planning of the project and thus influence their success and overall business.

The results of this study should be viewed in light of several limitations. They are mainly related to the choice of respondents. Due to market constraints, the survey could not be conducted among project managers with more experience in different fields of construction projects. Caution is required in extending findings to construction companies of different dimensions, belonging to different fields of construction and with different organizational settings. The results of the research need to be analyzed with regard to the different characteristics of the companies from which the respondents come, and in this way to form new frameworks of complexity. Although the findings are based on data from several construction companies, mostly from Southeast Europe, these outcomes can still provide reference for other countries considering the parallel construction industry experiences.

In addition to the conducted research, in order to classify the key elements of complexity in more detail, the same elements can be analyzed with regard to the types of construction projects that contractors tend to execute the most, as well as the size of the contracting firms themselves and the size of the construction projects they execute. In this way, more precise key elements of complexity would be defined with regard to the different characteristics of contractors and their projects. Thus, certain key elements of complexity constitute a good basis for a more accurate definition of the results and could thus significantly affect contractor performance.

6. Conclusions

The aim of this article was to classify groups of complexity with the associated key elements of complexity from the perspective of the contractor working on a construction project. Existing research related to the complexity of projects and the complexity of construction projects were analyzed. By researching the existing literature in the field of complexity, it was established that the existing research rarely or does not deal with the complexity of construction projects from the perspective of the contractor. In addition, the complexity of construction projects was found to be different for the different participants involved in the project, and the key elements of complexity are different for each of them. Through the literature review, the groups of complexity and elements of complexity that appear in the existing research were distinguished. Based on the frequency of their occurrence and the experiences of members of the focus group, the elements of complexity that are characteristic of contractors were distinguished as input data to conduct the present research. The research conducted among the construction project managers resulted in the creation of a classification comprising eight groups and ten associated key elements of complexity for each group of complexity. In this way, a framework of complexity for construction projects was formed from the perspective of the contractor and will hopefully serve as a basis for contractors to quantify the impact of complexity on the success of the projects they perform. Bearing in mind the impact of the contractor on the construction project, determining the key elements of complexity from the contractor's perspective affects the overall success of construction projects. In future works, it will be necessary to analyze and quantify the impact of the key elements of complexity on the results of construction projects according to the contractor's impact on the initiation of risk during the project. Based on this, a framework will be created, and by applying it, the contractor will be able to properly plan the objectives of the projects being performed and will thus influence the success of those projects.

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Engaging Engineering Students with the Stakeholders for Infrastructure Planning

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Abstract: Construction projects should be planned and executed in a way that minimizes the inconvenience to the local community. For that, it is crucial to incorporate public opinion by engaging them in the decision-making process. However, the public is generally involved indirectly in the planning of infrastructure projects through information-sharing reports and meetings, which have not shown to be very effective. This paper presents the findings of a case study as a hands-on experience for graduate engineering students toward engaging the public in the feasibility assessment of a real-world rehabilitation project. The case study involves the application of a simple additive weighting (SAW) multi-criteria decision-making (MCDM) approach to the assessment of various dimensions of the proposed rehabilitation alternatives. As a part of the MCDM framework, public opinion is sought to determine the relative importance of various criteria in making the final decision. The steps and processes of the case study are summarized and proposed in the form of a framework for engaging both students and the community members in the planning of construction projects. The case study and the framework serve as a structured introductory exercise for raising awareness in the students about the impact of public opinion on the planning of construction projects, and the existence of methods that can help them articulate participatory processes. This structured exercise is replicable for future researchers. It is expected that the application of the approach pursued in this study will help promote a culture of accommodating public engagement among engineering students as future engineers in the long term.

Keywords: multi-criteria decision-making; engineering education; public engagement; unmanned aerial vehicle

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1. Introduction

The primary goal of the construction industry is to enhance the quality of life of community members and serve the common welfare by providing physical facilities and infrastructure systems based on public needs and values [1]. Therefore, construction projects should be planned and executed in a way that minimizes the inconvenience to the local community [2,3]. However, there are often unexpected impacts of a project or action on others, called “externalities” [4]. To eliminate negative externalities, it is crucial to incorporate public opinion by engaging with them in the decision-making process. Regarding public engagement, an old concern should be addressed: can the general public have a major influence in planning decisions? [5].

Past examples in the literature have questioned the effectiveness of the required public engagement processes in transportation projects [6]. Several past studies [7,8] asserted that formal public engagement processes were generally “rituals designed to satisfy legal requirements” and that engineers were not adequately involved in community concerns [9,10]. If community concerns remain overlooked, future scholars and practitioners will continue to consider public engagement irrelevant to their practice [11]. One dominant perception is that engineering is about technical problem-solving, which precludes engineering students from engaging with public welfare concerns [12–14]. In the long term, such practices and perceptions can lead to failure in the consideration of community concerns and in the broader impacts of engineering projects on society [15]. Therefore, the onus is on undergraduate and graduate students to interrupt the cycle of oblivion and to develop a culture of accommodating public engagement [11].

This explains the need for an integrated framework to educate students and future engineers on how to get the public involved in the planning of construction projects. To address this need, this study proposes a framework for educating engineering students to engage the public in the planning of construction projects. This is followed by a case study that involves the engagement of engineering graduate students with the public in the feasibility assessment of various alternatives for a construction project (Suda Wall, Hamilton County, IN, USA). Throughout the case study, students were trained to adopt multi-criteria decision-making (MCDM) to engage community members in the decision-making process.

The case study and the introduced framework serve as a structured introductory exercise for raising awareness in the students about the impact of public opinion on the planning of construction projects, and the existence of methods that can help them articulate participatory processes. This structured approach is replicable for future researchers. The applications of the approach pursued in this study promote a culture of public engagement among engineering students, which can reduce the negative externalities of construction projects in the long term.

2. Background

Construction projects can incur various unintended or uncontrolled damage or social costs to the nearby society [16]. Economists [17,18] define social costs as "the overall impact of an economic activity on the welfare of society. Social costs are the sum of private costs arising from the activity and any externalities". The main issue with considering social costs in the design and planning stage of projects is that social costs are borne by the public rather than the project participants, and affected communities are not engaged in the planning and management of the projects [19]. The social costs are called "Negative externalities", when an act from an individual causes harm to other members of the society, who do not get compensated for the negative impact [20].

Complexities in quantifying the intangible effects of project externalities that also consider monetary evaluations have led to the development of several multi-criteria evaluation methods [21,22]. As a powerful decision-aid tool, multi-criteria decision-making (MCDM) models are becoming more accepted for assessing the feasibility of construction projects, as they allow for the consideration of multiple and occasionally conflicting criteria [23]. MCDM methods also provide the opportunity for considering the interests of various stakeholders [21,24]. For instance, the analytic hierarchy process (AHP) method [25] and ELECTRE [26], allow stakeholders to have their own criteria and preference [21].

Table 1 shows previous examples of the application of MCDM approaches to planning and feasibility assessments of various alternatives for civil engineering projects. In this table, the methods used by the authors as well as the means for public engagement are illustrated.

Table 1. Current research on public involvement in MCDM.

Authors	Application	Methods	Public Involvement Strategy
(Arroyo & Molinos-Senante, 2018) [27]	Selecting appropriate wastewater treatment technologies.	Choosing-by-advantages approach (CBA)	Indirect: Adding public acceptance criterion in the planning stage.

Table 1. *Cont.*

Authors	Application	Methods	Public Involvement Strategy
(Heravi et al., 2017) [28]	Selecting sustainable industrial building options.	Multi-criteria group decision-making, ELECTRE, grey system theory, ordered weighted averaging	Indirect: Considering social aspects in the planning stage.
(Yoon et al., 2009) [29]	Infrastructure systems assessment.	Analytical system for planning of infrastructure rehabilitation (ASPIRE)	Indirect: Considering social/political aspects in the planning stage.
Pellicer et al. (2016) [30]	Teaching graduate students on the sustainability of design and construction of infrastructure alternatives.	MCDM—AHP	None: General public is not among the stakeholders. Graduate students in construction field acted as experts.
(Zheng et al., 2016) [4]	Externality assessment of hydropower projects.	Input-output model for externalities	Indirect: Considering public benefits and negative externalities in the planning stage.
(Macharis et al., 2010) [21]	Turning Flanders into a top mobility and logistics region by 2020.	Multi-actor multi-criteria analysis (MAMCA), analytic hierarchy process (AHP)	Direct: Engaging various stakeholder groups using survey questionnaire to determine weights of the introduced criteria.
(Yoon et al., 2019) [31]	Wastewater infrastructure system planning.	MCDM-CBA—life cycle cost analysis-equilibria of power	Indirect: Quantifying the monetary impacts on the community.
(Büyüközkan & Karabulut, 2017) [32]	Comparison of thermal power with three renewable energy sources.	MCDM-AHP—VIKOR	Indirect: Considering social aspects in the planning stage.
(Ribas et al., 2019) [33]	Multi-criteria risk assessment of a large hydroelectric project	Fuzzy analytic hierarchy process (FAHP)	None: General public is not among the stakeholders.
Salas and Yepes (2022) [34]	Prioritizing the maintenance of different public facilities	MCDM—AHP	Direct: Engaging a team of 12 experts to determine weights of the introduced criteria.

As can be seen in Table 1, the main approach for considering the public involvement is through an indirect rather than a direct strategy, by adding criteria that consider the public needs. Yoon [31] adopted an equilibrium of power approach to demonstrate the benefits of construction projects to the community. However, it did not quantify the importance of the criteria based on the opinion of the local community. Another study on environmental and community risks of solar power plant construction sites in Australia considered the noise and dust when considering the impacts of the project on the community. However, the community was only engaged during the construction phase, and the agenda and minutes were published [35]. The table and these instances show that only on rare occasions, the public is directly involved in the planning of infrastructure projects. This is while the past research suggests that engagement approaches such as information sharing reports and meetings are not very effective [8].

This can be attributed to the dominant perception that engineering is about technical problem-solving, which precludes engineering students to consider both public welfare concerns and the broader impact of engineering projects on society [12–15]. In fact, a longitudinal study [36] on the public welfare beliefs of 326 engineering students at 4 US academic institutions: MIT, the Franklin Olin College of Engineering, Smith College, and the University of Massachusetts–Amherst, showed that the engineering students' perceptions of public welfare, in terms of their professional and ethical responsibilities and social consciousness, declined significantly over the course of their engineering education.

A more recent study [37] conducted 26 in-depth interviews with students at one public and one private university in the US. The outcome showed that the engineering students had difficulty justifying the value of non-technical work and integrating community knowledge into projects. For instance, one student mentioned that "I am an engineer—I don't know how to talk to people!", leading to the conclusion that engineers are not qualified to participate in surveys with communities. Another student emphasized their preference to have technical work rather than writing assignments: "I am an engineer! Give me something engineer-y!" These instances show that several students still stress technical aspects for defining the boundaries of engineering knowledge and practice, and tend to ignore community engagement [37].

In the past few decades, student-centered and collaborative learning approaches such as problem-based learning, project work, and guided small group work have become more common in higher education systems [38]. As the first step of problem-based learning, the students are first presented with the problem, and the learning needs are cooperatively identified under the guidance of the tutor. This is followed by a cycle of self-directed study, applying the obtained knowledge to addressing the problem, and summarizing the learned material. To be successful in engineering education, problem-based learning requires discussions guided by the teacher, problem-solving tutorials, as well as small group work. Interactive or co-operative learning facilitates student knowledge acquisition as well as the acquisition of the skill to improve their own knowledge [38]. Including case studies and discussion activities in the curriculum keeps students engaged with the ethical dimensions of their work [39].

Accordingly, this study presents the findings of a case study that involves the education of graduate engineering students for engagement with the public through the feasibility assessment of a real-world rehabilitation project in a team-based collaborative setting. As elaborated in the discussion section, the steps and processes of the case study are then summarized and proposed in the form of a framework for engaging both students and community members in the planning of construction projects through case studies.

3. Methodology for Case Study

The case study was conducted during the spring semester of a three-credit graduate-level civil engineering course, infrastructure planning, at Purdue University from January to May 2020. Twenty students were enrolled in the course and there were 3 h sessions once per week throughout the semester. The case study intended to provide hands-on experience with the planning, analysis, design, development, and feasibility study of the *Walden Ponds Project, Hamilton County, Carmel, Indiana, United States.* Students were divided into 4 groups of 5 students voluntarily. Each group evaluated certain dimensions of the problem and was assigned particular objectives to fulfill. They are demonstrated in Table 2.

Table 2. Student grouping and objectives.

Group	Objectives
Technical	• Collect data regarding technical issues • Identify constraints and issues around the project and the site • Provide the design team with recommendations for addressing drainage, i.e., dewatering, erosion control, and drainage, and retaining wall rehabilitation alternatives
Design and construction	• Collect basic information for design and schedule such as equipment and traffic condition • Provide specifications and design details
Planning and feasibility	• Identify constraints and issues around the project and the site • Identify the scope of project and work definitions • Determine cost estimates, schedules, risk, and logistical issues for each alternative
Social and environmental	• Collect data regarding social and political issues • Identify the relative importance of different criteria based on public opinion • Determine the benefit score for each alternative

In the case study, the students were engaged with the representatives of the homeowners' association (HOA) from the Walden Ponds community at Hamilton County to identify best-value solutions for the rehabilitation of an old retaining wall and improving the stormwater system in the county. An overview of the methods that the students used in the case study are discussed in the remainder of this section.

The students were asked to work in a team-based setting throughout the semester to interact with the owners of the project, who were the HOA representatives from the Walden Ponds community, to (1) understand the needs and concerns of the community, (2) identify current constraints of the project and conduct primary field testing, (3) engineer alternative solutions for the problem, (4) evaluate the benefits of each of the alternatives based on the social, technical, and economic aspects of the project and provide the best solution of design and schedule for performing the project, and (5) present the final outcome to the client in the form of a presentation and a final report, and come up with the "best value" alternative in coordination with the project owner. These steps are shown in Figure 1, which summarizes the methodology for the case study.

As Figure 1 shows, the community is involved in Steps 1, 4, and 5 of the decision-making process. Furthermore, as color-coded in the figure and discussed in the following sub-section, each of the student groups were responsible for certain steps carried out for the case study.

3.1. Step 1: Problem Definition

One of the class sessions was assigned to engage the students with representatives of HOA from the Walden Ponds community. During the session, HOA representatives made a presentation to the students about the problems, needs, constraints, and resources. There were two major objectives for the decision-making process: to identify solutions for (1) retaining wall rehabilitation and (2) drainage management. This step helped the students to get greater insights into owners' needs, concerns, constraints, and resources.

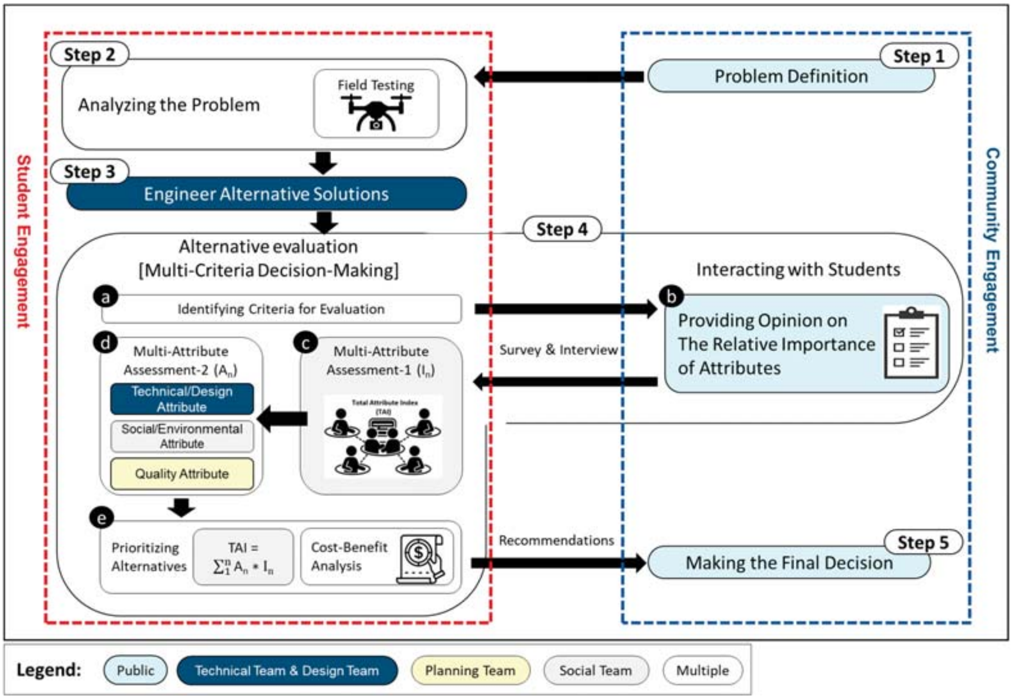


Figure 1. Methodology for case study.

3.2. Step 2: Analyzing the Problem and Field Testing

To further evaluate the site conditions, the leaders of the groups, who were nominated by the group members, did a site visit with the course instructor, project advisors, and HOA members. During the site visit, students evaluated the site conditions and documented the damages caused by the drainage problem to the retaining wall. The leaders of the groups were then tasked with communicating the outcomes of the site visit with the rest of their own teams.

Another part of the site visit was dedicated to data collection using unmanned aerial system (UAS), also known as drones. The collected data was used for generating 3-dimensional maps of the area. The data collection was conducted during the site visit by the course instructor with technical assistance. However, the group leaders and other students who were interested, had the chance to observe the process. DJI Mavic Pro, equipped with a 12 MP (Mega Pixel) RGB camera, was used to perform aerial surveys over the study area. Images collected from the DJI Mavic Pro were processed using a structure from motion (SfM) software—Agisoft Metashape Pro Version 1.7.6 (https://www.agisoft.com (accessed on 10 March 2020))—to generate 3D point clouds, digital surface models (DSM), and orthomosaic images. The surveyed coordinates of the GCPs were used in the SfM process to generate accurate geospatial data products that were used in an alternative proposal and evaluation.

3.3. Step 3: Engineer Alternative Solutions

After the site visit, the technical team was asked to identify possible alternative solutions for solving (1) the drainage problem, and the (2) retaining wall rehabilitation. The design team worked on providing design specification for the alternatives proposed by the technical team.

3.4. Step 4: Alternative Evaluation

The students were instructed to use MCDM to evaluate the identified alternatives. A considerable portion of the syllabus was dedicated to environmental assessment and different multi-criteria methods for the feasibility assessment of construction projects, including the analytic hierarchy process (AHP) [25], choosing by advantages (CBA) [40], and simple additive weighting (SAW) [41]. Since the purpose of this case study was to educate the students, SAW, which is the most simple, transparent, and user-friendly MCDM method and is even well-known to decision-makers, was selected [42]. Furthermore, a recent case study [43] on different MCDM methods such as simple additive weighting (SAW), weighted product method (WPM), and the analytical hierarchical process (AHP), showed that the outcomes of these methods are highly correlated.

All the groups were involved in conducting a multi-attribute assessment to evaluate the proposed construction alternatives for the identified problems based on both quantitative and qualitative assessments. To that end, several key attributes, A_n, which are the characteristics of the proposed alternatives, were used for the comparison of the alternatives. Each of the attributes, A_n, was weighted based on its relative importance, I_n. These two components, i.e., I_n and A_n, were then used to form a measure for the benefits associated with each alternative, the TAI:

$$Total\ Attribute\ Index\ (TAI) = \sum_{n=1}^{N} (I_n \times A_n) \tag{1}$$

To determine the *TAI*, it is necessary to (1) identify the criteria, (2) identify solution alternative scores with respect to each criterion, and (3) determine the weight for each criterion, as discussed in the following sub-sections.

3.4.1. Step 4-(a): Identifying Criteria

To identify appropriate criteria for comparing the suitability of the identified alternatives, the students were guided to conduct a literature review on the criteria commonly used in MCDM frameworks to incorporate a wide range of aspects. As discussed later in the results, these criteria include technical/design, quality, and social/environmental.

3.4.2. Step 4-(b), (c): Multi-Attribute Assessment–1 (I_n)

Multi-attribute assessment–1 (I_n), is a qualitative analysis used to identify the relative importance of various attributes in the view of the targeted community members, stakeholders, or decision-makers. This allows for the incorporation of public opinion (e.g., the relative importance of different factors in selecting the best construction alternative) in the decision-making and planning process of the projects.

To determine the relative importance of the considered criteria in the decision-making process (I_n), the social team was tasked with and guided through designing a brief survey questionnaire, to ask for the opinions and suggestions of the residents of Walden Ponds community. The survey was designed online on Qualtrics XM. To make the collected data unidentifiable, no personal information was collected in the survey questionnaire. The main purpose of the survey was to ask the two most important criteria in the view of Walden Ponds community. The results were aggregated automatically by Qualtrics, and linear scaling was used to determine the relative importance of each criterion based on the number of times it was selected by the respondents. Despite its simplicity, linear scaling provides reasonably accurate results for metric development [44–46]. This step requires public engagement, which results in the consideration of their opinion in the decision-making process.

3.4.3. Step 4-(d): Multi-Attribute Assessment–2 (A_n)

Multi-attribute assessment–2 (A_n) consists of three different analyses to determine technical/design, quality, and social/environmental attributes. Through multi-attribute assessment–2 (A_n) the available alternatives are compared with each other in a hierarchical fashion. Under each attribute, there are a number of dimensions, and each dimension is quantified based on a set of metrics. For instance, as elaborated in the next sub-section, the technical attribute has three dimensions, i.e., safety, logistic needs, and project duration. Logistic needs of each alternative are quantified based on three metrics, i.e., equipment needs, space requirements, temporary structures. After assigning metric scores and calculating dimension scores, the students used a geometric average formula to determine the attributes, A_n, based on the associated dimensions, D_m [47]:

$$A_n = \left(\prod_{m=1}^{M} D_{nm}\right)^{\frac{1}{M}} \quad (2)$$

where M is the number of dimensions, and n refers to alternative n. This formula assumes equal weights for the dimensions of each criterion. For instance, noise pollution and vibration caused by construction equipment are two dimensions for the social/environmental criterion. The weight of these two dimensions were considered to be the same. However, the weight of the social/environmental criterion in the overall benefit for an alternative, i.e., *TAI*, was determined using the survey questionnaire, as discussed in the previous section. It should be noted that the survey questionnaire only asked for the relative importance of the criteria and did not cover the importance of the dimensions under each criterion. This limitation can be addressed in future research studies.

Different student groups were involved in identifying the technical/design, quality, and social/environmental attributes for each alternative, as described below.

Technical/Design Attribute (T_i)

The objective of this analysis was to select the alternative that created minimal risk, constraints, as well as logistic issues and construction duration. The design and planning teams worked together to determine the overall technical/design score of each alternative i, T_i, based on safety risk (S_i), logistic needs (L_i), and duration (D_i), of the drainage and retaining wall rehabilitation alternatives using Equation (3):

$$T_i = C_T \times (Safety\ Risk\ (S_i) \times Logistic\ Needs(L_i) \times Duration(D_i))^{-1/3} \quad (3)$$

where C_T is a normalization factor to convert the technical/design scores given to alternatives to lie between 0 and 1. It should be noted that since higher safety risks, logistic needs, and duration are negative characteristics, a negative exponent has been used in Equation (3). The design team evaluated the risk and safety issues, while the planning team focused on evaluating the construction and logistic issues.

Safety Risk (S_i)

The design team was instructed to conduct a risk analysis to evaluate the type and the nature of the risks to the workers and the residents of the nearby communities for each alternative. Students in the design team quantified risk as the product of severity and chance of the potential adverse consequences (e.g., exceeding capacities such as the failure of the structure or overflow of the drainage). The severity and chance of adverse consequences were quantified with numbers, taking integer values between one and four [48,49]. Accordingly, the final risk score for each alternative was obtained by multiplying the score of chance and severity by subjective scoring of the proposed alternatives with respect to different risks (e.g., exceeding capacities such as the failure of the structure or overflow of the drainage). The final risk score for each alternative was obtained by summing over the product of the scores of the chance and severity of the risks for that alternative.

Duration (D_i)

To estimate the duration of the work, the planning team first developed the work breakdown structure (WBS). Next, the quantity and duration of the construction works associated with each task listed in the WBS were determined using standard data referenced in RS means [50]. In the end, the critical path method was used to determine the total construction duration based on the inter-dependency of the tasks using Microsoft Project.

Logistic Needs (L_i)

Construction might not go according to the plan due to site-specific and design-specific issues faced during the construction. According to Patty and Denton [51], equipment requirements and unforeseen work are the major areas of unforeseen project costs. Therefore, the planning team was asked to conduct a logistic assessment. The students identified three important factors, i.e., equipment needs, temporary structures, and storage requirements, and ranked the alternatives based on these three criteria.

Quality Attribute (Q_i)

The design team also evaluated the durability of each of the alternatives over the long term. To that end, the students in the design team used the same risk assessment approach used for characterizing safety risks. They compared the alternatives based on three durability risks, i.e., risk of overflow, risk of structure failure, and erosion. They determined the durability risk, and then the quality attribute for each of the alternatives using Equation (4):

$$Q_i = C_Q \left(Durability\ Risk_i\right)^{-1} \tag{4}$$

where C_Q, is a constant to convert the scores assigned to alternatives so that the maximum quality score for the alternatives becomes equal to 1.

Social/Environmental Attribute

The social team was asked to conduct a social/environmental analysis to determine the level of disturbance that each of the proposed alternatives will cause to the residents. The students leveraged the findings of experimental studies on the level of noise [52,53] and vibration [54,55] made by construction equipment to quantify the level of disturbance associated with the construction of the proposed alternatives. To that end, the social team used the type of machinery used for the construction activities and the duration of each activity to determine the generated level of noise and vibration. The list of activities and the duration of each activity were taken as inputs from the planning team.

The calculated noise and vibration were used to determine the social/environmental attribute, SE_i, of each alternative, as shown in Equation (5):.

$$SE_i = \left(\frac{C_{SE}}{\text{Vibration } (V_i) \times \text{ Noise}(N_i)}\right)^{\frac{1}{2}} \tag{5}$$

where C_{SE} is the normalization factor so that the highest score is 1.

3.4.4. Step 4-(e): Benefit-Cost Analysis

The objectives of this analysis are twofold: (1) to determine the costs of each alternative, and (2) to leverage the *TAI*, the costs, and to identify the best alternative for drainage management and retaining wall rehabilitation. To address these two objectives, first, the planning team conducted a financial analysis to calculate the construction costs of each alternative. Next, the social/environmental team conducted a cost-benefit analysis to identify the best solution.

Cost Estimation

For cost estimation, the planning team used RS means software's cost database, WBS, and the construction schedule to estimate the costs. Based on the assumptions made by the students, the finalized costs include materials costs, labor costs, overheads and profits (O&P), and equipment costs in USD in 2018.

Benefit Analysis

Once the attribute scores of each alternative were determined through Step 4, the social/environmental team used Equation (6) to weight these attributes by their associated level of importance determined through multi-attribute assessment-1 (I_n) to calculate *TAI*, which serves as the basis for comparing alternatives.

$$TAI_i = \left(I_T \times T_i + I_{SE} \times SE_i + I_Q \times Q_i\right) \quad (6)$$

where T_i, S_i, and Q_i are the technical, social/environmental, and quality scores of alternative *i*. While I_T, I_S, and I_Q are the associated weight of these three attributes in decision making. It is worth mentioning that these weights are determined based on multi-attribute assessment-1 (I_n), which involves asking the relative importance of these factors in the view of the public through a survey questionnaire.

Having the costs associated with each alternative, the social/environmental team conducted an incremental analysis to evaluate the impact of incremental increases in the costs on the gained benefits. The incremental or marginal analysis is a simple approach that assists decision-makers by providing a visual representation of benefit versus cost trends [31]. It involves the evaluation of the differences between two options from diverse benefit and cost aspects [56]. After sorting alternatives based on their costs, decision-makers decide whether the marginal benefits are worth the marginal costs [57].

3.5. Step 5: Making the Final Decision

The ordered list of alternatives and the incremental analysis results were then communicated with the HOA representatives in a meeting to determine the final alternative. During the meeting, the instructor described the overall flow and the distribution of the feasibility assessment among student groups. This was followed by presentations given by all members of each student group. During the presentation, the students described their assumptions, logic, and details of multi-attribute assessment-1 and multi-attribute assessment-2. The presentation was concluded by the cost-benefit analysis and incremental analysis results.

4. Case Study Results

This section elaborates on the outcomes of the case study conducted by the students. The students were engaged with the representatives of the homeowners in the Walden Ponds community throughout the semester to identify the best-value solutions for the needs of the residents.

4.1. Step 1: Problem Definition

As discussed, one of the class sessions was assigned to engage the students with the HOA representatives. The representatives communicated their needs and concerns with the students. The Walden Ponds subdivision, Carmel, IN, was developed in the 1980s on the site of a former outdoor movie theater. Overall, the subdivision is approximately 38 acres with 145 single-family houses. The existing retaining walls made by timber were projected to have a 70-year life. Nevertheless, in the middle of its lifespan, the timbers have deteriorated prematurely due to the water clogging in the absence of stormwater drains. There were, hence, two major objectives for the decision-making process: to identify solutions for (1) retaining wall rehabilitation and (2) drainage management.

The HOA representatives also mentioned the resources for the project, e.g., funding and management resources to do a mass mailing for the residents, funding for transportation of the students to do a site visit, and supplemental funding for necessary data acquisition or other activities. In addition to the presentation, the HOA representatives talked about the different dimensions of the project, e.g., social, technical, and planning, with the respective group. This helped the students get more insights into the problem and the owner's needs and constraints.

4.2. Step 2: Analyzing the Problem and Field Testing

As discussed, the leaders of the groups were then tasked with communicating the outcomes of the site visit with the rest of their own teams. Figure 2 shows the pictures taken through site investigation. As Figure 2a shows, the wooden wall has deteriorated significantly. In some cases, supplemental wood posts have been installed to maintain the integrity of the retaining wall, as shown in Figure 2b. Additionally, there was a risk of a retaining wall failure due to the loss of anchoring. This would lead to a landslide which, in turn, could cause damage to at least four houses that are located remarkably close to the retaining wall. Due to the unappealing look of the wall and water logging in the absence of stormwater drains, there was a risk for the property values to dwindle.

(**a**) (**b**) (**c**)

Figure 2. Site Investigation. (**a**) Water intrusion (1); (**b**) support post; (**c**) water intrusion (2).

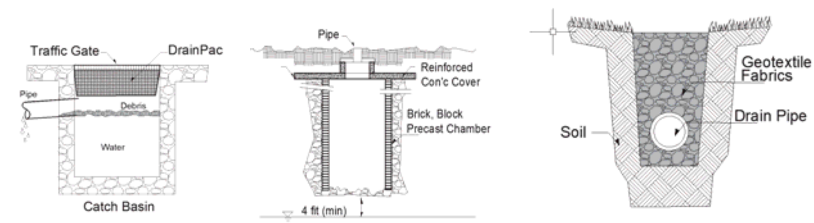
Another part of the site visit was dedicated to the data collection from drones. A total of 646 images were collected on these flights on 29 February 2020. Since the onboard GPS of the Mavic Pro was not accurate enough to generate precise aerial maps, eight ground control points (GCPs) were surveyed using a survey-grade Trimble R10 real time kinematics (RTK) GPS (Figure 3).

Figure 3. Spatial distribution of GCPs over the study area.

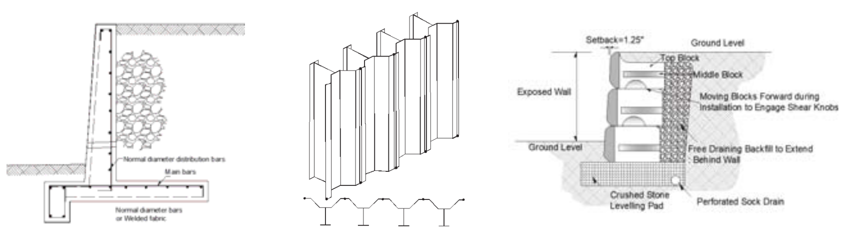
The generated fine spatial resolution 3D aerial maps were used for the technical/design analysis, to extract the geometric dimensions and identify the amount of work for particular drainage management alternatives.

4.3. Step 3: Engineer Alternative Solutions

After the site visit, the students had regular meetings with their instructor in their technical team, to communicate their issues and concerns and finalize the solution alternatives for solving (1) the drainage problem and (2) retaining wall rehabilitation. As Figure 4 shows, three different alternatives were proposed for each of the problems.



(**a**) Catch basin (**b**) Dry well (**c**) French drain



(**d**) Concrete cantilever retaining wall (**e**) Steel sheet piles (**f**) Redi-Rock wall

Figure 4. Proposed solutions for drainage management and retaining wall rehabilitation.

4.4. Step 4: Alternative Evaluation

Students were instructed to use simple additive weighting (SAW) MCDM to evaluate the identified alternatives. To conduct the MCDM, it is necessary to (1) identify the criteria, (2) identify solution alternative scores with respect to each criterion, and (3) determine the weight for each criterion. To that end, the student groups worked with each for the different tasks, as described below.

4.4.1. Step 4-(a): Identifying Criteria

The students were asked to identify the criteria for comparing the identified alternatives based on the existing MCDM frameworks and studies. For brevity, only a couple of the references reviewed by the students are provided as samples.

A review study of 105 hydropower plant feasibility studies used 3 broad criteria, i.e., technical, economic, and social/environmental [58]. A study regarding the environmental and community risks of a solar power plant construction sites in Australia [35] considered technical (e.g., transport of supplies to site and site access), social (e.g., disruption to the community and community acceptance), and environmental (e.g., noise, dust and air quality, drainage, and water management) criteria. The community was engaged only during the construction phase, and the agenda and minutes were published [35]. Another study on sustainable building assessment/certification recommended including noise pollution in the decision-making process [59].

Students selected the attributes and dimensions related to their focus based on the literature. As Table 3 shows, the identified criteria consider a wide range of aspects. As the table shows, the alternatives are compared based on the criteria in a hierarchical fashion. Under each criterion, there are a number of dimensions, and each dimension is quantified based on a set of metrics. For instance, the technical criterion has three dimensions, i.e., safety, logistic needs, and project duration. The logistic needs of each alternative are quantified based on three metrics, i.e., equipment needs, space requirements, and temporary structures.

Table 3. Criteria selected by the students.

Criteria	Dimension	Metric	Associated Student Team
Technical	Safety	• Excavation failure • Trip and fall • Collapse	Design team
	Logistic issues	• Equipment needs • Space requirements • Temporary structures	Planning team
	Project duration	NA	Planning team
Quality	Durability	• Risk of overflow • Failure of the structure • Erosion	Design team
Social/ environmental	Disturbance to local community	• Vibration • Noise	Social team

4.4.2. Step 4-(b),(c): Multi-Attribute Assessment–1 (I_n)

As discussed, to determine the criteria weights in the decision-making process (I_n), a brief survey was designed by the social team and was distributed, with the assistance of the HOA representatives, among the Walden Ponds community. The survey consisted of multiple-choice questions and a total number of 135 responses were collected. In addition to multiple-choice questions, the opportunity for providing comments was also provided so that the respondents could share their suggestions or extra information related to the question as well as the project, such as potential candidate sponsors for the project. Table 4 summarizes a selected number of survey questions and their associated target. Question 1 was aimed at identifying the relative importance of the criteria identified in previous stages, while the second question was asked for fundraising purposes.

Figure 5 shows the response of the participants to the first question of the survey. As demonstrated in Figure 5, safety, quality, and disturbances have been selected as the most important factors in 48, 43, and 9 percent of the responses, respectively. These ratios (0.48, 0.43, and 0.09) were used to determine the relative importance (I_n) of the criteria of technical, quality, and social/environmental factors in Equation (1).

Table 4. The survey questionnaire.

Scope	Description	Target
Social and environmental	Q1. Please choose the two factors that are most important to you (a) safety (b) quality (c) disturbance	Priorities
Financial	Q2. Which payback period would prefer for bearing the expenses incurred due to the repair or rehabilitation of the Suda wall? (a) one-time payment (b) bi-weekly (c) monthly (d) annual	Funding/financing options

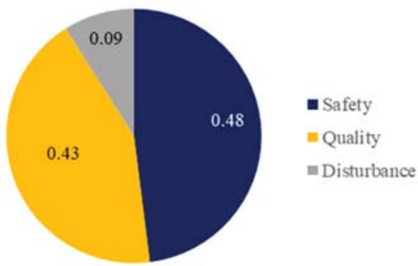


Figure 5. Priorities of the respondents.

The benefits of alternatives with respect to the considered attributes, A_n, were then determined through multi-attribute assessment–2 (A_n).

4.4.3. Step 4-(d): Multi-Attribute Assessment–2 (A_n)

This section presents the outcomes of the multi-attribute assessment–2 (A_n), which was aimed at identifying the benefits of each alternative. The multi-attribute assessment–2 (A_n) consists of three different analyses to determine technical/design, quality, and social/environmental attributes.

Technical Attribute

The design and planning teams worked together to determine the overall technical/design score of each alternative i, T_i, based on the safety risk (S_i), logistic needs (L_i), and duration (D_i) of the drainage and retaining wall rehabilitation alternatives using Equation (3).

Safety Risk

To evaluate the type and the nature of the risks to the workers and the residents of the nearby communities for each alternative, the design team conducted a risk analysis. To that end, the students in that team assigned a subjective score to the severity and probability of various potential risks, i.e., excavation failure, trip and fall, and collapse. The final risk score for each alternative was obtained by multiplying the score of chance and severity of the proposed alternatives (Table 5).

It is worth mentioning that more advanced tools such as virtual reality and augmented reality can be used for characterizing the workers' safety during the construction period [60–62].

Table 5. Technical/design analysis–safety risks associated with each alternative.

Problem	Dimension	Metric	Alternative 1			Alternative 2			Alternative 3		
			French Drain			Catch Basin			Dry Well		
			Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)
Drainage	Safety	Excavation failure	3	3	9	3	3	9	4	3	12
		Trip and fall	2	2	4	2	2	4	2	2	4
		Collapse	3	2	6	1	3	3	1	3	3
		Total			19			16			19
Retaining Wall			Concrete Wall			Steel Sheet Piles			Redi-Rock Wall		
			Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)
	Safety	Excavation failure	3	4	12	2	3	6	3	4	12
		Shoring risks	3	4	12	3	4	12	3	4	12
		Failure of the wall	1	4	4	1	4	4	2	4	8
		Total			28			22			32

Duration

The planning team used Microsoft Project and RS means [50] to determine the duration of construction for different alternatives. Table 6 shows the duration of the French drain as a sample. For the sake of brevity, the duration of the retaining wall rehabilitation alternatives as well as a sample schedule chart, is provided in Appendix A.

Table 6. Technical/design analysis–duration of each activity for French drain alternative.

Description		Qty.	Unit	Daily Output	Duration (Days)	Adjusted Duration (Day)
1. Excavation (excavating, trench or continuous footing, dense hard clay, 3/8 C.Y. excavator)	Main	179.0	B.C.Y.	132.00	1.36	2.00
	Arterial	98.94	B.C.Y.	132.00	0.75	
2. Pipe laying (public storm utility drainage piping, corrugated metal pipe)	Main	1611.0	L.F.	330.00	4.88	8.00
	Arterial	890.50	L.F.	330.00	2.70	
3. Backfill (excavating, trench backfill, 1 C.Y bucket, minimal haul, front end loader)	Main	110.25	L.C.Y.	200.00	0.55	1.00
	Arterial	38.80	L.C.Y.	200.00	0.19	
4. Soil compaction and finishing		-	-	-	1.00	1.00
Total duration					10.43 days	12 days

Logistic Needs

The students identified three important factors, i.e., equipment needs, temporary structures, and storage requirements related to logistic needs. They ranked the alternatives based on these three criteria, as summarized in Table 7.

Table 7. Technical/design analysis—logistic needs.

Problem	Dimension	Metric	Alternative 1	Alternative 2	Alternative 3
			French Drain	Catch Basin	Dry Well + Catch Basin
Drainage	Logistic needs	Equipment needs	3	1	2
		Space requirements	3	1	2
		Temporary structures	2	1	3
		Total	7	3	8

Table 7. *Cont.*

Problem	**Dimension**	**Metric**	**Alternative 1**	**Alternative 2**	**Alternative 3**
			French Drain	**Catch Basin**	**Dry Well + Catch Basin**
			Concrete wall	Steel sheet piles	Redi-Rock wall
Retaining wall	Logistic needs	Equipment needs	1	3	2
		Space requirements	1	2	3
		Temporary structures	3	2	1
		Total	5	7	6

Overall Technical Score

The students in the design and planning teams determined the final technical/design score for each alternative, as shown in Table 8. It is worth mentioning that the constant values in the formulas, i.e., 8.77 and 16.95, are for normalizing the overall technical scores between 0 and 1.

Table 8. Technical/design analysis—overall score.

Problem	**Dimension**	**Alternative 1**	**Alternative 2**	**Alternative 3**
		French Drain	**Catch Basin**	**Dry Well + Catch Basin**
Drainage	Safety	19	16	16
	Logistic needs	7	3	8
	Duration	12	14	15
	8.77/(safety × logistics × duration)$^{0.33}$	0.754	1.000	0.702
		Concrete wall	Steel sheet piles	Redi-Rock wall
Retainingwall	Safety	28	22	32
	Logistic needs	5	7	6
	Duration	98	42	25
	16.95/(safety × logistics × duration)$^{0.33}$	0.712	0.915	1.000

Quality Attribute

The design team evaluated the durability of each of the alternatives over the long term based on three durability risks, i.e., risk of overflow, risk of structure failure, and erosion. They determined the durability risk, and then the quality attribute for each of the alternatives using Equation (4). The outcomes are summarized in Table 9. *The constant* C_Q, 12.05, is multiplied to normalize quality scores between 0 and 1.

Social/Environmental Attribute

The social team used the type of machinery used for the construction activities and the duration of each activity to determine the generated level of noise and vibration. The list of the activities and the duration of each activity were taken as inputs from the planning team. As a sample, Table 10 summarizes the noise (in dBA) and vibration (quantified by the peak particle velocity reported in "in/sec") for the French drain.

Table 9. Quality attribute of each alternative.

Problem	Dimension	Metric	Alternative 1			Alternative 2			Alternative 3		
			French Drain			Catch Basin			Dry Well		
			Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)
Drainage	Durability	Risk of overflow	2	2	4	2	2	4	2	2	4
		Failure of the structure	3	3	9	1	3	3	1	3	3
		Erosion	2	4	8	2	4	8	1	4	4
		Durability risk			21			15			11
		10.99/(durability risk)			0.528			0.736			1.000
Problem	Dimension	Metric	Concrete Wall			Steel Sheet Piles			Redi-Rock Wall		
			Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)	Chance (C)	Severity (S)	Total (C × S)
Retaining Wall	Durability	Material deterioration	1	2	2	3	2	6	2	2	4
		Failure at joint	1	4	4	1	4	4	1	4	4
		Foundation settlement	2	3	6	2	3	6	3	3	9
		Durability risk			12			16			17
		12.05/(durability risk)			1.000			0.759			0.711

Table 10. The level of noise and vibration of French drain.

Option	Activity		Adjusted Duration (days)	Noise			Vibration		
				Equipment	Intensity (dBA)	Total	Equipment	PPV + (in/sec)	Total
French drain	Excavation (excavating, trench or continuous footing, dense hard clay)	Main line	2.00	Excavator	78.25 *	156.5	Excavator/loader/backhoe	0.008 ***	0.016
		Arterial		Excavator	78.25 *				
	Pipe laying	Main line	8.00	Movable crane	77 **	616	Crane	0.007 ***	0.056
		Arterial		-					
	Backfill (excavating, trench backfill, 1 C.Y bucket, front end loader)	Main line	1.00	Excavator	78.25 *	78.25	Excavator/loader/backhoe	0.008 ***	0.008
		Arterial		Excavator	78.25 *				
	Soil compaction and finishing		1.00	Vibrating roller	76.07 *	76.07	Vibratory compactor	0.209 ***	0.209
			12.00			926.8			0.29

+ Peak particle velocity, * based on [52], ** based on [53], *** based on [63].

It should be noted that the estimates for the noise and vibration were measured at a specific distance from the machinery, which is appropriate for comparison purposes. Repeating the same procedure for the remaining alternatives and using Equation (5), the social/environmental scores of the alternatives are determined by calculating the geometric average of the noise and vibration produced by each alternative, as demonstrated in Table 11. Like the technical and quality scores, the social/environmental scores were scaled between 0 and 1 using constant multipliers, i.e., 16.37 and 29.66.

Table 11. Social/environmental scores.

Problem	Attribute	Dimension	Alternative 1	Alternative 2	Alternative 3
			French Drain	Catch Basin	Dry Well + Catch Basin
Drainage	Social/environmental	Noise	927	1008	1081
		Vibration	0.289	0.305	0.303
	16.37/[(Noise × Vibration)$^{0.5}$]		1.000	0.904	0.934
			Concrete wall	Steel sheet piles	Redi-Rock wall
Retaining Wall	Social/environmental	Noise	7887.52	449	3439.5
		Vibration	0.58	1.96	0.49
	29.66/[(Noise × Vibration)$^{0.5}$]		0.439	1.000	0.723

4.4.4. Step 4-(e): Benefit-Cost Analysis

Once T_i, SE_i, and Q_i were determined, the social/environmental team used Equation (6) to calculate the *TAI* for each alternative as the basis for comparing alternatives. Using the TAI and the costs associated with each alternative, the social/environmental team conducted a cost-benefit analysis to identify the best solution. To do that, the social team used the cost estimates provided by the planning team.

Cost Estimation

For brevity, only the cost estimates for drainage are presented in Table 12. A summary table for the costs associated with the retaining wall alternatives is provided in Appendix A.

Table 12. The estimated costs for drainage management solutions.

Drainage Type	Item	Quantity	Cost/Unit ($)	Total Cost ($)
Catch basins	18″ Catch basins (2 openings)	52 nos.	160	8320.00
	4″ Corrugated pipes	1880 feet	61.5/100 ft.	1156.20
	4″ Corrugated pipes Couplers	19 nos.	4.2	79.80
	4″ Inlet/outlet T fittings	32 nos.	6	192.00
	4″ Elbow fittings	20 nos.	5.7	114.00
	Drain excavation	52 catch basins + 2800 ft. drainage line	123.71/yd^3	22,960.18
				$32,822.86
Dry wells	NDS flo-well	2 nos.	73.4	146.8
	Surface drain inlet with grate	2 nos.	31.85	63.7
	Landscape fabric (4′ × 200′)	1 roll	45	45
	4″ Inlet/outlet T fittings	2 nos.	6	12
	Excavation cost	2 wells + drainage line of 60 ft.	123.71/yd^3	16,225.06
				$16,492.5
French drain	EZ drain	2500 feet	50/50 feet	2500.00
	4″ Corrugated coupling	50	4	200.00
	4″ Corrugated end cap	18	3	54.00
	Excavation costs	2500 ft. drainage line (1.5′ × 2′)	123.71/yd^3	34,167.00
				$36,921.00

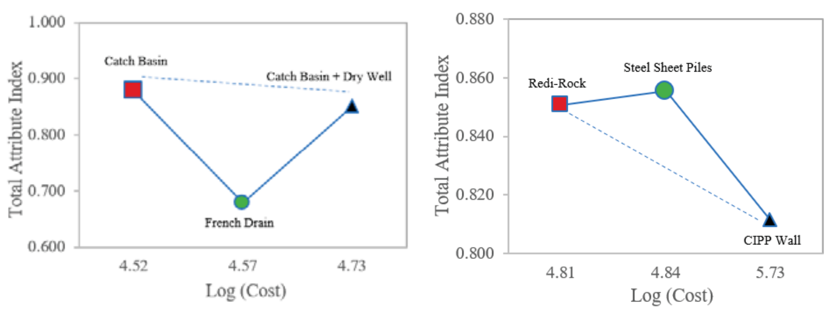
Benefit Analysis

The benefit of each alternative was measured based on the TAI, which was determined based on the technical/design, quality, and socio-environmental scores, weighted by their relative importance obtained from the survey questionnaire. Table 13 shows the TAI for each alternative.

Table 13. The benefits associated with the evaluated alternatives.

Problem	Attribute (A_n)	Weight (I_n)	Alternative		
			French Drain	**Catch Basin**	**Dry Well + Catch Basin**
Drainage	Technical and design	0.48	0.754	1.000	0.702
	Quality	0.43	0.528	0.736	1.000
	Socio-environmental	0.09	1.000	0.904	0.934
	TAI	1	0.679	0.878	0.851
			Concrete wall	Steel sheet piles	Redi-Rock
Retaining wall	Technical and design	0.48	0.712	0.915	1.000
	Quality	0.43	1.000	0.759	0.711
	Socio-environmental	0.09	0.439	1.000	0.723
	TAI	1	0.811	0.856	0.851

Figure 6a,b show the application of the incremental analysis to the selection of the best solution for drainage management and retaining wall rehabilitation, respectively. The vertical axis shows the TAI, while the horizontal axis shows the cost on a logarithmic scale. The costs are shown on a logarithmic scale to increase the readability of graphs.



(**a**) Drainage management (**b**) Retaining wall

Figure 6. Final alternative comparison.

As Figure 6a shows, the catch basin was proposed as the most appropriate solution for drainage management, as it has the highest benefit and the lowest cost. Regarding the retaining wall alternatives shown in Figure 6b, steel sheet piles turned out to be the alternative, with the highest benefit for retaining wall rehabilitation. However, Redi-Rock was the second-best alternative and had relatively lower costs. In this condition, the final decision becomes dependent on several factors, including the amount of money the county was willing to spend on solving the drainage issue. In the face of budget limitations, Redi-Rock can be seen an acceptable alternative with more affordable costs. Furthermore, presenting the advantages of each alternative with respect to each of the criteria, i.e., technical/design, quality, and social/environmental, would assist the decision-makers in making a more informed decision. To that end, the results of a more detailed incremental analysis were communicated to the owner, as discussed in the next section.

4.5. Step 5: Making the Final Decision

The prioritized list of alternatives as well as the incremental analysis results were communicated with the HOA representatives in the last session of the course to determine the final alternative. Figure 7 shows the detailed incremental analysis for each attribute of the retaining wall alternatives.

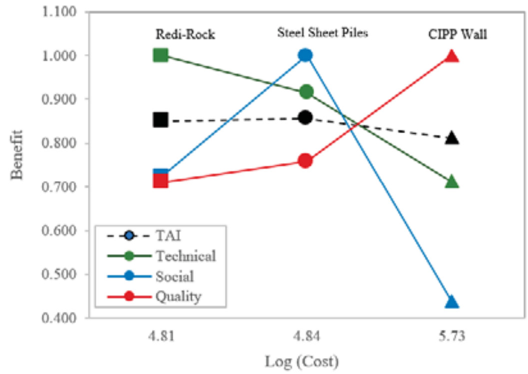


Figure 7. Incremental analysis for retaining wall alternatives.

As it can be seen in Figure 7, steel sheet piling had the highest TAI and social/environmental score, signifying that it would be the lowest inconvenience to the public. This alternative also had an acceptable durability over the long term. However, the risks that might occur during the construction were higher for this alternative as it involved pile driving, which could initiate z landslide or settlement for the buildings in the vicinity. This shows that engineers are more competent than the general public in elaborating on the social impacts of their work [36]. These insights were communicated to the HOA representatives and there were follow-up discussions with the owner, students, and the instructor. The owners decided to opt for the Redi-Rock alternative.

5. Proposed Framework for Students and Community Engagement

As discussed in the previous section, during the case study, the students were instructed to work in a team-based setting to provide recommendations for a construction project. During the process, the students learned to collaborate and communicate with each other as well as the owner of the project, and the HOA representatives from the Walden Ponds community, as an essential element of the decision-making process. Throughout this unique hands-on experience, the students were encouraged to engage the public in the decision-making process, not only through the consideration of social and environmental factors, but also through the incorporation of their opinions and judgments via the survey. This attitude can follow the students in their future careers as engineers.

Successful repetition of such an instruction approach can promote community engagement and reduce the negative externalities of construction projects in the long term. To that end, the utilized approach is presented in the form of a framework for educating engineering students to engage with the stakeholders for infrastructure projects. Figure 8 shows the proposed framework.

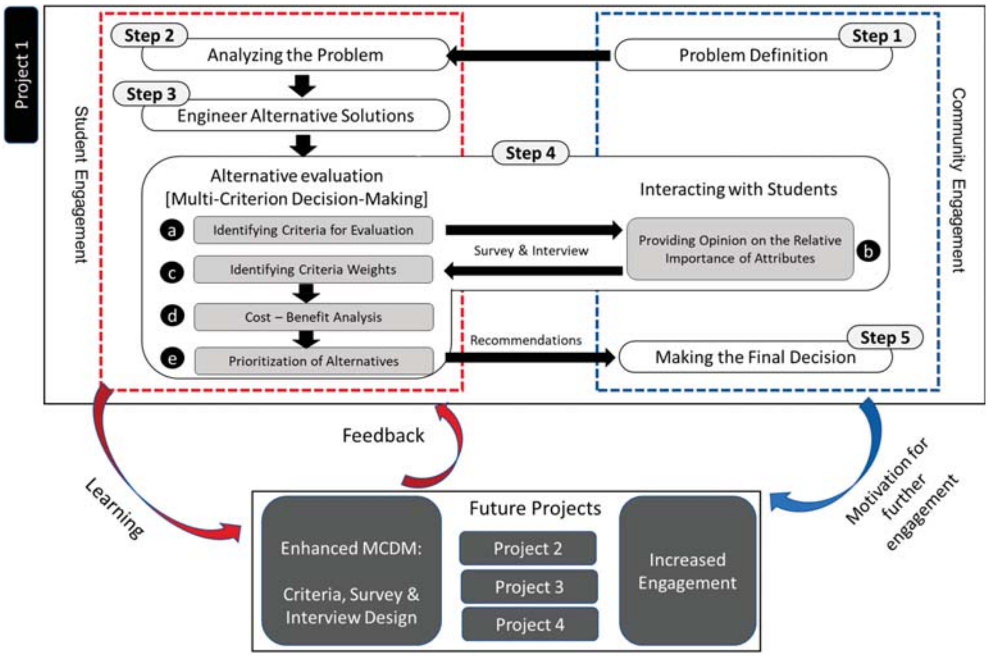


Figure 8. The proposed framework for engaging students with the stakeholders for infrastructure planning projects.

As Figure 8 shows, the steps of the proposed framework are (1) problem definition, which is initiated by the community to understand the needs, requirements, and constraints of the project, (2) analyzing the problem, (3) engineer solution alternatives for the problem, which involves the identification and engineering design of various alternatives, (4) evaluation of various alternatives with respect to several aspects, e.g., social, technical, and economic, while considering the public opinion with regards to the relative importance of the considered aspects, and (5) presenting and communicating the outcomes of the alternative evaluations to the client, while highlighting key advantages and disadvantages of the proposed alternatives, and determining the "best value" alternative in coordination with the project owner.

As demonstrated in Figure 8, the community is engaged in the decision-making process in three different steps, i.e., Steps 1, 4, and 5. The representatives of the public play a key role in communicating their problems, needs, constraints, and resources to the students in Step 1. In Step 4, public opinion on the relative importance of various criteria is acquired through a survey questionnaire. Lastly, in Step 5, the outcomes of the project such as the cost-benefit and incremental analysis results, are communicated to the public or their representatives.

The primary difference of the proposed framework from the existing body of knowledge is its ability to incorporate the needs of the community members in the decision-making process. Similar work such as Pellicer et al. [30] have also demonstrated procedures to include the preferences of the community members in infrastructure planning projects. However, in their case, the students only acted as community members and provided preferences. Whereas, in this work, the community members were actually engaged in the decision-making process. For enhancing the community engagement of engineering students, Segalàs et al. [64] made two recommendations, that (1) courses need to have a stronger focus on the social and institutional aspects of the projects and that (2) courses must apply a constructive and community oriented pedagogical approach.

As explained earlier and shown in Figure 8, the proposed framework incorporates these two recommendations. On the other hand, Wolcott et al. [65] suggested having a capstone project on the community engagement in the engineering curriculum to raise awareness on community engagement. The proposed framework also includes course projects for community engagement. In a nutshell, the proposed framework has commonalities with few existing frameworks on public engagement in infrastructure and planning and teaching community engagement to engineering students [66]. However, it builds on the existing frameworks in two major ways. First, it provides a step-by-step approach for raising awareness in students about the impact of public opinion on the planning of construction projects, and the existence of methods that can help them articulate participatory processes. This structured approach is replicable by future researchers. Furthermore, the framework offers a feedback loop, which provides the groundwork for the assessment of its improvements through its application to future projects. On one hand, such improvements can be in the form of an enhanced MCDM framework, criteria selection, survey and interview design, etc., as well as the training of future students to acquire the necessary set of skills and gain the attitude and behavior to engage the public in the decision-making process. On the other hand, observing their impact on the final decision can encourage the public to engage in future projects.

6. Conclusions

This study leverages the findings of a case study on the feasibility assessment of a real-world rehabilitation project to propose a framework for raising awareness among undergraduate and graduate engineering students toward increased engagement with the public. The case study served as an introductory exercise intended to raise awareness in the students of the impact that public opinion might have on the planning of construction projects, and to provide hands-on experience on the application of the existence of methods that can help them articulate participatory processes. In the case study, engineering graduate students collaborated with the instructor and the HOA representatives in a team-based setting. The case study intended to provide hands-on experience with the planning, analysis, design, development, and feasibility analysis. The students were divided into four groups of five students voluntarily. Each group evaluated certain dimensions of the problem. Throughout the case study, the students were engaged with the HOA representatives to identify the best-value solutions for the rehabilitation of an old retaining wall and improving the stormwater system in the community. The benefit analysis involved the determination of the benefits of each alternative with respect to technical/design, quality, and socio-environmental aspects. The determined benefits were then weighted based on the opinion of the residents of the Walden Ponds community and integrated into a benefit index, the *Total Attribute Index (TAI)*. The students communicated the outcomes of the alternative evaluation and incremental analysis to assist the HOA representatives to select the best-value option depending on the level of their available budget, as well as the trade-offs between social, technical, and quality aspects of various alternatives.

The approach used for the case study is then generalized in the form of a framework for educating engineering students to engage with the stakeholders for infrastructure projects. The proposed framework comprises five steps: (1) problem definition, (2) analyzing the problem, (3) engineer solution alternatives, (4) alternative evaluation, and (5) making the final decision. In the proposed framework, the public is engaged in the definition of the problem, the evaluation of the proposed alternatives, and making the final decision. Including public opinion in the quantitative weight of the MCDM facilitates reducing the negative externalities of construction projects in the long term.

The case study and the framework serve as an introductory exercise for raising awareness in students about the impact of public opinion on the planning of construction projects, through a step-by-step MCDM framework for incorporating public opinion in the feasibility assessment of an infrastructure project. This structured approach is replicable for future researchers. Furthermore, the framework offers a feedback loop, which provides the groundwork for the assessment of the observed improvements as a result of its application to future projects. Such improvements can be in the form of (1) an enhanced MCDM framework, criteria selection, survey, and interview design, etc., (2) training of future students to acquire the necessary set of skills and gain the attitude, and behavior to engage the public in the decision-making process, and (3) encouraging the public to engage in future projects.

Observing the impact of the feedback loop requires a longitudinal study, or at least a pre- and post-training evaluation after a course involving such case studies. Therefore, there is a need for developing a more thorough framework that includes an element for evaluating the effectiveness of the proposed approach in the training of students in the design and development of participatory processes for the planning of construction projects. This can be an opportunity for future research in this area. It is expected that the application of such comprehensive frameworks would help to interrupt the cycle of oblivion and promote a culture of accommodating public opinion among engineering students as future engineers in the long term.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Figure A1. Drainage layout for French drain.

Table A1. The construction work and duration of the alternatives for retaining wall rehabilitation.

Alternative	Activity	Quantity	Unit	Daily Output	Adjusted Duration
Sheet piling	Compaction of loose soil	-	-	-	1
	Utility drainage piping wyes/tees	100.00	Ea.	15	7
	Twisted pair cable (for sliding prevention)	100.00	C.L.F	7	15
	Hammering of sheets into place	1530.00	V.L.F.	540	3
					25 days
Redi-Rock	Excavation (1/2 CY excavator)	770.37	B.C.Y,	540	2
	Subgrade	2500.00	S.F.	800	4
	Assembling (flatbed trailer or boom truck)	8168.00	S.F.	205	40
	Backfilling	577.78	L.C.Y	650	1
					46 days
Concrete wall	Excavation	770.4	BCY	540	2
	Concrete 300 ksi (structural concrete gravity retaining wall)	7949.21	Ft^3		
	Footing	3656.64	Ft^3	125	30
	Wall	4292.57	Ft^3	125	35
	Cutting, bending, and placing of rebar	121.37		8	15.0
	Formwork (Pr.) (exterior shutter)	13,937.5	Ft^2		
	Footing	3484.38	SFCA	305	12
	Wall	10,453.13	SFCA	305	35
	De-shuttering	13,937.50	SFCA	1000	14.0
	Curing	139.38	C.S.F.	55	3.0
	Back filling	577.78	L.C.Y.	650	1
					98 days

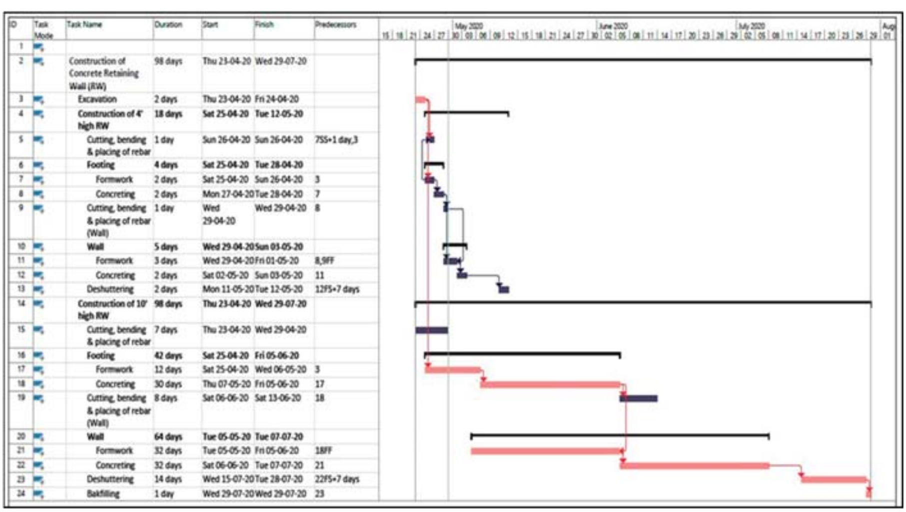

Figure A2. Sample schedule: the concrete wall alternative.

Table A2. The estimated costs for the construction of the retaining wall alternatives.

Alternative	Item	Qty.	Unit	Total Costs
Redi-Rock	Stone blocks, cut stones (28″ × 60″ × 96″)	153	Ton	$47,259.84
	Subgrade	2500	S.F.	$11,700.00
	Drainage piping underdrain fabric	100	Ea.	$4997.00
				$63,956.84
Sheet piling	Sheet piling, high strength steel piling, 50,000 psi	153 (32.2 tons)	Ton	$2244.66
	Steel plate (structural) for connections and stiffeners	1000	S.F.	$12,100.00
	Utility drainage piping wyes/tees	100	Ea.	$40,812.00
	Steel bolt, hex head, plain steel	1000	Ea.	$4500.00
	Twisted pair cable (for sliding prevention)	100	C.L.F	$9350.00
				$69,006.66
Concrete wall	Concrete 300 ksi (structural concrete gravity retaining wall)	7949.21	Ft^3	$68,303.69
	Rebar A36 (beam bolsters for reinforcing steel)	121.37	klb	$85,190.00
	Formwork (Pr.) (exterior shutter)	13,937.5	Ft^2	$336,912.00
	Pip underdrain wrapped 4″ (erosion control underdrain)	772.5	Ft	$42,976.70
				$533,382.39

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