MODELING THE CAUSAL FACTORS OF CHANGE ORDER APPROVAL DELAYS IN PUBLIC BUILDING PROJECTS IN ADDIS ABABA: A FUZZY AHP, DEMATEL AND QFD APPROACH

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A THESIS SUBMITTED TO THE FACULTY OF CIVIL TECHNOLOGY OF FEDERAL TECHNICAL AND VOCATIONAL TRAINING INSTITUTE IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CONSTRUCTION TECHNOLOGY AND MANAGEMENT

OFFICE OF GRADUATE STUDIES

FEDERAL TECHNICAL AND VOCATIONAL TRAINING INSTITUTE

FACULTY OF CIVIL TECHNOLOGY

DEPARTMENT OF BUILDING CONSTRUCTION TECHNOLOGY

JUNE, 2026

ADDIS ABABA, ETHIOPIA

Modeling the Causal Factors of Change Order Approval Delays in Public Building Projects in Addis Ababa: A Fuzzy AHP, DEMATEL AND QFD Approach

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A Thesis Submitted to the Faculty of Civil Technology of Federal Technical and Vocational Training Institute in Partial Fulfillment of the Requirements for the Degree of Master of Science in Construction Technology and Management

Office of Graduate Studies

Federal Technical and Vocational Training Institute

Faculty of Civil Technology

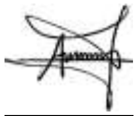
Department of Building Construction Technology

June, 2026

Addis Ababa, Ethiopia

DECLARATION

This thesis, " Modeling the Causal Factors of Change Order Approval Delays in Public Building Projects in Addis Ababa: A Fuzzy AHP, DEMATEL QFD Approach" is entirely original with no submissions to other universities for a similar purpose, I, Ayenew Melese, certify. Appropriate citations acknowledge the references used in this thesis.



Ayenew Melese	________	13-06-2026
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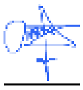
RECOMMENDATION OF ADVISORS/ SUPERVISORS

This research major advisor and supervisor, Meseret Getnet [PhD], attests that I have closely advised and supervised the student throughout its development. I have also read the draft thesis, " Modeling the Causal Factors of Change Order Approval Delays in Public Building Projects in Addis Ababa: A Fuzzy AHP, DEMATEL and QFD Approach " which was created under my direction. As a result, I advise sending the thesis to the department for additional assessment.

Meseret Getnet [PhD]		13-06-2026
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I thus attest that Ayenew Melese’s final thesis, " Modeling the Causal Factors of Change Order Approval Delays in Public Building Projects in Addis Ababa: A Fuzzy AHP, DEMATEL and QFD Approach" appropriately incorporates the committee's recommendations and suggestions.

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As members of the Board of Reviewers for Ayenew Melese's open defense we, the undersigned, have read and assessed the thesis titled " Modeling the Causal Factors of Change Order Approval Delays in Public Building Projects in Addis Ababa: A Fuzzy AHP , DEMATEL and QFD Approach" and determined the candidate's level of comprehension of the research. Thus, this certifies that the thesis or dissertation thesis has been approved and that we advise putting it into practice.

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Acknowledgement

First and foremost, I would like to express my deepest gratitude to Almighty God and the Holy Virgin Mary for giving me strength, wisdom, health, patience, protection, and guidance throughout my academic journey and for helping me successfully complete this thesis. Without their blessings and mercy, this achievement would not have been possible.

I would like to extend my sincere and heartfelt appreciation to my advisor, D/r Meseret Getnet, for his continuous support, valuable guidance, constructive comments, encouragement, and professional advice throughout the entire research process. His commitment and willingness to support me greatly contributed to the successful completion of this study.

I would also like to thank all experts, respondents, colleagues, friends, and my family members who provided important support, encouragement, and cooperation during the course of this research.

Finally, I would like to appreciate my own commitment, perseverance, patience, and hard work throughout the challenging journey of this research. Completing this thesis has been a valuable academic and personal achievement for me.

May Almighty God bless all those who contributed directly or indirectly to the success of this thesis.

ABSTRACT

Change orders are inevitable in construction projects; yet prolonged approval delays continue to undermine the performance of public building projects in Addis Ababa. These delays frequently cause substantial cost overruns, repeated schedule extensions, quality compromises, and contractual disputes, thereby diminishing the value of public infrastructure investments. Previous local studies identified change orders as a major issue but relied mainly on descriptive statistical methods that offered limited insight into causal interrelationships and actionable solutions. This study developed a comprehensive causal modeling framework integrating the Delphi technique, Fuzzy Analytic Hierarchy Process (FAHP), Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL), and Fuzzy Quality Function Deployment (FQFD). A two-round Delphi process with experienced professionals validated ten critical factors. Fuzzy AHP prioritization, based on expert judgments from fifteen professionals, revealed client-initiated scope changes and additional orders as the highest-ranked factor (normalized weight = 0.178), followed by financial problems of the client (0.158) and multi-level bureaucratic approval layers (0.141). These three factors together accounted for nearly 48% of the total weight. Fuzzy DEMATEL analysis identified five root driver factors, with bureaucratic approval layers showing the strongest causal influence (highest D–R value). Poor logistics and material supply control emerged as the central bottleneck in the influence network. A causal-chain model was developed illustrating how institutional and client-related root causes propagate through the system to create approval delays. Fuzzy QFD then translated these findings into prioritized mitigation strategies. The top interventions included establishment of a dedicated Change Control Committee, implementation of a one-stop digital approval portal, adoption of BIM-enabled digitalization, provision of ring-fenced budgets for variations, and incorporation of automatic price-escalation clauses. This study provides systemic causal insights and practical, evidence-based recommendations to reduce change order approval delays in Ethiopia's public building sector.

Keywords: Change order approval delays, Fuzzy AHP, Fuzzy DEMATEL, Fuzzy QFD, causal-chain model, public building projects, Addis Ababa, Ethiopia

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List of Acronyms and Abbreviation

AHP – Analytic Hierarchy Process

BIM – Building Information Modeling

COA – Center of Area

CPI – Consumer Price Index

CR – Consistency Ratio

D – Dispatched Influence (DEMATEL)

DEMATEL – Decision-Making Trial and Evaluation Laboratory

FAHP – Fuzzy Analytic Hierarchy Process

FDEMATEL – Fuzzy Decision-Making Trial and Evaluation Laboratory

FQFD – Fuzzy Quality Function Deployment

GDP – Gross Domestic Product

ILO – International Labour Organization

KPI – Key Performance Indicator

MCDM – Multi-Criteria Decision-Making

QFD – Quality Function Deployment

R – Received Influence (DEMATEL)

RII – Relative Importance Index

SLA – Service Level Agreement

T – Total-Relation Matrix (DEMATEL)

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The construction industry serves as a vital engine of economic growth and national development, particularly in emerging economies like Ethiopia. It plays a critical role in delivering public infrastructure, building facilities, and essential social services. However, the industry is inherently complex, dynamic, and uncertain, which makes construction projects highly susceptible to various systemic challenges that can adversely affect overall project performance. Among the most significant and recurring challenges is the management of change orders, also traditionally referred to as variation orders. Change orders are formal modifications to the original project scope, design, specifications, quantities, or contractual conditions. Change orders are often impossible to avoid due to changing client needs, unexpected site conditions, design mistakes, or new regulations (Arain & Pheng, 2006) however, handling them poorly especially when the approval process gets dragged out creates severe bottlenecks. These delays trigger a domino effect of cost overruns, extended project timelines, low productivity on site, poor quality control, and intense legal disputes between parties (Gunduz & Mohammad, 2018; Love & Peter Edwards, 2002).

In public construction projects, the change order approval process is particularly problematic. It typically involves multiple stakeholders, hierarchical decision-making structures, and extensive bureaucratic procedures. Delays in granting formal approvals often disrupt ongoing construction activities, postpone contractor payments, escalate claims, and introduce severe uncertainty among project participants. In developing countries such as Ethiopia, these challenges are further intensified by institutional constraints, weak coordination among stakeholders, inadequate documentation practices, and lengthy administrative processing systems.

The study focuses exclusively on factors affecting the duration of the change-order approval process. Although several variables were initially identified from studies investigating change-order occurrence, they are included in this research only after expert validation confirmed their relevance to approval delay mechanisms. Thus, the unit of analysis is the change-order approval process rather than the occurrence of change orders.

Ethiopia has made substantial investments in public building projects to support urban development and socioeconomic transformation. Nevertheless, many of these projects continue to suffer from poor performance directly linked to unresolved change orders. Local studies have consistently identified change orders as a major contributor to project delays and cost escalation in Addis Ababa. For instance, Andualem (2014) highlighted design modifications, inadequate working drawings, and errors in design documents as primary causes of variations. Similarly, Dejene (2020) and Girum (2022) pointed out that scope changes, contractual inconsistencies, and insufficient project planning significantly undermine project success.

While previous local studies have provided useful insights into the isolated causes and impacts of change orders, most have relied strictly on descriptive statistical methods such as the Relative Importance Index (RII), mean score analysis, and frequency rankings. Although these techniques are effective for initial problem identification and individual factor prioritization, they are limited in explaining the complex causal relationships, feedback loops, and interdependencies among the various factors influencing change order approval delays. In practice, the approval process for change orders in public building projects functions as a highly intricate and dynamic decision-making system. It is shaped by the continuous and complex interactions among various interrelated elements, including technical, managerial, contractual, organizational, and institutional factors.

Delays rarely result from a single isolated cause; instead, they emerge from the combined, interactive effects of multiple interrelated root factors. This creates a significant knowledge gap regarding the underlying causal structure and influence patterns of change order approval delays in the Ethiopian construction context.

To address this gap, the present study develops a robust, integrated framework that combines the Delphi method with Fuzzy Multi-Criteria Decision-Making (FMCDM) tools. Specifically, this research utilizes the Delphi Technique to screen and validate critical factors, followed by an integrated Fuzzy Analytic Hierarchy Process (FAHP), Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL), and Fuzzy Quality Function Deployment (FQFD) approach. This comprehensive methodology enables the identification and prioritization of the most critical factors, the mapping of cause-effect relationships and influence directions, and the direct translation of these findings into targeted, actionable engineering and administrative mitigation strategies for more effective change order management in public building projects across Addis Ababa.

1.2. Statement of the Problem

Delays in approving change orders remain one of the most serious challenges facing public building projects in Addis Ababa. These delays frequently result in substantial cost overruns, repeated schedule extensions, quality problems, and contractual disputes, thereby reducing the value of public infrastructure investments (Dejene, 2020).

Local evidence highlights the magnitude of the issue. Andualem (2014) identified variation orders as a major contributor to schedule delays and cost increases, while Dejene (2020) reported that more than two-thirds of the studied projects suffered significant cost overruns and time extensions due to slow evaluation and approval processes. Girum (2022) also noted a sharp rise in claims and disputes linked to frequent scope and design changes.

Although previous studies have drawn attention to the problem, most relied on descriptive statistical methods such as the Relative Importance Index (RII) and mean score analysis. These approaches are useful for identifying individual factors but fall short in revealing the complex causal interrelationships and feedback loops among them. Consequently, they provide limited actionable solutions for addressing the root causes of approval delays. This creates a critical research gap, particularly in the context of Addis Ababa's public projects, where multi-layered bureaucracy, institutional constraints, and poor stakeholder coordination turn change order approval into a highly intricate and prolonged process.

The concern of this study is not why change orders occur, but why the approval process becomes delayed after a change order has been initiated. Therefore, factors identified from the broader change-order literature are re-examined according to their influence on approval-delay performance.

The present study addresses this gap by developing a comprehensive causal modeling framework that integrates the Delphi technique, Fuzzy Analytic Hierarchy Process (FAHP), Fuzzy DEMATEL, and Fuzzy QFD. This approach identifies and prioritizes critical factors, maps their cause-effect relationships, and translates the findings into practical, prioritized mitigation strategies to improve change order approval processes in Addis Ababa's public building projects.

1.3. Research Questions

The following research questions were answered in the study:

i. What are the most critical factors influencing change order approval delays in Addis Ababa's public building projects as validated by a multi-round expert consensus?
ii. How do these critical factors rank in terms of their perceived importance in causing approval delay, according to experienced industry professionals?
iii. What are the underlying causal structure and influence relationships among the critical factors affecting change order approval time?
iv. Which factors act as the fundamental 'causes' (drivers) and which are the resulting 'effects' within the change order approval process?
v. Which mitigation interventions should be prioritized to most effectively address the root-driver factors, and how can these solutions be systematically mapped for maximum impact?

1.3.1. Research Hypotheses

Although this study primarily adopts an exploratory causal modeling approach, several directional hypotheses were formulated based on the synthesis of existing literature and the observed realities of public construction projects in Addis Ababa. These hypotheses provide a theoretical foundation for the application of advanced methods such as Fuzzy DEMATEL, which is specifically designed to test and visualize causal relationships among complex factors. The hypotheses focus on the expected influence of major factor groups on change order approval delays.

H1: Client-related factors, particularly frequent scope changes and additional orders, exert the strongest positive influence on the duration of change order approval processes in public building projects.

H2: Financial constraints faced by the client, including delayed fund releases and inadequate budgeting for variations, significantly prolong change order approval times by creating uncertainty in decision-making.

H3: Multi-level bureaucratic and regulatory procedures involving government agencies act as a major root driver, amplifying delays through excessive coordination requirements and hierarchical approval layers.

H4: Contractor-related factors such as poor logistics and material supply control have a strong interdependent relationship with other factors and function as a central bottleneck that intensifies overall approval delays.

H5: Institutional and client-related root causes have greater causal prominence (higher driving power) than technical or site-specific factors, which tend to act more as effect factors in the change order approval system.

These hypotheses are not intended for conventional statistical testing but serve as guiding propositions that inform the structuring of pairwise comparisons in Fuzzy AHP and the construction of the direct-relation matrix in Fuzzy DEMATEL. By explicitly framing expected causal directions and influence patterns, they strengthen the theoretical rationale for employing fuzzy multi-criteria decision-making tools and help bridge the gap between descriptive findings in previous studies and the systemic causal analysis undertaken in this research.

1.4. Objectives of the Study

1.4.1. General Objective

The primary aim of this research is to develop and validate a comprehensive decision-making framework that identifies, prioritizes, and models the causal interrelationships among factors influencing change order approval delays in public building projects in Addis Ababa, and to propose targeted, evidence-based mitigation strategies for project managers and policymakers.

1.4.2. Specific Objectives

The specific objectives of the study are stated as follows:

i. To identify and reach expert consensus on the critical factors influencing change order approval delays in public building projects using a multi-round Delphi technique.
ii. To prioritize the identified factors based on their perceived importance by eliciting expert judgments using the Fuzzy Analytic Hierarchy Process (Fuzzy AHP).
iii. Analyze the causal interrelationships and influence structure among the critical factors using the Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) method.
iv. To develop a causal-chain model that classifies factors into cause-and-effect groups, thereby identifying the root-driver factors that trigger approval delays.

v. To prioritize strategic mitigation interventions using a Fuzzy Quality Function Deployment (FQFD) approach, mapping potential solutions against the root-driver factors identified in the causal-chain model.

1.5. Significance of the Study

This research holds significant implications for advancing both academic understanding and practical project management in the Ethiopian construction sector. Academically, the study addresses a critical gap by moving beyond descriptive analyses to develop a scientifically validated framework that elucidates the causal relationships among factors contributing to change order approval delays. By integrating Fuzzy AHP, Fuzzy DEMATEL and QFD methodologies, this research contributes novel insights into the complex dynamics of project delays, offering a more nuanced understanding than previously available studies, which primarily focused on factor identification and ranking. The development of a causal-chain model serves as a foundational piece of knowledge, providing a robust, evidence-based decision-making framework that can inform future research in construction project management, particularly in the context of developing economies.

From a practical standpoint, the findings of this study offer actionable insights for various stakeholders involved in public building projects in Addis Ababa. Project managers benefit from a clear identification of root-driver factors, enabling them to prioritize interventions and allocate resources more effectively to mitigate delays at their source, rather than merely addressing symptoms. Policymakers and government bodies can leverage the strategic mitigation framework to formulate targeted policies and improve existing procedural guidelines, fostering a more efficient and timely delivery of public infrastructure. Furthermore, consultants and contractors gain a deeper understanding of the interdependencies among delay factors, facilitating better collaboration and proactive risk management in project execution. Ultimately, by reducing change order approval times, this research aims to enhance project performance, minimize cost overruns and schedule slippages, and contribute to the successful realization of public value in Ethiopia's ambitious development programs.

1.6. Scope and Delimitations of the Study

This research is specifically scoped to model the causal factors contributing to change order approval delays within public building projects located in Addis Ababa, Ethiopia. The study focuses exclusively on the approval phase of change orders in publicly funded building construction projects executed under government procurement regulations.

For the purpose of this study, the change order approval process is operationally defined as beginning from the formal submission of a change order request (including supporting documentation such as technical justifications, cost estimates, and time impact analysis) by the contractor or consultant to the client or relevant approving authority. The process ends at the point of final formal approval or rejection, evidenced by the issuance of an official variation order or written communication authorizing (or denying) the implementation of the proposed change. This boundary includes all intermediate review, evaluation, negotiation, and bureaucratic clearance stages involving multiple government agencies, but excludes the subsequent implementation, valuation, and payment phases of the approved change.

Methodologically, the study is delimited to the application of integrated Fuzzy AHP, Fuzzy DEMATEL, and Fuzzy QFD methodologies, utilizing expert judgments elicited from a purposively sampled panel of experienced professionals. The selection of experts is confined to those with substantial hands-on experience in public building projects within Addis Ababa, ensuring contextual relevance of the findings.

While the study aims to identify general principles of causal relationships, the direct generalizability of specific findings is limited to the public building construction sector in Addis Ababa due to the unique regulatory, institutional, and administrative context of the city. The research does not extend to private sector projects, road or heavy infrastructure works, or other phases of change order management beyond the defined approval boundaries. Furthermore, although external macroeconomic and political factors are acknowledged, the primary focus remains on the direct and indirect causal influences operating within the project-specific and organizational domains relevant to the approval process.

The study focuses exclusively on factors affecting the duration of the change-order approval process. Although several variables were initially identified from studies investigating change-order occurrence, they are included in this research only after expert validation confirmed their relevance to approval-delay mechanisms. Thus, the unit of analysis is the change-order approval process rather than the occurrence of change orders.

Generally, this chapter has introduced the research context, outlined the problem of change order approval delays in Ethiopian public building projects, and clearly defined the study's objectives, significance, and operational scope. It establishes that approval delays are systemic rather than isolated administrative shortcomings. Chapter Two builds on this foundation with a comprehensive literature review.

1.7. Organization of the Thesis

This thesis is organized into five chapters, each building logically upon the previous one to present a coherent investigation into the causal factors of change order approval delays in public building projects in Addis Ababa.

Chapter One introduces the research background, articulates the statement of the problem, presents the research questions and objectives, discusses the significance of the study, and outlines the scope and delimitations. It also provides a brief overview of how the thesis is structured.

Chapter Two presents a comprehensive review of the relevant literature. It examines the construction industry and project performance, explores the nature and impacts of change orders, discusses change order management practices in developing countries with particular emphasis on Ethiopia, and critically analyzes methodological approaches used in previous studies. The chapter identifies key research gaps and establishes the conceptual foundation for the present study.

Chapter Three details the research methodology. It describes the study area, Research Approach, Research Design and Framework, population and sampling strategy, data collection instruments, and the analytical techniques employed, including the Delphi method, Fuzzy AHP, Fuzzy DEMATEL, and Fuzzy QFD. Issues of reliability, validity, and ethical considerations are also addressed.

Chapter Four presents the empirical results and discussion. It reports the outcomes of the Delphi expert consensus, pilot study, Fuzzy AHP prioritization, Fuzzy DEMATEL causal analysis, the development of the causal-chain model, and the prioritization of mitigation strategies through Fuzzy QFD. The findings are interpreted in relation to existing literature and their practical implications for the Ethiopian construction sector.

Chapter Five summarizes the key conclusions, offers practical recommendations for policymakers and project stakeholders, acknowledges the limitations of the study, and suggests directions for future research. The thesis concludes with a bibliography and appendices containing the research instruments and supplementary materials.

This structure ensures a systematic progression from problem identification to methodological rigor, empirical analysis, and practical application.

CHAPTER TWO

LITERATURE REVIEW

2.1. INTRODUCTION

Construction projects are inherently complex and dynamic systems characterized by technical uncertainties, multiple stakeholders, and constantly changing conditions. Change orders, also known as variation orders, represent formal modifications to the original project scope, design, or specifications. While often unavoidable, ineffective management of these changes particularly delays in the approval process frequently leads to schedule overruns, cost escalations, quality issues, and contractual disputes. Although a considerable body of literature addresses the causes and impacts of change orders, much of the existing knowledge remains fragmented, relying heavily on descriptive approaches that identify factors in isolation rather than examining their interrelationships.

This chapter critically reviews relevant studies on construction project performance, change orders, and approval delays, with special emphasis on findings from developing countries and Ethiopia. It synthesizes key patterns, highlights persistent challenges, and exposes major methodological gaps, particularly the limitations of conventional techniques such as the Relative Importance Index (RII) and Mean score analysis. By doing so, the review establishes a strong conceptual foundation for the present study and justifies the adoption of an integrated hybrid framework combining the Delphi technique, Fuzzy Analytic Hierarchy Process (FAHP), Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL), and Fuzzy Quality Function Deployment (QFD) to provide a more comprehensive causal understanding and practical solutions for change order approval delays in Addis Ababa’s public building projects.

2.2. Overview of the Construction Industry and Project Performance

The construction industry is a vital sector of the global economy, playing a significant role in the development and growth of countries. It is a complex and multifaceted industry, covering a wide range of activities, including the construction of buildings, infrastructure and industrial facilities. The construction industry makes a significant contribution to the global economy by providing employment opportunities, generating income and stimulating economic growth (Pheng & Hou, 2019).

The construction industry makes a significant contribution to the global economy, accounting for a significant portion of global GDP. According to the International Labour Organization (ILO), the construction industry accounts for about 6% of global GDP, with annual industry revenues exceeding $10 trillion. The industry provides employment opportunities to millions of people around the world, and the ILO estimates that it employs more than 270 million people worldwide. The construction industry is also an important contributor to economic growth, as the output of the industry has a multiplier effect on the economy (kpmg.com/africa, 2014). One of the most important roles of the construction industry is in infrastructure development. The construction industry is responsible for the construction of roads, bridges, airports, and other critical infrastructure that is essential for economic growth and development. The industry also plays a critical role in the construction of housing and commercial buildings that provide housing and jobs for individuals and businesses (Francis, 2018). In addition, the construction industry is also involved in the construction of industrial facilities such as manufacturing plants and power plants, which are critical to the growth and development of industries. In addition to its economic importance, the construction industry also plays a vital role in social and environmental sustainability. The industry is responsible for the development of green buildings and sustainable infrastructure, which reduces carbon emissions and promotes environmental sustainability. The industry also plays a vital role in supporting social sustainability by providing affordable housing and public facilities, which promote social cohesion and overcome inequality.

The construction industry is considered a great indicator industry to the overall health of a nation's economy. When the construction demand increases, that means that many other industries are growing as well, and vice versa. The construction industry is composed not only of companies that actually build structures, but also those that design, develop, repair, or maintain structures. The construction of infrastructures such as roadways, railroads, or airports is included in our transport manufacturing industry.

There are several types of construction; heavy construction, including civil projects such as dams, sewer systems, and infrastructure; commercial building, including apartments, offices, retail, hotels, schools, and public buildings; and residential building. In addition to new structures, these categories include remodeling, renovations, additions, and removals.

Construction projects are complex projects to perform due to the ever-changing project location, geography, stakeholders, manpower of different background and the complexity of the product itself. Effective planning is important to tackle difficulties arising out of these changing factors (Mubarak, 2015). The construction industry everywhere faces problems and challenges. However, in the developing countries, these difficulties and challenges are present alongside a general situation of socio-economic stress, chronic resource shortages, institutional weaknesses and a general inability to deal with the key issues. There is also evidence that the problems have become greater in extent and severity in recent years (Ofori, 2012).

The construction industry faces significant global challenges, including labor shortages, supply chain disruptions, rising material and labor costs, and the need for increased sustainability and technology adoption. These issues affect project timelines, costs, and overall efficiency.

The construction industry is vital for the development of any nation. In many ways, the pace of the economic growth of any nation can be measured by the development of physical infrastructures, such as buildings, roads and bridges. Construction project development involves numerous parties, various processes, different phases and stages of work and a great deal of input from both the public and private sectors, with the major aim being to bring the project to a successful conclusion. The level of success in carrying out construction project development activities were depend heavily on the quality of the managerial, financial, technical and organizational performance of the respective parties, while taking into consideration the associated risk management, the business environment, and economic and political stability (Akintoye, 2022).

The common assessment of the success of construction projects is that they are delivered on time, to budget, to technical specification and meet client satisfaction. However, the criteria for success are in fact much wider, incorporating the performance of the stakeholders, evaluating their contributions and understanding their expectations. Successful construction project performance is achieved, when stakeholders meet their requirements, individually and collectively.

Collectively, the reviewed studies demonstrate that construction project underperformance rarely stems from single technical failures. Instead, delays, cost overruns, and quality problems are repeatedly associated with interdependent organizational, contractual, and institutional weaknesses. These findings suggest that project performance problems should be understood as systemic outcomes rather than isolated events. This perspective is particularly relevant to the present study, as it frames change order approval delays not merely as procedural shortcomings, but as manifestations of deeper inefficiencies within public construction management systems.

2.3. Change Orders in Construction Projects

The uncertainty and complex characteristic of construction project have increased the degree of uncertainty involved in the scheduling and execution stages. Unlike manufacturing, construction has conventionally fragmented planning and design from construction processes which have resulted in some scope and design related changes during the construction.

Changes in construction projects are habited and usually occur from various sources, by different causes, at any progress of a project, and may have great adverse impacts on items such as costs and schedule delays. Such changes are Incomplete/inconsistent drawings; design error/defect; design change; omissions of site conditions and build ability; changes in codes and regulations (Khalid K. Naji, 2022).

A change is any type of modification or alteration from the previous contract sign to accomplish the specific scope of work, estimated cost and prescheduled time of construction project. In a common sense change is any addition, omission or alteration to the contract document and the nature of planed project to accept the requested idea to one or more parties from the other parties in the construction industry. This includes change applied to designs, specifications, project locations and organizations (Clough, 2015).

Changes are normally unavoidable from the construction project. Project owner is the most influential party to change at the stage of design or pre-contract and during construction phase or after contract awarded due to market desire and business conditions or technological developments. These construction changes may modify the project situations like design and specifications. Design modifications induce the result of design improvements or optimizations and consequently which effect project performances. Likewise, errors and omissions in design documents or construction defects are the leading agent of a change. In general the change factors which occur on the construction project consume additional cost and time from the awarded contract. For this reason change in the construction project is unwanted and un-welcomed by all construction parties. Thus in common sense changes can be defined as the major causes of time extensions, cost overruns and quality defects at any stage of a construction project (Mekonen, 2025).

The construction projects are commonly over stressed by the case of frequent change and unpredictable parameters. The source of construction change originate from several sources including resources, project involved parties, contractual issues and environmental factors. Due to this reason, construction projects are challenged by variations which may cause schedule delay and cost overruns in the project accomplishment (Sears, 1994)).

The occurrence of change or variation in a construction industry is a most habited and practitioner problem but we have not still developed effective change management system to overcome the problem face in the industry. Even though the case of design change in construction project is very common there are many types of changes other than it in the construction project which makes challenge on the performance of construction project.

Construction project is a mission, undertaken to create a unique facility, product or service within the specified scope, quality, time and cost. In practice, however, some construction projects encounter change, delay on completion time or poor workmanship upon completion. In the construction industry even though the scope of the projects and the extent of construction processes vary significantly, they tend to have one thing in common which is change and most of the change orders are issued during the construction execution period (Alia Alaryan, 2014).

Change orders have long been an inherent part of the construction industry. It is seldom to spot a construction project being executed without a change which normally arises as a result of some causes attributed to the different parties involved in the project execution. Upon acknowledging its existence, the change or variation is formally regularized by the issuance of a change order which is a document describing the scope of the change and its impact on both cost and/or time.

(Zain Ghazi Al-Kofahi, 2020) Define a change order as modifications or alterations to pre-existing conditions, assumptions, or requirements. When change orders occur, they can have a serious impact on the quality, time, and cost of projects and, ultimately, affect the construction program.

Further, if the change order is not managed properly, it affects construction performance in multiple directions. According to Gunduz and Mohammad (2018), the most significant impacts of change orders in rank order are: increased project re-planning increased project management efforts, poor contractor relationship with the client, increased reworks and demolition works, loss of efficiency due to work interruption, and delay of payments. Increase project re-planning means the project needs to be planned again when there is additional works. This situation could change the sequence of the works and may affect the continuing works. On the other hand when we see Increased in project management efforts includes increased project financing, increased site logistics requirements. Poor contractor relationship with the client is a factor for omission works. When there is omission work, the contractor may already do some procurement for that part of the work. This would lead to problems with poor relationship with the client. Increased reworks and demolition works increased in project management efforts, loss of efficiency due to work interruption and delay of progress payments. Loss of efficiency due to work interruption is the change orders impact the regular progress and this would cause productivity losses due to disruption of regular progress and learning curve. Delay of payments may interrupt ongoing progress and generate delays. The contractors and subcontractors depend on the progress payment to pay material suppliers. Delays of payments negatively affect the payment schedule of contractors and this situation would lead to poor cash management and project efficiency.

Maamari and Khan (2021) confirmed that increase in project cost; disputes between parties to the contract, and delay in completion schedule were the most significant impacts of change orders on projects. Change orders play a significant role in determining the cost performance of a project. Additional Material, Additional Labor cost and indirect costs are the effect of change orders on construction project cost (Girum, 2022).

Dejene (2020) states that change orders have impacts and influence on the financial capacity of clients. These incur additional costs to the projects and shortage of budget. It impacted on schedule of the projects that completion date of these projects extended because of additional work. Scope of the projects can be decrease or increase as change order seen in construction. Payment time affected due to very late because of the adjustment of costs of these buildings. Change order also has impact on Coordination between parties during adjusting the cost (Dejene, 2020).

While the literature consistently recognizes change orders as inevitable in construction projects, it simultaneously indicates that their negative consequences are largely management-driven rather than intrinsic. The persistence of adverse impacts across different countries suggests that the fundamental challenge lies not in the existence of change orders, but in the way they are evaluated, coordinated, and institutionalized. However, most studies conceptualize change order management primarily as a technical documentation activity, rather than as a complex decision-making system. This limitation has contributed to an overemphasis on identifying causes of change orders, with comparatively little attention given to the approval mechanisms through which these changes translate into project delays.

2.4. Change Order Management and Approval Delays in Developing Countries and Ethiopia

Most changes, if not managed properly through a formalized change management process will have considerable impact as they disrupt work and affect tits orderly sequence, adversely impacting productivity and accordingly causing schedule delays and cost over runs. So that managing changes effectively is crucial to the success of a construction project (Girum, 2022). Change management is a critical problem faced by the construction industry. It has been revealed that improving the administrative process of change orders is beneficial in reducing the cost and risk for all the project participants and encourages a more trustful relationship.

To mitigate the change order the contractor needs to plan a strategy to fix the time lag occurring on the delivery of the project, the logistics facilities; take up adequate financial pre-planning to avoid alterations or change in work during the implementation phase i.e. during work-in-progress; and it is necessary to avoid using change orders to maximize profit (Tadesse, 2009). And also consultant should clearly understand the scope of the work to avoid future changes in design. The consultant should ensure that the materials required and the other equipment's are readily available in the pre-planning stage; and avoid miscommunication among the team of design draftsmen to minimize the future change orders and cost overruns thereby. Tigist also recommend as a client should conduct a deep assessment of plan before the initiation of the project to avoid change in project scope during the execution stage; and it is a must for the client to do proper financial pre-planning to cover the overall project and to keep provision for the contingency expenses (Tigist, 2017).

Ruben (2018) suggested several measures for reducing change orders, including adequate advance planning by all parties before works start on site, thorough completion of design and working drawings, complete contract documents at the tender stage, clear client briefs, enhanced communication, proactive participation by all parties, supervision by experienced and dedicated supervisors, and ensuring that designs and specifications fall within the approved budget with the budget team participating during the design phase.

Dejene (2020) emphasized that the three parties (client, contractor, and consultant) should participate in construction according to their roles to ensure a proper construction process. The client should have sufficient financial capacity and provide a clear brief and scope of works before tendering. If the client provides a clear scope, brief design, and sufficient budget, change orders will be minimized. Design and bid documents must be prepared by well-experienced and capable professionals and should be thoroughly reviewed before tendering. The site conditions, including detailed soil investigations, must be properly observed to forecast unforeseen situations. Sometimes the actual site conditions are not adequately detailed, which leads to change orders (Dejene, 2020).

Assaf & Al-Hejji, 2006 recommended several points for project participants to minimize the negative impacts of changes in construction projects.

Owners should consider the following factors:

- Timely payments to the contractor
- Reducing the number of change orders during construction
- Reviewing and approving of design documents on time
- Scrutinizing and paying specific attention during project delivery phase

Contractors should give special attention to following factors:

- Balancing the labor quantity in compatible with task amount
- Attempting to increase the productivity of labor
- Reducing the financial and cash flow problems
- Giving priority for planning and scheduling
- Efficient site management and supervision

Consultants should look to the following points:

- Reviewing and approving design documents on time
- Having a positive flexibility in responsibilities
- Considering the correspondence between the cost and quality

Finally; Architect/design engineer should focus on the following issues:

- Producing design documents on time
- Trying to lessen mistakes and discrepancies in design documents

Tadesse, (2009), also suggested recommendations based on the research and literature review as follow:

- The project professionals should be involved during the project design phase in order to reduce the probable changes due to errors, discrepancies and omissions during the construction phase.
- The effective coordination and communication between project team members should be established in order to help to reduce and eliminate the changes arising from project design as well as variations caused by contractual conflicts and discrepancies.
- The controlling of design and detailing of the drawings should be executed by the consultants carefully; in order to reduce the change order during the construction phase and also to provide the opportunity for reviewing and finalizing the design documents during the design stage.
- A brief project scope and objectives should be provided for the contractors and project team members in order to eliminate and reduce the changes arising from the unclear project scopes.

Although Ethiopian and international studies consistently acknowledge change order approval delays as a major contributor to construction project underperformance, they predominantly treat these delays as isolated lists of administrative problems rather than as dynamically interacting systems. Concepts such as slow decision-making, poor inter-agency coordination, financial constraints, and documentation inefficiencies are frequently cited; however, their causal relationships and relative influence remain largely unexplored. As a result, existing literature offers limited guidance on prioritization and fails to clarify which factors act as root drivers versus dependent effects. Although these studies provide valuable insights into the general causes and impacts of change orders, they give limited attention to the specific administrative and procedural mechanisms within the approval workflow itself. The following subsection therefore examines the bureaucratic, organizational, and decision-making processes that often prolong approval times in public sector projects.

2.4.1. Administrative and Procedural Mechanisms Prolonging Approval Delays

While many studies have examined the causes of change orders themselves, fewer have focused specifically on the administrative and procedural bottlenecks that delay their approval. In public sector projects, the approval workflow typically involves multiple hierarchical layers, inter-agency coordination, and formal documentation requirements that often extend far beyond technical evaluation. These procedural complexities frequently transform what should be a straightforward review into a protracted bureaucratic process.

In the Ethiopian context, public procurement and financial regulations require change orders to pass through several stages, including technical assessment by consultants, financial verification by the client's budgeting unit, endorsement by higher management, and in many cases, approval from external regulatory bodies such as the Ministry of Finance or the Federal Public Procurement and Property Administration Agency. Each stage introduces additional review time, documentation requests, and opportunities for delays. Studies conducted in similar developing country settings highlight that multi-level approval chains, overlapping mandates between institutions, and the absence of clear service level agreements significantly extend processing times (Assaf & Al-Hejji, 2006; Gunduz & Mohammad, 2018).

Organizational decision-making structures further compound these challenges. In public building projects, approval authority is often distributed across different departments and levels of government, leading to fragmented responsibility and slow consensus building. Decision-makers frequently hesitate to approve variations due to concerns over budget implications, audit risks, and accountability, resulting in repeated referrals and requests for additional justification. This risk-averse culture, combined with limited delegation of authority, creates systemic inertia in the approval workflow.

Moreover, inadequate digital systems and reliance on manual documentation exacerbate procedural delays. The absence of integrated project management platforms means that information exchange between parties remains slow and prone to miscommunication. Previous research in Ethiopia has noted that poor coordination among client representatives, consultants, and regulatory agencies often leads to repeated cycles of clarification and revision, further prolonging the time from submission to final decision (Dejene, 2020; Girum, 2022).

These administrative and bureaucratic dimensions are critical because they often act as amplifiers of other change order factors. Even well-justified variations can experience significant delays when trapped in complex procedural mazes. The present study therefore pays particular attention to these workflow-related factors, using Fuzzy DEMATEL to map their causal influence within the broader system of approval delays.

Most previous studies identified factors responsible for the occurrence of change orders. However, relatively few studies have investigated the factors affecting the approval process after a change order has been initiated. Therefore, the present study adopts these literature derived factors as candidate approval delay factors and evaluates them according to their influence on the efficiency and duration of the approval process.

2.5. Critical Factors Influencing Change Order Approval Delays

According to Andualem study the main causes of change orders on public building projects, are, change in design by the consultant, errors and omissions in design, inadequate working drawing details, and unforeseen problems (Andualem, 2014). Further from the desk study, Andualem find out, change in design, incomplete contract documents, impediment in prompt decision making process, inadequate working drawing details, and change in specifications were the major causes of variations.

Jamal found the main causes of change orders are Owner instructs modification to design, Owner instructs additional works Insufficient coordination among the parties, Ambiguities and mistakes in specifications and drawings, Modifications in materials specifications, Severe weather conditions on the job site, and Changes in government regulations and laws are the most important change orders factors (Jamal, 2015).

Change in specifications, Alterations in design and drawing, Time lag, Change of scope, Errors and omissions in design, Insufficient Logistics in the project implementation, errors and omissions in design, and lack of design clarity are the most significant causes of change orders affecting the construction projects (Khan, 2021).

According to the study of Dejene the main cause of change order in construction project are errors and omissions in design as well as in other documents, change of client interest, modification in design, change of plans or scope and shortage of time during preparation of design and BOQ or bid document are the main causes that should be given attention from planning the project up to tendering stage (Dejene, 2020).

According to Girum study the most significant causes of change order are Errors and Omissions in Designs, Design Changes, and Conflicts in contractual Documents, Lack of clarity in scope and Differing site Conditions (Girum, 2022).

2.5.1. Client-Related Factors:

Client-related factors are among the most frequently cited causes of change orders and approval delays. (Muhammad, et al., 2015) described client-related rework as changes directly initiated by the client or their agents. The study found that replacement of materials by the client was the most common cause, while client-related rework is primarily driven by changes in plans or scope. Similarly, Tadesse (2009) identified the client's changes, extra orders, poor choice of materials or methods, and inaccurate information as significant contributors to variations in Ethiopian federal road projects. Mohamad K. Alaryan, (2012) noted that clients are the main requesters of change orders. The three primary client-related causes they identified are modifications to the original design, addition of new work or scope, and unclear initial design brief. Other notable causes include the desire to use better specifications, alternative materials or new technology, and omission of works or scopes. Additionally a technical report by Federal Construction Council, (1983), indicates that unnecessary changes in construction are due to client or client's agents. This is also confirmed by (Andualem, 2016), in the investigation on public building projects in Addis Ababa where client's additional works are identified as the major factor causing change orders. Again, (Ijaola, 2012) also reported similar results in both Nigeria and Oman. Another study investigated by (Tigist, 2017), declares delays in public construction projects in Addis Ababa City Roads Authority are associated with user changes. In addition to this (Ayman, 2016), describes as change of client is the cause of delay in Egypt, as well as (Ogunlana, Promkuntong, & Jearkjirm, 1996), in Thailand and (Chao-Hui Wu, Statistical analysis of causes for design change in highway construction on Taiwan, 2005), in Taiwan. According to (Bon-Gang Hwang, 2014), client-related factors are Change of plans or scope by the client, Inadequate/ incomprehensive project objectives by the client, Change in specification by the client, Financial problems faced by client, Weakness in motivation the decision making by the client, Replacement of materials by the client, Change in specification by the client, and Obstinate nature of the client. Many investigations show that client-related changes play major effects on the project schedule and cost outcomes. Due to this implication, client credits are significant and should be completely understood at the early phase of the project (Mikael Hygum Thyssen, 2010).

2.5.2. Consultant-Related Factors:

According to Mendelsohn (1997), nearly 75% of problems or reworks in construction projects originate during the design phase. Inadequate communication among design consultants often leads to faults and omissions in project documentation (Peter E. D. Love, 2004) . The design and delivery team frequently misunderstands the client's requirements and needs. Therefore, Peter E. D. (2004) recommend that effective communication and a harmonious relationship between clients and their design team, along with active client involvement in the design process, can significantly reduce design-related rework.

Key designer-related causes include failure to forecast the irregular progression of the project at the design stage, errors in design, the use of outdated design and construction standards, and the adoption of inappropriate construction technology (Abebit, 2013). Modification to design was identified as the second most frequent problem causing change orders in both Oman and Nigeria (Ijaola, 2012). Design consultants are often responsible for deviations such as poor or incomplete drawings, change orders due to inadequate project briefs, errors and omissions, and inconsistent site conditions (Mohamad K. Alaryan, 2012) .

Additional significant causes include improper design or partial design improvements, inconsistent information in drawings, discrepancies between contract documents, lack of geotechnical investigation or wrong interpretation of findings, and insufficient detail regarding existing site conditions (Tadesse, 2009; Ting-ya Hsieh, 2004). Design omissions (Andualem, 2016), incomplete drawings (Ogunlana, Promkuntong, & Jearkjirm, 1996), design errors (Hamzah, Khoiry, Arshad, Badaruzzaman, & Tawil, 2012) , and poor quality of design (Chao-Hui Wu, Statistical analysis of causes for design change in highway construction on Taiwan, 2005) are among the main consultant-related factors that contribute to cost and schedule escalations. Ultimately, many design changes arise due to failures in the coordination of design information.

2.5.3. Contractor-Related Factors:

According to Mohamad K. Alaryan, (2012), change orders caused by contractors often stem from requests to use available materials, alternative construction methods to save time or cost, rectification of construction mistakes, and efforts to improve the quality of work on site. Similarly, (Chao-Hui Wu, Statistical Analysis of Causes for Design Change in Highway Construction on Taiwan, 2005)noted that contractors may modify construction methods to suit existing site conditions, request changes from original methods to new ones, or commit incorrect construction practices that lead to on-site repair work. Improper project planning frequently results in errors during task implementation and the adoption of unsuitable construction methods (Girum, 2022; Rahel, 2016; Andualem, 2016) identified poor site or project management skills, delays in appointing subcontractors, delays in subcontractors' work, poor workmanship, low productivity, and poor logistic control as major contractor-related factors contributing to change orders.

These issues highlight that many contractor-initiated changes arise from inadequate planning, resource management problems, and execution deficiencies on site. Addressing these factors requires stronger pre-construction planning and improved coordination between contractors and other project stakeholders.

2.5.4. Third Party Related Factors:

Project outcome is most impacted by the regulation imposed by the third parties (Love & Peter Edwards, 2002). Change of work occurs by the cause of government agencies, Neighborhoods communities and Coordinating with utility systems are some of the third party factors reported in (Ting-ya Hsieh, 2004), study. In a separate study, (Andualem, 2014; Getachew, 2009; Chao-Hui Wu, Statistical analysis of causes for design change in highway construction on Taiwan, 2005; Tadesse, 2009), also recognized change order happens by the cause of The complaint from neighborhood, The request made by end user, The request from investor who came while construction has started, The request from regulatory bodies are major third party factors. In Malaysia, regulatory body request changes and the problem with neighbors are the significant third parties causes of design change (Sambasivan & Yau, 2007). (Mekonen, 2025), found out socio-political conditions as factors in their study. They also revealed as lack of communication with local authorities will influence project performance. Andualem (2016), additionally described design change due to public agencies (roads, utilities and public services) is under the third party factors.

2.5.5. Environmental Related Factors:

Weather conditions have a great impact on the performance of construction projects, as highlighted in the study on Factors Affecting Success of Projects in Addis Ababa City Roads Authority (Tigist, 2017) . This cause is considered as an example of force majeure discussed in various literatures. The cause may result in adjustment of contract schedule to compensate for the lost time due to weather conditions which leads to change orders in construction projects. According to Alia et al. (2014), environmental conditions are among the causes of change orders in construction projects. They found the significant causes of design change which are categorized under environmental conditions include changes in weather conditions, occurrence of natural disasters such as floods and earthquakes, insufficient information on geological conditions, and unforeseen ground conditions.

During site investigation, not all physical and environmental site conditions can be fully identified or accurately reflected in project drawings and specifications. As a result, unforeseen or differing conditions may emerge during construction, requiring changes to the original scope of work and leading to change orders (Jamal, 2015). These changes often justify contractor claims for additional time and costs; however, if such claims are not properly addressed by the owner, disputes may arise. Thus, differing site conditions constitute a major source of change orders, cost overruns, and contractual conflicts in construction projects.

Unforeseen site conditions, constraints, and restrictions require consultants to modify the previous designs to suit actual site conditions (Andualem, 2014). Getachew (2009) reported that cost overruns resulting from change orders due to site conditions are a common problem in Ethiopian Road Construction Projects. According to a study on change orders in residential building projects by Mohamad K. Alaryan, (2012), inadequate details of existing site conditions is one of the major causes of change orders in construction projects. Most of the time, the design is done without sufficient site information such as existing underground structures or constraints due to adjacent structures. Consultants are then required to make proper site visits to mitigate design problems (Olawale & Sun, 2010).

In addition, approving authorities may overlook the agreement of the proposed plans with building by-laws, codes, and government rules (Andualem, 2014), and a late request for design amendment can be detrimental to project performance. Therefore, both clients and consultants should maintain good relationships with regulatory bodies and seek regular updates to ensure smooth planning approval (Girum, 2022).

2.5.6. Political and economic Related Factors

Generally, the designer assures that his design is in compliance with the regulations of the local authority. However, there are conditions in which new regulations may be issued between the design and construction period which may cause some changes to the previous plan (Matusala Bassa, 2019).

According to Jemal (2015), laws, procedures, and guidelines concerning building development projects and planning permissions are subject to approval by local regulatory bodies. Therefore, it is significant that the proposed development fully conforms to the rules and regulations specified by the local authorities. Andualem (2016) further expanded the following factors under political and economic related causes of change orders: materials on the market, equipment and tools on the market, economic conditions, and laws and regulations. Tadesse (2009) pointed out that physical environmental conditions and economic policies are factors of political and economic influence in their study.

According to (Chao-Hui Wu, Statistical Analysis of Causes for Design Change in Highway Construction on Taiwan, 2005), change orders due to government policy or regulatory changes are very common. Additionally, unfamiliarity with state rules and laws (Muhammad, et al., Causes of Variation Order in Building and Civil Engineering Projects in Nigeria., 2015) is a possible cause of change orders due to a lack of experience on building and civil engineering projects in Nigeria, which may be avoidable with the involvement of experienced professionals. Complex and confusing government regulations (Andualem, 2016) and changes in laws and policies (Getachew, 2009) are also important influences on project change orders. Certain building projects may face a change of decision-making authority during either the planning phase or the construction phase because of politics or elections. The interpretation and understanding of rules and regulations often varies among different regulatory bodies (Ting-ya Hsieh, 2004).

Table 2.1 Comparative Summary of Key Studies on Change Orders and Approval Delays

Author (Year)	Context	Method	Key Factors Identified	Major Limitations	How Current Study Addresses the Gap
(Ofori, 2012)	Global (Developing countries)	Qualitative review	Global (Developing countries)	Broad descriptive; no prioritization or causal modeling	Fuzzy approach +causal structure
(Arain & Pheng, 2006)	Singapore (Institutional)	Literature + Case study	Client needs, design errors, site conditions	Factors in isolation; no causal links	Fuzzy DEMATEL for cause-effect modeling
(Gunduz & Mohammad, 2018)	International	RII (Survey)	Design deficiencies, coordination issues	Descriptive ranking only	FAHP + DEMATEL integration
(Love & Peter Edwards,	Global	Case studies	Technical & organizational interactions	Symptom-focused, no root driver	Causal-chain model development

2002)				analysis	
(Chao-Hui Wu, 2005)	Taiwan	Statistical analysis	Government policy, design changes	No interrelationship modeling	Fuzzy approach + causal structure
(Mohamad K. Alaryan, 2012))	Oman & Nigeria	Survey + Qualitative	Design inconsistencies, contractor requests	Isolated factor analysis	Systemic modeling of interdependencies
(Muhammad, et al., Causes of Variation Order in Building and Civil Engineering Projects in Nigeria., 2015)	Nigeria	Qualitative	Client rework, scope changes	No prioritization or causal framework	Prioritization via FAHP
(Andualem, 2014; Andualem, 2016)	Addis Ababa Public Buildings	RII + Desk study	Design changes, client additions	Purely descriptive	First Fuzzy AHP + DEMATEL in Ethiopian context
(Dejene, 2020)	Jimma Zone, Ethiopia	RII	Design errors, client scope & financial issues	No causal relationships	Hybrid Fuzzy MCDM framework
(Girum, 2022)	Addis Ababa	Mean score analysis	Design errors, contractual conflicts	Factors treated independently	Causal-chain model + Fuzzy QFD
(Mekonen, 2025)	Ethiopian Road Projects	Mean score	Resource & contractual problems	No mitigation modeling	Translation of findings into prioritized strategies via QFD
(Khalid K. Naji, 2022)	Global	Literature review	Incomplete drawings, regulatory changes	Broad & descriptive only	Empirical causal modeling

Table 2.1 presents a carefully selected comparative summary of key studies on change orders and approval delays, serving as a focused synthesis rather than an exhaustive catalogue of all literature reviewed in this chapter. The studies were chosen based on their relevance and citation frequency in the Ethiopian context, while maintaining a balanced representation of international and local research. Emphasis was placed on methodological diversity encompassing qualitative reviews, case analyses, and descriptive statistical approaches such as the Relative Importance Index (RII) and means score analysis to clearly illustrate their shared limitation: the tendency to identify and rank factors in isolation without exploring underlying causal interrelationships. This selective approach ensures brevity and readability while directly highlighting the research gap that the present study addresses. Most previous studies relied heavily on descriptive statistical methods (RII and mean scores) that treat factors independently. In contrast, this research bridges the gap by adopting an advanced hybrid Fuzzy MCDM framework integrating the Delphi technique, Fuzzy AHP, Fuzzy DEMATEL, and Fuzzy QFD to achieve systemic causal modeling and prioritized, evidence-based mitigation strategies

The synthesis of the reviewed literature shows that change order approval delays rarely result from single events. Rather, they arise from a complex web of interrelated technical, managerial, institutional, and external factors. In Addis Ababa's public building projects, these delays are mainly driven by client-related decisions, consultant shortcomings, bureaucratic hurdles, financial constraints, and resource supply issues. To ensure clarity and avoid repetition, the critical factors distilled from an initial long list of over 50 causes through literature review and validated via a two-round Delphi technique plus pilot study are systematically presented in Table 2.2.

Table 2.2: Final Critical Factors Influencing Change Order Approval Delays (Synthesized and Validated)

No.	Thematic Group	Critical Factor (Short Name)	Operational Definition (Concise)	Key References	Literature Support Level
F1	Client-Related	Client-initiated scope changes & additional orders	Client-driven modifications to project scope, plans, or extra work orders during	(Andualem, 2016; Muhammad, et al., 2015; Mohamad K. Alaryan,	Very High

			execution	2012).	
F2	Client-Related	Change in specification	Client requests for better quality, materials, or technical standards	(Bon-Gang Hwang, 2014; Girum, 2022; Tadesse, 2009).	High
F3	Client-Related	Financial problems of the client	Budget shortfalls, delays in fund release, and inadequate financial planning	(Bon-Gang Hwang, 2014; Dejene, 2020; Andualem, 2016).	Very High
F4	Consultant/Designer-Related	Design errors, omissions & poor/incomplete drawings	Mistakes, inconsistencies, and inadequate details in design documents	(Andualem, 2014; Mohamad K. Alaryan, 2012; Peter E. D. Love, 2004).	Very High
F5	Consultant/Designer-Related	Site and geotechnical assessment inadequacies	Poor site data, lack of soil tests, inconsistent site information, and unforeseen ground conditions	(Mohamad K. Alaryan, 2012; Andualem, 2016).	High
F6	Contractor-Related	Poor workmanship & corrective construction mistakes	Substandard execution and on-site errors requiring rework	(Rahel, 2016; Girum, 2022; Chao-Hui Wu, 2005).	High
F7	Contractor-Related	Poor logistics and material supply control	Failures in supply chain management, procurement, and material delivery	(Rahel, 2016; Girum, 2022; Andualem, 2016).	Very High
F8	Third Party / Regulatory	Government agencies & bureaucratic approval layers	Multi-level regulatory reviews, government	(Andualem, 2016; Hsieh, Lu, & Tzeng, 2004; Chao-	Very High

			interference, and bureaucratic delays	Hui Wu, 2005).	
F9	Political & Economic	Material availability in the market	Shortages and unavailability of construction materials in the local market	(Andualem, 2016; Tadesse, 2009; Muhammad, et al., 2015).	High
F10	Political & Economic	Economic conditions and price inflation	Inflation, market volatility, and changes in laws/policies affecting project costs	(Andualem, 2016; Girum, 2022; Chao-Hui Wu, 2005).	High

This table presents the ten critical factors distilled from an initial long list of over 50 potential causes identified through an extensive review of local and international literature (see Appendix I: Comprehensive List of Factors in Causes of Change Orders Approval Delay). These factors were further synthesized and validated through a two-round Delphi technique plus pilot study involving experienced professionals, ensuring relevance and consensus within the Addis Ababa public building context. The operational definitions are concise and tailored to reflect real-world manifestations during the change order approval process. Literature Support Levels indicate the strength of empirical backing, where High denotes factors cited in ≥5 major studies and Very High highlights those most consistently emphasized across the reviewed works. These ten factors served as the core variables for the subsequent Fuzzy AHP prioritization, Fuzzy DEMATEL causal modeling, and Fuzzy QFD mitigation strategy development in this study.

2.6. Methodological Approaches for Causal Modeling

2.6.1. Limitations of Conventional Descriptive Methods

Previous studies on construction delays, including those related to change order approvals, have frequently employed descriptive statistical techniques to identify and rank causal factors. The Relative Importance Index (RII) and mean score analysis represent some of the most prevalently employed methodologies. For example, RII has been utilized to prioritize factors such as insufficient planning, ineffective communication, and design discrepancies based on feedback obtained from project stakeholders in the domain of road construction

(Tsegay Gebrehiwet & Hanbin Luo, 2017) . These methodologies ascertain the relative importance of various factors through the allocation of numerical weights derived from stakeholder perceptions, thereby rendering them both lucid and readily interpretable.

Mean score analysis, in a comparable manner, synthesizes responses to ascertain the mean significance of various factors. Studies like those by (Okereke, Zakariyau, & Afonne, 2023) used this methodology emphasizes the significance of addressing delays attributable to contractor inefficiencies or client-related complications within construction endeavors. Such methodologies possess considerable merit due to their straightforwardness and capacity to establish a transparent hierarchy of determinants, thereby enabling project managers to concentrate on the paramount issues.

Descriptive statistical techniques like mean score analysis and RII have significant drawbacks despite their extensive use. These methods frequently address delay issues separately, missing the intricate connections between them. For example, although RII is unable to simulate such dynamic interactions, poor communication may make delays brought on by design faults worse (Berlinda Lessing, 2017) . The subjective survey data that these approaches mostly rely on may also add bias or oversimplify the complex nature of delays. Due to the complicated interactions between bureaucratic procedures, stakeholder disputes, and insufficient documentation, this restriction is especially pertinent to change order approval delays (Birgonul, 2024) .

Furthermore, these approaches don't offer useful information on the causal framework of delays. Although they highlight the key elements, they don't describe how these elements interact or cause delays. The need for more sophisticated approaches is highlighted by the lack of a model that can adequately represent these dynamic interactions.

Research that offers useful models of the dynamic interactions of delay variables is severely lacking, according to the literature. Although factors can be ranked using descriptive approaches, the underlying causes and their interdependencies cannot be adequately addressed by them. This is especially pertinent to the goal of the study, which is to create a causal-chain model that combines components into cause-and-effect categories in order to pinpoint the factors that are the main drivers. Understanding how elements like postponed decision-making or insufficient financing set off a series of events that result in approval delays requires a dynamic model (Ajayi & Chinda, 2022).

2.6.2. Rationale for Advanced Causal Modeling

The evolution of construction management research has necessitated a departure from traditional descriptive methods, which often proved inadequate for capturing the systemic complexity of change order delays. Historically, studies in this domain relied heavily on the Relative Importance Index (RII) or mean score rankings to evaluate factors. However, as recognized during the conceptualization of this study, these linear methods operated under the flawed assumption of factor independence (Huang, 2011) .In the context of the Ethiopian public building sector, change order delays were viewed not as isolated incidents, but as results of a complex web of mutual influences and feedback loops that required a more sophisticated analytical lens.

Consequently, a significant methodological shift was adopted to move beyond these traditional limitations. This transition was designed to empower project managers with a scientifically validated tool capable of reflecting the ambiguous reality of the construction environment. To achieve this, an integrated framework combining Fuzzy Set Theory, the Analytic Hierarchy Process (AHP), Decision-Making Trial and Evaluation Laboratory (DEMATEL) and the Quality Functional Deployment (QFD) was established as the primary diagnostic engine of the research.

This research aims to fill this gap by employing advanced methodologies to map these relationships in the context of public building projects in Addis Ababa.

2.6.3. Addressing Subjectivity through Fuzzy Logic Integration

A fundamental challenge identified in the analysis of change order delays was the inherent subjectivity of human judgment. Expert evaluations expressed through linguistic terms such as highly frequent or critically significant often contained shades of grey that traditional crisp numerical scales failed to capture. To address this, Fuzzy Set Theory was integrated into the model, following the principle that human reasoning is often approximate rather than exact (Zadeh, 1965).This allowed for the transformation of vague expert opinions into precise mathematical intervals (Fuzzy Numbers), ensuring that the uncertainty and cognitive "fuzziness" of the participants were preserved. This approach provided a more honest and reliable data foundation than could be achieved through standard deterministic methods (Long Chen, 2021).

The use of a fuzzy-based method in this study is justified because it offers a more accurate way to capture the uncertainty and subjectivity that naturally exist in respondents' judgments.

In recent research, scholars increasingly show that traditional numerical scales often fail to represent how people actually think, especially when they evaluate complex issues using linguistic terms such as slightly important, highly significant, or moderate influence. Fuzzy logic can translate these uncertain, human-like expressions into meaningful numerical values without forcing participants into strict categories, which reduces bias and information loss. Recent studies in construction management and social-science modelling (Jilcha, 2022) confirm that fuzzy approaches handle ambiguity more realistically and produce more reliable priority rankings in decision-making contexts similar to this research.

In this study, fuzzy logic was incorporated to account for the uncertainty and subjectivity inherent in expert judgments, particularly when evaluating qualitative aspects that cannot be expressed precisely. Linguistic opinions were transformed into fuzzy numbers to maintain natural reasoning and avoid the limitations of rigid numerical scales. This process generated more realistic and dependable data, thereby strengthening the reliability of the analysis and supporting subsequent prioritization and causal modeling.

2.6.4. Fuzzy AHP for Prioritization of Factors

The Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is suggested as a reliable way for ranking the variables affecting change order approval delays in order to overcome the drawbacks of conventional approaches. The classic Analytic Hierarchy Process (AHP), which assigns weights to criteria based on expert opinions via pairwise comparisons, is expanded upon by fuzzy AHP (Shapiro, 2017). Conventional AHP, on the other hand, makes exact assumptions that might not accurately represent the ambiguity or uncertainty that characterize human decision-making, particularly in intricate contexts like building projects.

To deal with this ambiguity, fuzzy AHP uses fuzzy set theory, which enables professionals to make assessments using linguistic scales (e.g., moderately important or very important) converted into fuzzy numbers (Zadeh, 1965). This is especially helpful for setting priorities for elements where expert opinions may differ, such as conflicting stakeholders or inadequate documentation. For example, (Li & Wang, 2018) used fuzzy AHP to rank risk variables in building projects, showing that it can take subjective uncertainty into consideration while still producing a clear ranking of the elements. In line with the explicit goal of gathering expert opinions to rank issues according to their perceived relevance, this study will use fuzzy AHP to prioritize important factors influencing change order approval delays.

Within this research, Fuzzy AHP was applied to systematically structure and prioritize the identified delay factors based on their relative importance. The method decomposed the complex decision problem into hierarchical levels, enabling clear pairwise comparisons and consistent expert judgments. The resulting weights objectively highlighted the most influential factors, providing a rational basis for subsequent causal analysis and focusing attention on the issues with the greatest impact on change order approval performance.

2.6.5. Fuzzy DEMATEL for Causal Relationship Modeling

The Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) is suggested as a way to model the causal linkages between delay variables. By charting the impact structure between variables, DEMATEL is an effective technique for examining cause and effect interactions (Lin & Wu, 2008).It classifies factors into cause and effect group siding in the identification of root-driver causes of delays. By using fuzzy logic to control the uncertainty in expert assessments, the fuzzy extension improves DEMATEL similar to Fuzzy AHP (Hatefi & Tamošaitienė, 2019).

Because it can uncover underlying causal structures, such as how bureaucratic inefficiencies or a lack of cooperation among stakeholders may be the reason of delayed approvals, fuzzy DEMATEL is especially well-suited to this research. This study's goal of examining the causative linkages between the variables affecting change order approval delays will be accomplished by using Fuzzy DEMATEL, which will produce a clear cause-and-effect dynamics map.

After prioritization, Fuzzy DEMATEL was employed to examine the interrelationships among the weighted factors and understand how they influence one another within the approval system. Since delays typically arise from interconnected causes rather than isolated issues, the method quantified both direct and indirect effects and illustrated them through cause–effect diagrams. This analysis helped distinguish driving factors that trigger delays from dependent factors that result from them, providing deeper insight into the dynamics of the approval process.

Consequently, the use of Fuzzy DEMATEL enabled the study to move beyond simple ranking and to uncover the underlying structure of cause effect relationships among the factors. This deeper understanding of interdependencies was essential for identifying the root drivers responsible for approval delays.

2.6.6. Integration of FAHP–FDEMATEL–FQFD for Strategic Mitigation

The synthesis of Fuzzy AHP (FAHP) and Fuzzy DEMATEL was utilized to perform a dual-layered analysis of the identified factors. FAHP was first employed to establish a structured hierarchy, enabling the precise weighting of variables based on their relative importance to the project lifecycle. However, acknowledging that importance does not inherently imply causality, Fuzzy DEMATEL was then applied to uncover the hidden architecture of influence (Wu & Lee, 2007) . This critical step allowed the study to distinguish between Effect factors which represented the visible symptoms of delays and Root-Driver factors, which acted as the fundamental triggers of the delay cascade. By identifying these causal links, the study moved beyond simple ranking to understand the deep interconnectedness of project risks (Yang, 2014) .

It was established that the development of a causal model was not the ultimate destination of this research, but rather a rigorous analytical prerequisite for problem resolution. Identifying root causes served as the essential diagnostic phase required to inform the subsequent prescriptive phase. Therefore, the intelligence gathered from the FAHP and DEMATEL analyses was utilized as the primary input for the Fuzzy Quality Function Deployment (FQFD) process. QFD has been widely recognized as an effective decision-support tool for translating prioritized requirements into implementable technical or managerial actions (Akao, 1990) .

By linking the Root-Drivers directly to specific mitigation strategies through the QFD Relationship Matrix, the study was able to fulfill its fifth objective. This transition ensured that the research culminated in a prioritized, actionable roadmap rather than just a theoretical diagram. The integration of FAHP, FDEMATEL, and FQFD has been recommended in complex decision environments because it systematically combines prioritization, causal diagnosis, and strategic deployment within a unified framework (Huang, 2011) . This integrated methodology successfully bridged the gap between understanding the origins of delays and implementing high-impact, evidence-based solutions for the Addis Ababa public construction sector.

Therefore, integrating FAHP, Fuzzy DEMATEL, and FQFD ensured that the methodological process progressed logically from diagnosis to solution development. This integration strengthened the practical relevance of the research by linking analytical findings directly to strategic mitigation actions.

2.6.7. Evidence of Method Applicability and Final Justification

In a variety of domains, fuzzy AHP and fuzzy DEMATEL have been effectively used to tackle issues including uncertainty and intricate interactions. Fuzzy AHP has been utilized in the construction industry to assess contractor performance (Hsieh, Lu, & Tzeng, 2004). Similarly, Fuzzy DEMATEL has been applied to analyze supply chain risks (Chang B. , 2011) and to model interdependencies in project scheduling (Yang, 2014) . These applications show how adaptable these techniques are for managing intricate systems, which makes them appropriate for simulating change order approval delays in public construction projects.

These approaches provide a strong framework for achieving the study goals in the Addis Ababa setting, where public construction projects encounter particular difficulties like resource constraints and regulatory complexity. This project will create a thorough model that maps the causal linkages between important components and prioritizes them by combining fuzzy AHP and fuzzy DEMATEL. This will open the door for focused mitigation techniques.

The limits of conventional descriptive statistical techniques, such as mean score analysis and RII, in capturing the dynamic interactions among delay variables are brought to light by the assessment of methodological approaches. By handling uncertainty and simulating intricate causal links, fuzzy AHP and fuzzy DEMATEL provide sophisticated solutions. These techniques support the study's goals of determining, ranking, and examining the contributing elements to modification order approval delays in Addis Ababa's public construction projects. By expanding on these approaches, this research seeks to create a framework for strategic mitigation that will help legislators and project managers efficiently cut down on approval delays.

Overall, existing methodological approaches have been effective in identifying and ranking delay factors, but remain insufficient for explaining how these factors interact to generate approval bottlenecks. The dominance of descriptive statistical tools reflects a tendency toward surface-level diagnosis rather than structural explanation. This has resulted in an accumulation of factor lists without corresponding causal frameworks. Consequently, recent construction management scholarship increasingly emphasizes the need for multi-criteria and systems-oriented techniques capable of capturing uncertainty, interdependence, and feedback effects. The integration of Fuzzy AHP and Fuzzy DEMATEL directly responds to this need by enabling both prioritization and causal modeling within a unified analytical framework.

2.7. Research Gap

A review of existing literature shows that failure to complete construction projects on time and within budget is a widespread problem in Ethiopia, particularly in public infrastructure initiatives. Large-scale projects including roads, railways, housing developments, sugar factories, irrigation dams, and power plants frequently suffer from repeated change orders that lead to significant time and cost overruns, disputes, and in some cases, early contract termination (Andualem, 2014; Dejene, 2020; Girum, 2022).

While several local studies have examined the causes and impacts of change orders in Ethiopia, most have relied on descriptive statistical methods. For example, Andualem (2014, 2016) used the Relative Importance Index to assess variation orders in public building projects in Addis Ababa. Dejene (2020) applied the same technique in Jimma Zone, Girum (2022) used mean score analysis in Addis Ababa, and Mekonen (2025) employed mean scores for road projects. These studies have successfully highlighted important issues such as design errors, client changes, financial constraints, and site conditions. However, they share a common limitation: they treat factors as independent variables and stop at ranking their importance. None of them have explored the dynamic interrelationships between factors or attempted to distinguish root causes from their effects, especially within the critical approval phase of change orders.

Consequently, a significant gap remains in the literature. There is limited understanding of how these factors interact and reinforce one another to cause prolonged approval delays in the specific context of Addis Ababa's public building projects. Furthermore, no previous study in Ethiopia has applied advanced causal modeling techniques such as Fuzzy AHP combined with Fuzzy DEMATEL to develop a systemic cause-and-effect framework, nor has any integrated QFD to translate findings into prioritized practical solutions.

This study seeks to fill this important gap by modeling the causal factors of change order approval delays using an integrated Fuzzy AHP, Fuzzy DEMATEL, and FUZZY QFD approach. By doing so, it aims to provide not only a deeper theoretical understanding but also actionable insights that can help reduce approval delays and improve project performance in the Ethiopian public construction sector.

2.8. Critical Synthesis of Literature and Conceptual Implications

The literature reviewed indicates that change orders in construction projects arise from a wide range of interrelated sources. Frequently reported causes include client-initiated design changes, financial-driven schedule modifications, unclear project scope definition, delayed or poor decision-making, additions and omissions of work, inadequate time allocated for design, ineffective communication during tendering, consultant-initiated change requests, limited consultant experience, contractor-driven design modifications to enhance constructability and quality, weak contractor involvement during the design phase, and deficiencies in project planning and scheduling. These findings confirm that change orders are not the result of a single party's actions, but rather emerge from weaknesses distributed across the project system.

Previous studies have examined change orders from multiple perspectives, including construction change management practices, factors influencing change orders, assessment of variation orders, and identification of major sources of changes.

Figure 2.1 summarizes the main streams of literature and illustrates the broad research attention given to the change order approval delay phenomenon.

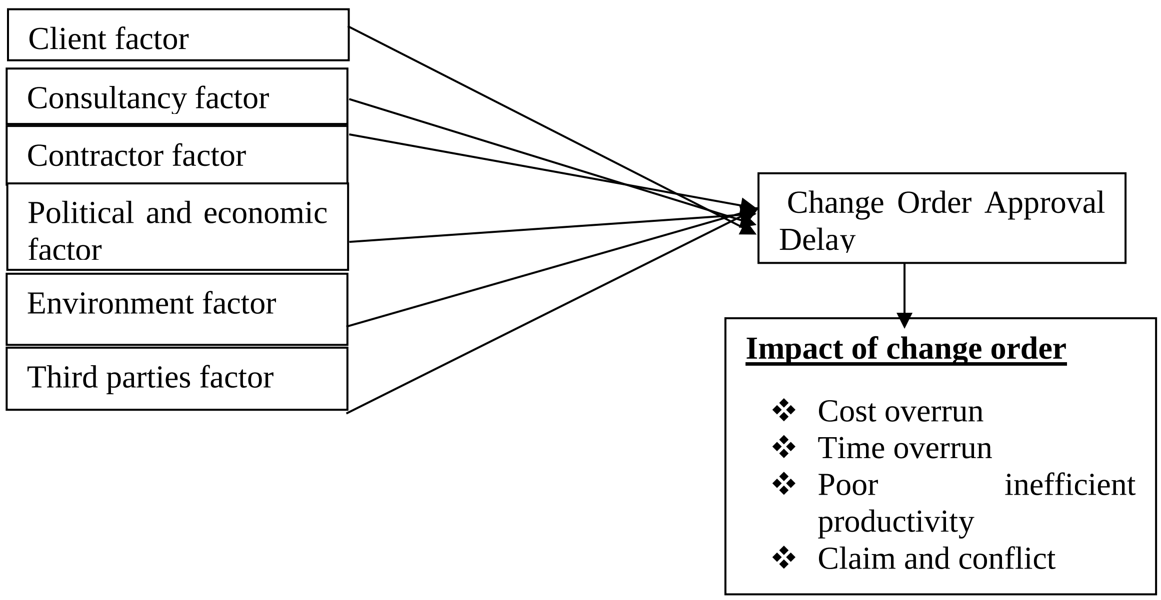

Figure 2.1.summary of literature on change orders

Figure 2.1 shows that change order approval delays stem from a complex web of interacting factors rather than single, isolated issues. This understanding forms the basis for applying advanced causal modeling techniques to examine how these factors shape approval delays and to strengthen decision-making in public building projects.

The literature consistently confirms that change orders are an unavoidable feature of construction projects, particularly within complex public-sector building environments. However, the persistent association between change orders and project underperformance suggests that the fundamental problem lies not in the occurrence of changes themselves, but in the mechanisms used to manage and approve them. Across both international and Ethiopian contexts, change orders are repeatedly linked to time overruns, cost escalation, productivity loss, disputes, and, in extreme cases, early contract termination. These recurring findings identify change order approval as a critical weakness in construction project delivery systems.

A deeper synthesis reveals that approval delays stem from multiple interdependent domains, most commonly categorized as client-related, consultant-related, contractor-related, and external factors. Client-related issues such as delayed decisions, unclear objectives, and financial instability often act as initiating conditions. Consultant-related deficiencies, including design errors, incomplete documents, and weak coordination, operate as technical drivers that increase both the frequency and complexity of change requests. Contractor-related factors introduce operational pressures through constructability challenges, claims, and alternative proposals, while external factors contribute regulatory, market, and environmental uncertainty. Importantly, these domains do not function independently; rather, they interact and reinforce one another, thereby compounding approval difficulties and prolonging decision cycles.

Despite the extensive documentation of these factors, most existing studies remain largely descriptive. Both Ethiopian and international research predominantly employ conventional statistical techniques that treat delay factors as independent variables. While this approach has generated comprehensive lists and relative rankings of causes, it has provided limited insight into the causal structure of approval delays. Specifically, little attention has been given to how factors influence one another, which factors serve as root drivers, and which act primarily as dependent outcomes. Consequently, practitioners are left with limited strategic guidance on where interventions would produce the greatest systemic improvement.

Another important gap identified in the literature is the limited conceptualization of change order approval as a decision-making system. Although many studies acknowledge problems such as bureaucratic procedures, poor coordination, and slow responses, they rarely examine the structural relationships among technical, managerial, and institutional elements. Approval delays are therefore often framed as procedural inefficiencies rather than as systemic phenomena shaped by feedback loops, dependency structures, and hierarchical influences.

These limitations point to the necessity of moving beyond purely descriptive assessments and adopting a methodology that can explain why relationships occur. The research therefore requires an analytical approach that can handle uncertainty in expert judgments, rank qualitative factors systematically, and map the underlying cause–effect pathways among interdependent variables. In line with this need, systems-oriented multi-criteria decision-making methods offer a more robust foundation. The Fuzzy Analytic Hierarchy Process (Fuzzy AHP) supports the structured prioritization of factors when judgments are imprecise, whereas Fuzzy DEMATEL helps reveal the driving and influenced factors within a network of complex interactions.

This study views change order approval delays as the result of an interconnected system rather than isolated administrative weaknesses. By integrating Fuzzy AHP and Fuzzy DEMATEL, the research develops a causal framework that explains how delays are created, reinforced, and intensified in Ethiopian public building projects. To address the identified theoretical and methodological gaps, key delay factors are validated, prioritized, and analyzed based on their cause–effect relationships using a structured decision-support approach. Accordingly, the study adopts a hybrid framework that combines Delphi, FAHP, Fuzzy DEMATEL, and FQFD to incorporate expert knowledge, manage uncertainty, and translate analytical results into practical improvement strategies. The next chapter outlines the methodology and the step-by-step procedures used to implement this model.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. Introduction

This chapter presents the research methodology adopted to achieve the objectives of the study, which focuses on modeling the causal factors influencing change order approval delays in public building projects in Addis Ababa. It systematically describes the research approach and design, study area, population and sampling strategy, data sources, collection instruments, and data analysis techniques.

Change order approval processes in public construction projects are inherently complex. They involve multiple stakeholders, intertwined technical and administrative procedures, and heavy reliance on subjective expert judgments under conditions of uncertainty. Conventional descriptive methods are inadequate for capturing these dynamics. Therefore, this study adopts a pragmatic research approach centered on an integrated Fuzzy Analytic Hierarchy Process (FAHP), Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL), and FUZZY Quality Function Deployment (FQFD) framework. Fuzzy AHP is utilized to prioritize the critical factors based on expert judgments; Fuzzy DEMATEL examines the causal interrelationships and distinguishes root drivers from effect factors, while QFD translates the analytical findings into prioritized mitigation strategies. This hybrid methodology effectively links problem diagnosis with practical decision-making interventions for improving change order approval performance.

All data processing and analysis were conducted using Microsoft Excel and Python software to ensure accuracy, transparency, and computational efficiency. Excel was primarily used for organizing expert responses and structuring pairwise comparison and direct-relation matrices, while Python handled advanced fuzzy computations, consistency checks, matrix operations, defuzzification, and the integrated FAHP–FDEMATEL–FQFD prioritization. This combination leveraged the strengths of both tools within the study’s methodological framework.

3.2. Study Area

This study was carried out in Addis Ababa, the capital of the Federal Democratic Republic of Ethiopia. The city was deliberately chosen as the study area because it accommodates a large number of public building projects and serves as the country’s main administrative, political, and economic hub. Addis Ababa is home to numerous public institutions that function as project clients and involves a wide range of construction stakeholders, including government agencies, consulting firms, and contractors.

In addition, public building projects in Addis Ababa are implemented within a well-defined administrative and regulatory system that guides project approval procedures, contract administration, and the management of change orders. These institutional and procedural conditions reflect those commonly found in public construction projects throughout Ethiopia. As a result, Addis Ababa offers a suitable and representative setting for investigating the factors contributing to change order approval delays and for developing a causal modeling framework that can be applied to similar public building projects at the national level.

3.1. Location map

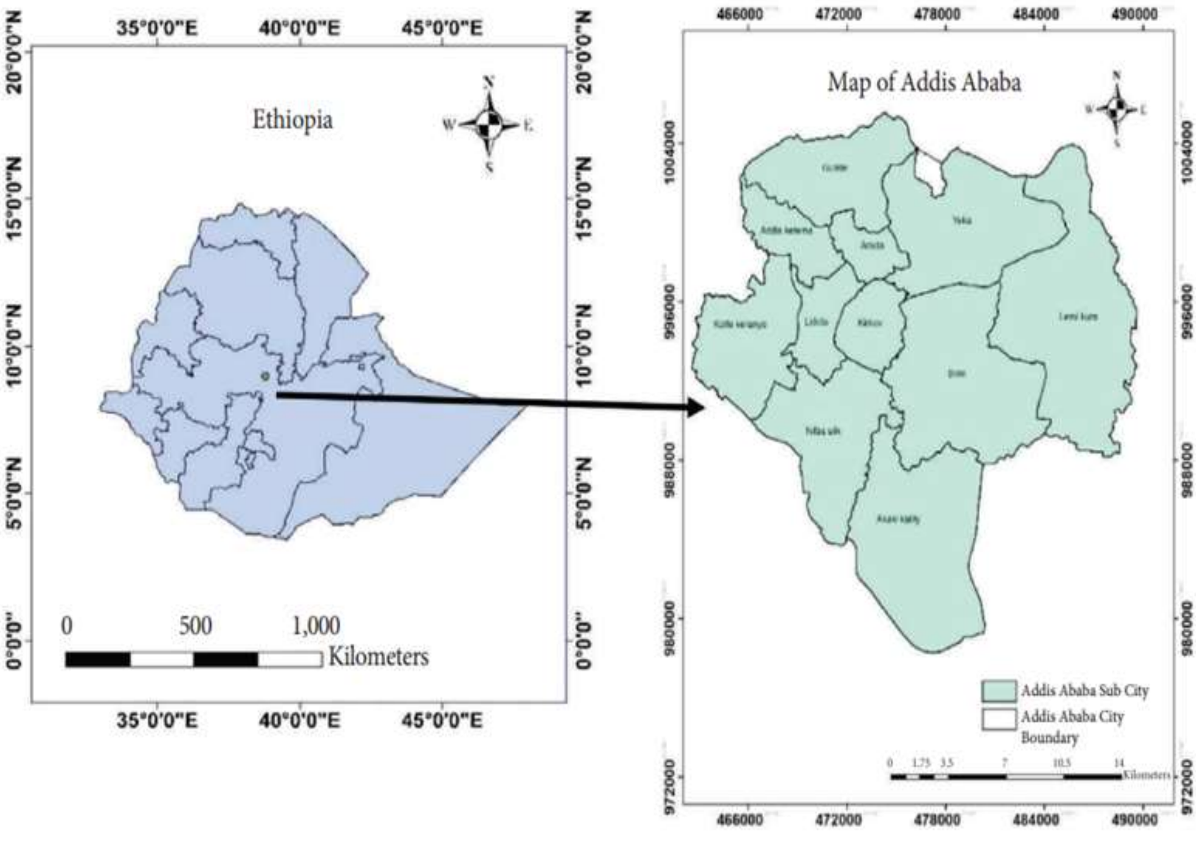

Figure3.1. Location of Study Map

3.3. Research Approach and Design

3.3.1. The Research Approach

This study adopts a pragmatic research approach, which emphasizes selecting research methods based on their suitability for addressing the research problem and achieving the study objectives rather than adhering to a single philosophical or methodological paradigm. Pragmatism is particularly appropriate for construction management research, where complex, real-world problems require practical and evidence-based solutions that integrate both qualitative and quantitative perspectives. Change order approval delays in public building projects arise from technical, procedural, contractual, and human-related factors, necessitating a flexible and problem-oriented research strategy. Because these delays are shaped by both objective project conditions such as administrative procedures, documentation systems, and contractual requirements and subjective human elements including professional experience, expert judgment, and decision-making behavior, relying exclusively on either qualitative or quantitative methods would be insufficient to capture the full complexity of the issue. Accordingly, the pragmatic paradigm supports the integration of expert knowledge with quantitative analysis to ensure a comprehensive evaluation of delay factors (Creswell & Clark, 2018; Teddlie, 2009).

Within this framework, expert judgments form the core source of data for identifying, assessing, and evaluating the relative importance of delay factors. These judgments are systematically converted into measurable inputs through pairwise comparisons, influence scores, and fuzzy linguistic scales, enabling rigorous mathematical and statistical analysis. The study therefore employs fuzzy multi-criteria decision-making (MCDM) techniques, which are well suited to complex construction problems characterized by uncertainty, interdependence, and imprecision in human assessments. The use of fuzzy logic enhances the model's capacity to handle ambiguity and subjective evaluations, while maintaining analytical robustness and replicability. By integrating expert knowledge with quantitative modeling, the research overcomes the limitations of purely descriptive or purely numerical approaches and produces objective, reliable, and scientifically defensible results (Zadeh, 1965; Saaty, 1980; Pedrycz, 1983; Huang, 2011).

The methodological core of the research is the integration of three complementary analytical techniques. The Fuzzy Analytic Hierarchy Process (FAHP) is employed to prioritize critical delay factors according to their relative importance; the Fuzzy Decision-Making Trial and

Evaluation Laboratory (FDEMATEL) is used to model the causal relationships and interdependencies among these factors; and Quality Function Deployment (QFD) translates the identified root causes into actionable and prioritized mitigation strategies. Together, these tools convert subjective expert assessments into structured analytical models that bridge practical knowledge with quantitative decision support. Overall, this quantitative, expert-driven, and MCDM-based framework provides a scientifically validated foundation for identifying, prioritizing, and modeling the causal drivers of change order approval delays, thereby supporting the development of evidence-based improvement strategies for public building projects (Fontela, 1972; Saaty, 1980) .

3.3.2. The Research Design and Framework

This study adopted an explanatory multi-method research design. The approach was chosen to provide not only a clear understanding of the factors influencing change order approval delays but also to uncover the complex ways in which these factors interact within the public building project environment in Addis Ababa. Rather than treating the problem as a collection of isolated issues, the design views delays in change order approval as outcomes of interconnected technical, organizational, institutional, and procedural dynamics. This perspective allowed the research to move beyond surface-level descriptions toward a deeper, more meaningful explanation of the underlying causes and potential solutions.

The overall research framework guiding the study is presented in Figure 3.2. It follows a systematic and progressive structure that begins with problem identification and a thorough review of existing literature. From this foundation, critical factors were identified and refined through a two round Delphi process involving seasoned professionals with extensive experience in public construction projects. This expert-driven validation ensured that the factors examined were both relevant and context-specific to the realities of Addis Ababa's construction sector.

A pilot study was subsequently carried out with five senior experts to test and improve the research instruments. Their feedback led to necessary refinements in the questionnaire, enhancing its clarity, logical flow, and overall effectiveness before the main data collection exercise. Once the instruments were finalized, the full survey was administered to gather expert judgments.

The analytical core of the framework integrates three complementary fuzzy multi-criteria decision-making techniques. First, the Fuzzy Analytic Hierarchy Process (FAHP) was employed to establish the relative importance of each critical factor. Next, the Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL) were used to explore the causal relationships and directional influences among these factors, distinguishing root causes from their resulting effects. These two methods together informed the development of a causal-chain model that illustrates how various factors trigger and amplify approval delays. Finally, Fuzzy Quality Function Deployment (FQFD) was applied to translate the identified root drivers into practical, prioritized mitigation strategies.

This integrated design reflects a conscious effort to bridge theoretical rigor with practical relevance. By combining expert consensus, systematic prioritization, causal mapping, and solution-oriented analysis, the framework offers a comprehensive pathway from problem diagnosis to actionable recommendations. It is hoped that this approach will contribute not only to academic understanding but also to meaningful improvements in the management of public building projects in Ethiopia.

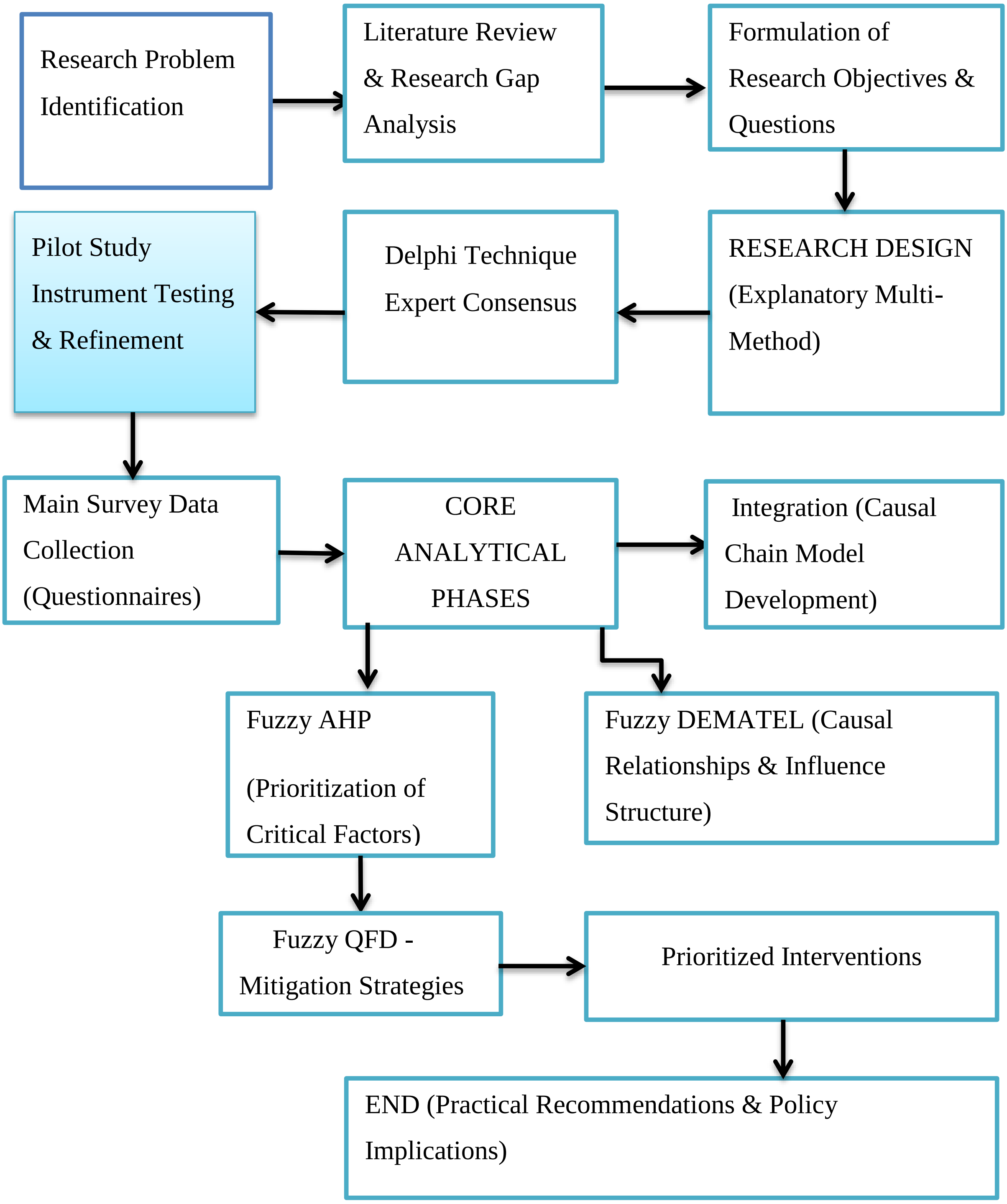

Figure 3.2: Research Design and Framework Flow Diagram

This diagram presents the integrated research design and methodological framework of the study. It adopts an explanatory multi-method approach that begins with problem identification and literature synthesis, followed by expert validation through the Delphi technique and pilot study. The core analysis integrates Fuzzy Analytic Hierarchy Process (FAHP) for prioritization, Fuzzy Decision-Making Trial and Evaluation Laboratory

(FDEMATEL) for causal modeling, and Fuzzy Quality Function Deployment (FQFD) for translating root causes into prioritized mitigation strategies, culminating in a causal-chain model and actionable recommendations for reducing change order approval delays in Addis Ababa's public building projects.

3.4. Population and Sampling Strategy

3.4.1. Target Population of the Study

The target population of this study consists of senior construction professionals with more than 10 years of relevant experience. These experts are directly involved in the planning, administration, design, supervision, and execution of public building projects in Addis Ababa. They were selected because they play central roles in the initiation, evaluation, negotiation, and approval of change orders, thereby providing firsthand knowledge essential to the research problem.

The population includes three main stakeholder groups. The first group consists of client representatives from public institutions, such as senior project managers and technical officers responsible for project oversight and contractual approvals. The second group comprises consultants, including experienced architects, engineers, and supervision experts who handle design changes and inter-party coordination. The third group includes contractors, particularly senior project managers and engineers who initiate change requests and manage on-site implementation.

These three groups represent the key actors in the change order approval process. Focusing on professionals with over 10 years of experience ensures mature and reliable expert judgments. The broader pool of professionals with similar qualifications in Addis Ababa is 450 individuals. For this study, a sample size of 5–20 participants drawn from this pool is feasible and appropriate. Such sample sizes are standard and acceptable in expert-based studies employing the Delphi technique, Fuzzy AHP, and DEMATEL methods, particularly in the Addis Ababa context where the number of highly qualified specialists is limited.

This approach ensures high-quality data while remaining practical for a researcher working in Addis Ababa. It effectively balances depth of expertise with methodological rigor, thereby supporting reliable causal modeling and practical recommendations for addressing change order approval delays in public building projects.

3.4.2. Sampling Technique

This study employed a purposive (judgmental) sampling technique to select participants who possess the knowledge and experience required to provide reliable expert judgments for the analysis. This approach is considered the most suitable technique when a study requires in-depth information from a select group of individuals who function as experts in a particular domain (Ilker Etikan, 2016). Purposive sampling is particularly appropriate for studies that rely on expert-based evaluation, where the depth and quality of respondents' expertise are more critical than the size of the sample. This approach is widely applied in Fuzzy AHP, Fuzzy DEMATEL and Fuzzy QFD studies, as these methods depend on informed professional judgment rather than statistical generalization (Huang, 2011).

Experts were deliberately selected based on specific criteria to ensure that the collected data accurately reflect practical conditions in public building projects. One key selection criterion was a minimum of ten years of professional experience in the construction industry, which ensures that respondents have sufficient exposure to project management processes and decision-making environments. In addition, participants were required to have direct involvement in public building projects, enabling them to provide context-specific insights relevant to the study area. Furthermore, practical experience in change order management was considered essential, as the study focuses on analyzing factors influencing change order approval delays.

By applying these selection criteria, the study ensured that the sampled experts were capable of providing informed, consistent, and credible judgments. The use of purposive sampling therefore enhances the reliability of the expert evaluations and supports the validity of the subsequent Fuzzy AHP, Fuzzy DEMATEL and Fuzzy QFD analyses. This sampling approach is consistent with the methodological requirements of expert driven multi criteria decision-making studies and aligns with the overall objectives of the research.

3.4.3. Sample Determination

The target sample size for this study was set at 5–20 completed questionnaires. This range is considered appropriate and robust for multi-criteria decision-making (MCDM) studies, which prioritize the quality, relevance, and consistency of expert judgments over large sample sizes for statistical generalization (Ortíz-Barrios & al., 2023).

Change order approval delays in public building projects are complex, context-specific issues that benefit more from deep insights provided by experienced professionals than from broad

Surveys. In expert-driven methodologies such as the Delphi technique, Fuzzy AHP, Fuzzy DEMATEL, and Fuzzy QFD, small to medium panels of qualified experts are standard and sufficient when participants possess substantial domain knowledge and practical experience.

To ensure transparency and address the composition of the expert panels across different phases of the research, the study used two distinct groups of experts. Table 3.4 presents a detailed breakdown of the expert composition, including the number of participants, stakeholder representation, and strict competency criteria for each phase.

Table 3.1: Expert Panel Composition and Competency Criteria across Research Phases

Research Phase	Number of Experts	Panel Group	Composition (Client / Consultant / Contractor)	Competency Criteria
Delphi Technique (Factor Identification & Validation) + Pilot Study (Instrument Refinement)	5	Group 1 (Dedicated Delphi Panel)	2 Client representatives 2 Consultants 1 Contractor	- Minimum 10 years of experience in public building projects in Addis Ababa - Direct involvement in at least 6 & above change order processes - Senior positions (e.g., Project Director, Lead Engineer, Contracts Manager) - Educational qualification: MSc preferred (minimum BSc in Civil Engineering or Construction Management)

Main Survey (Fuzzy AHP & Fuzzy DEMATEL) + Fuzzy QFD (Mitigation Strategy Prioritization)	15	Group 2 (Main Expert Panel – Different from Group 1)	5 Client representatives 5 Consultants 5 Contractors (QFD used a proportional of the same 15)	- Minimum 10 years of experience in public building projects - Direct involvement in change order evaluation, approval, or implementation in at least 6 major projects - Balanced representation across stakeholder groups - Educational qualification: BSc or MSc in Civil Engineering, Construction Technology & Management, or related fields - Currently active in public sector projects in Addis Ababa

The Delphi and Pilot Study phases used the same small panel of five highly experienced experts (Group 1). This group was kept entirely separate from the larger main survey panel to avoid bias and ensure independent perspectives. The Fuzzy AHP, Fuzzy DEMATEL, and Fuzzy QFD stages were conducted with a different panel of 15 experts (Group 2). A subset of 15 experts from this group participated in the QFD stage. All participants across both groups were purposively selected based on their relevant expertise, ensuring rich and credible data for the study.

3.5. Data Sources and Study Variables

3.5.1. Sources of Data

This study integrated both secondary and primary data sources. Secondary data were obtained through a comprehensive review of academic literature, government reports, and previous studies on change orders and construction delays in Ethiopia and other developing countries. This provided the initial long list of potential factors. Primary data consisted of structured expert judgments collected through questionnaires specifically designed for the Delphi technique, pilot study and Fuzzy AHP, Fuzzy DEMATEL, and Fuzzy QFD phases. These judgments formed the core empirical basis for factor validation, prioritization, causal modeling, and the development of mitigation strategies.

3.5.2. Variables of Study

The variables of the study were developed through a systematic, multi-stage process. An initial pool of over 50 potential factors was identified from the literature review. These were then refined and validated into a focused set of critical factors through the two-round Delphi technique involving five senior experts (Group 1). The validated factors were further tested and refined during the pilot study with the same panel.

The main survey, conducted with a separate panel of 15 experts (Group 2), provided the data for Fuzzy AHP prioritization and Fuzzy DEMATEL causal analysis. The root-driver factors identified from the DEMATEL results were subsequently used as inputs in the Fuzzy QFD phase (also with experts from Group 2) to map them against practical mitigation strategies. This progressive refinement ensured that the variables were both theoretically grounded and practically relevant to the realities of public building projects in Addis Ababa.

The variables were initially identified through a comprehensive review of change order literature. However, before being included in the analytical model, all variables were screened and validated through a two-round Delphi process to ensure their direct relevance to change-order approval delays rather than merely to change-order occurrence.

3.6. Data Collection Instruments

The primary data collection instrument for this study was a structured, self-administered questionnaire specifically designed to capture expert judgments for the integrated Fuzzy

Analytic Hierarchy Process (FAHP), Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL), and Fuzzy Quality Function Deployment (QFD) framework. The questionnaire was systematically developed based on a comprehensive literature review, the outcomes of two Delphi rounds for factor validation and refinement, and insights gained from a pilot study with five experienced professionals. These preparatory steps ensured that the instrument was contextually relevant to public building projects in Addis Ababa, clear in its instructions, logically structured, and practical for busy construction experts.

Prior to the main survey, the questionnaire underwent a rigorous pilot test to assess its clarity, relevance, and usability. The pilot combined the self-administered structured questionnaire with brief semi-structured interviews. Its main objectives were to verify that the ten critical factors were clearly worded and understandable, confirm the logical presentation of the FAHP pairwise comparisons and FDEMATEL influence ratings, and evaluate overall completion time and cognitive load. Five carefully selected experts (two client representatives, two consultants, and one contractor) who had participated in the Delphi phase but were excluded from the main survey provided feedback. Their input focused on instruction clarity, linguistic scale appropriateness, and the distinction between importance judgments (FAHP) and causal influence assessments (FDEMATEL). Qualitative comments were thematically analyzed, leading to minor refinements in wording, examples, and formatting to reduce ambiguity and respondent fatigue. These adjustments resulted in a final instrument that was clear, efficient, and well-suited for generating high-quality data for advanced fuzzy multi-criteria analysis.

The final questionnaire consisted of five logically sequenced sections that mirrored the sequential stages of the research methodology. This design created a natural progression from respondent profiling and factor validation to quantitative analysis and practical mitigation inputs.

The first section was gathered general background information about the respondents. It included questions on employment status (permanent, contractual, or temporary/daily), current designation (client representative, consultant, contractor, or other), years of relevant experience in public building projects, number of public building projects involved in, highest educational qualification, and gender. This section helped verify the expertise of participants and allowed for contextual analysis of responses across different stakeholder groups.

The second Section was focused on the validation and practical confirmation of the ten critical factors that emerged from the Delphi process and were further refined during the pilot study. This section presented each factor (coded F1 to F10) together with a clear, concise description. Respondents were asked to confirm whether these factors accurately reflected the main causes of change order approval delays based on their experience (Yes/No, with explanation if No), rate the overall relevance of the list (Very Relevant, Relevant, Moderately Relevant, or Not Relevant), and optionally suggest any additional factors. This validation step strengthened the content validity of the factors and ensured their applicability to real-world conditions in Addis Ababa's public building projects before moving to the analytical sections.

The third section was contained the core quantitative components aligned with the Fuzzy AHP methods and It was presented a pairwise comparison matrix. Experts evaluated the relative importance of each of the ten factors using the standard 1–9 linguistic scale (with corresponding triangular fuzzy numbers developed by (Saaty, 2008) ranging from '1 - Equally important' to '9 - Extremely more important'. This format required n (n-1)/2 comparisons, where n is the number of factors, a key reason why the number of variables was carefully distilled in the preliminary phase.

Respondents filled only the upper triangular part of the matrix, with the diagonal preset to 1. Clear instructions, a practical example, and guidance on maintaining logical consistency were included to improve response quality, incorporating feedback from the pilot study.

The fourth section was structured for the direct-relation matrix for the Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL) and it also contained the core quantitative components aligned with FDEMATEL. This section required a different cognitive task: instead of importance, respondents were asked to evaluate the degree of direct influence that each critical factor exerts on every other factor. A five-point linguistic scale was employed for this purpose: '0 - No influence', '1 - Low influence', '2 - Medium influence', '3 - High influence', and '4 - Very high influence' (with associated triangular fuzzy numbers). This scale is well-suited for capturing the directional, cause-and-effect relationships that are the focus of DEMATEL (Dalalah & Batieha, 2011). The diagonal was preset to zero, and instructions emphasized evaluating only direct influences based on practical experience. An illustrative example was provided to clarify the directional nature of the assessments. These two matrices supplied the essential data for prioritizing the factors (FAHP) and modeling their causal interrelationships (FDEMATEL) while accounting for uncertainty through fuzzy logic.

Section 5 collected qualitative inputs to support the Fuzzy Quality Function Deployment (QFD) phase. For each of the ten critical factors, respondents were asked to suggest one or two practical mitigation strategies based on their professional experience (e.g., processes, tools, policies, or coordination mechanisms). An optional open field allowed additional general comments on mitigating change order approval delays in Addis Ababa public building projects. This section bridged the diagnostic findings from FAHP and FDEMATEL with actionable recommendations, providing rich material for constructing the relationship matrix in the House of Quality and prioritizing interventions.

The questionnaire was designed to take approximately 30–45 minutes to complete, a timeframe refined through pilot testing to balance depth with practicality for busy professionals. Clear instructions, linguistic scales, and examples were provided throughout to minimize ambiguity. Participation was voluntary, all responses were treated with strict confidentiality, and the data were used solely for academic purposes. The instrument was distributed both electronically (via email) and in printed format according to respondent preference, with appropriate follow-up to achieve a good response rate.

By integrating validation, prioritization, causal modeling, and mitigation suggestions within one well-structured tool, the questionnaire effectively operationalized the study variables and delivered high-quality inputs for the integrated Fuzzy AHP–Fuzzy DEMATEL–Fuzzy QFD analysis.

The final phase of this research framework moves from diagnosis to solution through a specialized Quality Function Deployment (QFD) instrument. This stage acts as the vital link between understanding the problem and taking strategic action. QFD is highly regarded as a decision-support tool because it effectively transforms abstract stakeholder needs or complex problems into concrete, prioritized managerial steps (Hauser & Clausing, 1988) . By using this tool, the study builds a "House of Quality" (HOQ) based on expert insights. The focus here is on the "functional walls" of the matrix, where we systematically connect identified causal needs to practical, actionable solutions (Chan & Wu, 2002).

To ensure the study remains focused on direct, tangible impacts, the instrument specifically maps proposed mitigation strategies (the "How’s") against the root-driver factors (the "What’s") that emerged from the DEMATEL analysis. I have intentionally omitted the "correlation roof" of the house to keep the focus sharp on the alignment between problems and solutions, thereby simplifying the prioritization process for decision-makers. Because expert opinions often carry natural uncertainty, the instrument uses a fuzzy linguistic scale. This allows the model to respectfully capture the shades of grey and subjectivity inherent in human judgment when evaluating how well an intervention might work (Kahraman & Büyüközkan, 2006) .

By focusing on the relationship matrix (the core "walls" of the House of Quality), this study effectively links the identified challenges with practical mitigation strategies in the context of Addis Ababa's public building projects. This fuzzy-integrated approach goes beyond simple factor ranking to produce a scientifically grounded, actionable roadmap. It equips project stakeholders with clear priorities, enabling them to allocate resources more effectively and reduce change order approval delays.

3.7. Data Analysis Techniques and Tools

The analytical phase of this research was designed to transition from a broad identification of delay factors to a sophisticated modeling of their relative importance and causal interdependencies. To address the inherent ambiguity and subjectivity in expert judgments, the study integrated two advanced multi-criteria decision-making (MCDM) methodologies: Fuzzy Analytic Hierarchy Process (Fuzzy AHP), Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) and FQFD.

3.7.1. Computational Environment and Software

Data processing and analysis for this study were performed using Microsoft Excel and Python. Microsoft Excel was utilized for initial data organization, structuring expert judgment matrices, preliminary aggregations, and developing the House of Quality matrix in the Fuzzy QFD phase, owing to its accessibility and user-friendly interface for construction management data.

Python was employed as the primary tool for the core computational tasks. These included fuzzy number operations, matrix computations, consistency checks, defuzzification using the Center of Area (COA) method, FAHP priority weight calculation, FDEMATEL total-relation matrix development, and the full Fuzzy QFD analysis (relationship matrix weighting and technical prioritization). Leveraging powerful libraries such as NumPy and Pandas, Python provided the flexibility, precision, and transparency required for the integrated FAHP–

FDEMATEL–FQFD framework. All scripts were clearly documented to ensure reproducibility of the results.

3.7.2. The Delphi Technique for Consensus and Validation

To ensure the identification and refinement of critical factors influencing change order approval delays were grounded in expert consensus rather than subjective interpretation; this study employed the Delphi technique. This method, originally developed by the RAND Corporation in the 1950s for forecasting in uncertain environments (Dalkey & Helmer, 1963), is a structured, iterative process that solicits and aggregates anonymous opinions from a panel of experts to achieve convergence on complex issues. It is particularly suited for construction management research, where factors are multifaceted and influenced by contextual nuances, as it mitigates biases such as groupthink or dominant personalities through controlled feedback and anonymity (Hallowell & Gambatese, 2010).

In this study, the Delphi technique was applied over two rounds to distill an initial list of over 50 factors derived from a comprehensive literature review (as detailed in Appendix- I) into a validated set of the most critical ones for modeling. The panel consisted of five seasoned experts, purposefully selected based on stringent criteria: at least 10 years of experience in public building projects in Addis Ababa, representation across key stakeholder groups (two clients, two consultants, and one contractor), and involvement in at least six major projects. This composition ensured diverse perspectives while maintaining a manageable group size for in-depth analysis, consistent with Delphi best practices that recommend panels of 5–15 experts for specialized topics (Shang, 2023).

The process began with Round one, where experts independently rated each of the initial >50 factors on a 5-point Likert scale (1 = Not Relevant, 5 = Highly Relevant) and voted "Yes" or "No" on inclusion in the final list, providing brief justifications for "Yes" votes. Responses were aggregated anonymously, calculating mean relevance scores and the percentage of "Yes" votes. Factors meeting predefined thresholds mean relevance ≥4.0 and ≥80% "Yes" votes (i.e., at least 4 out of 5 experts) were prioritized for advancement, aligning with quantitative consensus criteria to enhance objectivity (Sandford, 2007). Experts also nominated any missing factors and suggested redundancies. Aggregated results, including anonymized feedback, were shared with the panel to inform Round two. The Delphi process was executed in two rounds as follows:

In Round two, the prioritized factors from Round one, plus any newly nominated ones, were re-evaluated using the same rating and voting mechanism. This iteration allowed experts to refine their judgments based on group insights, fostering convergence. Additional feedback on redundancies and merges was solicited to eliminate overlaps. Final aggregation focused on factors achieving the same thresholds, with expert-suggested merges applied to produce a concise, non-redundant list of 12 critical factors. This two-round structure balanced efficiency with rigor, as stability was achieved without needing further iterations (Gracht, 2012).

Data analysis was conducted using Microsoft Excel for aggregation, ensuring transparency and replicability. The technique's validity was bolstered by the experts' profiles (detailed in the results chapter) and the iterative feedback loop, which promoted consensus while respecting individual expertise. Ethical considerations, such as anonymity and voluntary participation, were upheld throughout. This Delphi application not only validated the factors for subsequent Fuzzy AHP and DEMATEL modeling but also bridged the gap between literature-derived insights and real-world applicability in Addis Ababa's public building context.

3.7.3. Fuzzy Analytic Hierarchy Process (Fuzzy AHP)

The Fuzzy Analytic Hierarchy Process (Fuzzy AHP) was employed to evaluate and establish the relative importance of the identified delay factors. This method was specifically chosen to address the limitations of traditional AHP by effectively managing the inherent subjectivity and cognitive uncertainty found in expert evaluations (Buckley, 1985).

Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is an established multi-criteria decision-making technique that integrates classical Analytic Hierarchy Process with fuzzy set theory to handle the vagueness and imprecision inherent in expert judgments when prioritizing complex factors (Alharairi, Amin, Zolfaghari, & Fang, 2025). The application of Fuzzy Analytic Hierarchy Process (Fuzzy AHP) in this study is intended to prioritize the critical factors influencing change order approval delays in public building projects. Because the problem involves subjective professional judgments and uncertainty, fuzzy logic is integrated to better capture the way experts naturally express their opinions using linguistic terms. The inputs to this stage consist of expert responses collected through structured questionnaires, where specialists compare identified factors in pairs based on their relative importance to change order approval delays. These linguistic evaluations are converted into fuzzy numbers and organized into fuzzy pairwise comparison matrices, which are then aggregated to represent the collective judgment of the expert panel.

The main outputs of the Fuzzy AHP analysis are the normalized weights and priority rankings of the critical factors. These results provide a clear measure of the relative importance of each factor and establish a validated priority structure grounded in professional experience. This stage directly supports the first specific objective of the study, which is to identify and prioritize the critical factors influencing change order approval time in public building projects. In addition, the resulting prioritized factor set forms a reliable analytical foundation for the subsequent Fuzzy DEMATEL analysis, ensuring that the causal modeling phase is built upon systematically weighted and context-relevant variables.

The implementation of this technique followed a systematic, multi-step procedure to ensure mathematical rigor and practical relevance. Initially, the research problem was organized into a clear hierarchical structure, linking the primary goal Prioritization of factors influencing change order approval delays of the study to the critical factors under investigation. This hierarchical representation clarifies the relationships between the research goal and the contributing factors and forms the basis for pairwise comparisons (Saaty, 1980).To capture professional expertise accurately; data was gathered through pairwise comparisons using intuitive linguistic scales, which were subsequently translated into triangular fuzzy numbers to represent the range of human judgment more realistically.

To ensure a balanced consensus, individual expert judgments were consolidated into a single unified matrix using the geometric mean method. Following this aggregation, the fuzzy synthetic extent method was applied to calculate the fuzzy weights for each specific factor. To make these findings actionable and easy to interpret for project managers, the fuzzy weights were converted into distinct crisp numerical values through the Center of Area (COA) defuzzification method. Finally, these values were normalized and ranked, providing a clear and prioritized list that identifies which factors exert the most significant influence on change order approval delays.

In this study Fuzzy AHP is used to prioritize the critical factors influencing change order approval delays.

The resulting weights serve two purposes: To identify the most influential factors based on expert judgment and to provide structured inputs for subsequent causal modeling using Fuzzy

DEMATEL. This ensures that both the importance and the causal influence of factors are systematically addressed.

The FAHP implementation followed a systematic multi-step procedure as described below.

Step 1: Construction and aggregation of Fuzzy Pairwise Comparison Matrices

A linguistic evaluation scale was first established and transformed into corresponding triangular fuzzy numbers, which were then used to construct fuzzy pairwise comparison matrices from expert judgments and subsequently aggregated into a single consensus matrix representing the collective evaluation of the expert panel.

Experts express their judgments using linguistic terms, which are converted into triangular fuzzy numbers (TFNs) defined as:

$$\tilde{a} = (l, m, u)$$

Where:

- l = lower bound
- m = most probable
- u = upper bound

With $l \leq m \leq u$

Saaty (1980) proposed using a 1-to-9 scale for pairwise comparisons between two elements (refer to Table). For instance, a value of 7 indicates that one element is of Very strong important compared to the other, while a value of 6 signifies that its importance lies between “strong” and “very strong” relative to the other element, a typical linguistic scale (see table 3.1).

Table3.2: A typical linguistic scale of FAHP

Scale	Linguistic term	TFN	Reciprocal values
1	Equal importance	(1, 1, 1)	(1,1,1)
2	Weakly more important	(1, 2, 3)	(1/3,1/2,1/1)
3	Moderate importance	(2, 3, 4)	(1/4,1/3,1/2)
4	Moderately strong important	(3, 4, 5)	(1/5,1/4,1/3)
5	Strong importance	(4, 5, 6)	(1/6,1/5,1/4)
6	Strong to very strong important	(5, 6, 7)	(1/7,1/6,1/5)
7	Very strong important	(6, 7, 8)	(1/8,1/7,1/6)

8	Very to extremely strong important	(7, 8, 9)	(1/9,1/8,1/7)
9	Extreme importance	(8, 9, 9)	(1/9,1/9,1/8)

The reciprocal of a fuzzy number is defined as:

$$\tilde{a}^{-1}\left(\frac{1}{u},\frac{1}{m},\frac{1}{l}\right)$$

For each level of the hierarchy, a fuzzy pairwise is constructed see Eq3.1.

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & (1,1,1) \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3.1]$$

Where $\tilde{a}ij$ Represents the fuzzy importance of factor *i* over factor *j*.

Multiple experts are involved; their judgments' are aggregated using the fuzzy geometric mean see Eq3.2.

$$\tilde{a}_{ij} = \left(\prod_{k=1}^{K} u_{ij}^{k}\right)^{\frac{1}{k}} , \left(\prod_{k=1}^{K} u_{ij}^{k}\right)^{\frac{1}{k}}, \left(\prod_{k=1}^{K} u_{ij}^{k}\right)^{\frac{1}{k}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3.2]$$

Where K; is the number of experts. This step synthesizes individual opinions in to a single representative fuzzy matrix.

Step 2: Consistency verification of the initial judgments

Before deriving final weights, the logical consistency of expert judgments must be examined. Since direct consistency indices for fuzzy matrices are still theoretically debated, this study verifies consistency by defuzzifying the aggregated fuzzy matrix into a crisp matrix using the center of area method COA (Liu, 2020).

$$a_{ij} = \frac{l_{ij} + m_{ij} + u_{ij}}{3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3.3]$$

The resulting crisp matrix is then tested using the classical AHP consistency procedure (Saaty, 1980). The principal eigenvalue λmax is obtained, and the Consistency Index (CI) is computed as:

$$CI = \frac{\lambda_{max} - n}{n-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3.4]$$

The Consistency Ratio (CR) is calculated as:

$$CR = \frac{CI}{RI} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots [3.5]$$

Where RI is the random index corresponding to matrix order n, Decision rule (Saaty, 1980) Judgments are considered acceptable if CR<0.10. If the threshold is exceeded, experts are requested to review and revise their comparisons. This step ensures the rational coherence of expert evaluations and strengthens the credibility of the derived priorities.

A critical step in ensuring the reliability of expert judgments in the Fuzzy AHP involves checking the consistency of pairwise comparisons. The Consistency Ratio (CR) is calculated by comparing the Consistency Index (CI) against a Random Index (RI) value that corresponds to the size of the comparison matrix. These RI values, originally developed by Saaty, represent the average consistency expected from randomly generated matrices of varying orders. For instance, the RI for a 3×3 matrix is 0.58, a 10×10 matrix is 1.49 rising gradually to 1.48 for a 12×12 matrixes. In this study, all aggregated expert matrices achieved CR values well below the acceptable threshold of 0.10, confirming that the judgments were logically consistent and suitable for further fuzzy synthetic extent analysis and prioritization.

Step 3: Calculation of fuzzy synthetic extent values

Following (Chang D.-Y. , 1996), extent analysis method, the fuzzy synthetic extent for each criterion is computed see Eq3.6.

First, the fuzzy sum of each row:

$$\sum_{j=1}^{n} \tilde{a}_{ij} = \left(\sum l_{ij}, \sum m_{ij}, \sum u_{ij},\right) \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots [3.6]$$

Then, the fuzzy sum of all elements:

$$\sum_{i=1}^{n} \sum_{j=1}^{n} \tilde{a}_{ij} = \left(\sum l_{ij}, \sum m_{ij}, \sum u_{ij},\right) \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots [3.7]$$

The fuzzy synthetic extent value is:

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{a}_{ij} \otimes \left(\sum_{i=1}^{n} \sum_{j=1}^{n} \tilde{a}_{ij}\right)^{-1} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots [3.8]$$

Where $\otimes$ denotes fuzzy multiplication and $(\ )^{-1}$ represents the fuzzy inverse. This step determines the relative dominance of each factor under uncertainty.

Step 4: Determination of degree of possibility

The degree of possibility that $\tilde{S}_i$ is greater than $\tilde{S}_j$ is defined as:

$$V(\tilde{S}_i \geq \tilde{S}_J) = \begin{cases} 1, & if\ m_i \geq m_j \\ 0, & if\ l_j \geq ui \\ \dfrac{l_j - u_i}{(m_i - u_i) - (mj - lj)}, & otherwise \end{cases} \quad \ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots [3.9]$$

This expresses the likelihood that one fuzzy number is greater than another and forms the basis for weight derivation (Chang D.-Y. , 1996).

Step 5: Determination of normalized weight vector and Final Priority Ranking ((by descending weight)

For each criterion:

$$d_i = minV(\tilde{S}_i \geq \tilde{S}_J) = , i \neq j \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots\ldots\ldots [3.10]$$

The preliminary weight vector or unnormalized weight vector is:

$$W' = (d1, d2, \ldots\ldots\ldots, dn)$$

The normalized weight vector is:

$$W_i = \frac{d_i}{\sum_{i=1}^{n} d_i} \ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots\ldots\ldots [3.11]$$

These values represent the weight and priorities of the criteria then ranked according to descending order of W.

3.7.4. Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL)

The Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) is an advanced extension of the classical DEMATEL method, which combines fuzzy set theory with DEMATEL to model and visualize causal interrelationships among complex factors under uncertainty (Abdullah & Goh, 2019). The purpose of employing the Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) method in this study is to examine the causal relationships among the critical factors influencing change order approval delays and to model their interaction structure. While Fuzzy AHP establishes the relative importance of factors, it does not explain how these factors influence one another. Therefore, Fuzzy DEMATEL was applied to uncover the direction and strength of influence between factors and to distinguish root-driver causes from resulting effects. The primary inputs to this stage are expert assessments of the degree of influence between pairs of factors, expressed using linguistic terms and transformed into fuzzy values. These evaluations are compiled into an initial fuzzy direct-relation matrix that reflects the collective perception of interdependencies within the change order approval system.

The main outputs of the Fuzzy DEMATEL analysis include the total relation fuzzy matrix and the computed influence indicators (D and R values), which allow the classification of factors into cause and effect groups. These outputs are further used to construct a causal diagram that visually represents the influence structure governing change order approval delays in public building projects. This stage directly fulfills the second and third specific objectives of the study, which aim to analyze the causal interrelationships among factors and to identify the fundamental driver factors responsible for approval delays. Moreover, the causal results provide the analytical basis for developing the strategic mitigation framework, thereby supporting the final objective of proposing targeted, evidence-based guidance for stakeholders.

To investigate the complex interdependencies and hidden influences between the identified factors, this study employed the Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) method. While importance ranking explains what factors are significant, DEMATEL is essential for understanding the "why" and "how" by mapping out whether a factor acts as a root cause or a resulting effect within the system (Fontela, 1972). The implementation of this technique followed a logical, step-by-step progression to ensure the results were both mathematically sound and easy to interpret. Initially, a fuzzy direct-relation matrix was constructed to capture expert opinions on how much each factor directly impacts another. To form a collective view, these individual expert assessments were merged into a single, unified fuzzy matrix. To make the complex fuzzy data understandable for practical use, before normalization matrix it was converted into simple crisp numbers using the Center of Area (COA) method.

This matrix was then normalized to standardize the data, allowing for the calculation of the total-relation matrix through matrix operations in Excel. This crucial step identifies both the direct and indirect connections between all factors.

From this, two key values were calculated for every factor: D (dispatching influence), which shows how much a factor affects others, and R (receiving influence), which shows how much it is affected by others. By looking at the difference between these two values (D−R), the study successfully categorized factors into two groups: Cause factors, which are the primary drivers of delays, and "Effect" factors, which are the symptoms. Finally, a cause-effect diagram was created to visually map these relationships, providing a clear and simple roadmap for decision-makers to target the root sources of change order approval delays. in this study Fuzzy DEMATEL Computational Procedure are presents the mathematical formulation of the Fuzzy DEMATEL method adopted to model the causal relationships among the factors influencing change order approval delays in public building projects. By using general Formula with step as follows:-

The Identification of factors, linguistic terms, and fuzzy scale are the set of influencing factors be defined as:

$$F = \{F_1, F_2 \ldots . F_n\}$$

Experts evaluated the direct influence of factor F$i$on factor F$j$using linguistic terms. These linguistic judgments were transformed into triangular fuzzy numbers (TFNs) to handle uncertainty and vagueness (Wu & Lee, 2007).linguistic scale adopted in this study.

Table 3.3: linguistic scale of FDEMATEL

Scale	Linguistic term	Triangular fuzzy number (l, m, u)
0	No influence	(0, 0, 0.25)
1	Low influence	(0, 0.25, 0.50)
2	Medium influence	(0.25, 0.50, 0.75)
3	High influence	(0.50, 0.75, 1.00)
4	Very high influence	(0.75, 1.00, 1.00)

These fuzzy numbers represent the minimum, most likely, and maximum possible degrees of influence.

Step 1: Construction and aggregation of the fuzzy direct-relation matrix

In order to identify the model of the relations among the n criteria, an n × n matrix is first generated. The influence of the element in each row exerted on the element in each column of this matrix can be represented a fuzzy number. If multiple k experts' participated, their opinions are used; all experts must complete the matrix. Arithmetic mean of all of the experts' opinions is used to generate the direct relation matrix z.

Their judgments were aggregated into a single collective matrix as follow (Tzeng & Li, 2009):

$$\tilde{z}_{ij} = \left(\frac{1}{k}\sum_{r=1}^{k} l_{ij,}^{r}\ \frac{1}{k}\sum_{r=1}^{k} m_{ij}^{r},\frac{1}{k}\sum_{r=1}^{k} u_{ij}^{r}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3.13]$$

The final fuzzy direct-relation matrix (also called original aggregated matrix) is $Z\tilde{}$:

$$\tilde{Z} = \begin{bmatrix} (0,0,0) & \tilde{z}_{12} & \cdots & \tilde{z}_{1n} \\ \tilde{z}_{21} & (0,0,0) & \cdots & \tilde{z}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \tilde{z}_{n2} & \cdots & (0,0,0) \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3.14]$$

Where: the diagonal elements are set to zero:

$$\tilde{z}_{ij} = l_{ij,}\ m_{ij,}u_{ij} \qquad\qquad \tilde{z}_{ii} = (0,0,0)$$

Step 2: Defuzzification of the direct-relation matrix (before normalization)

To perform matrix calculations, the fuzzy direct-relation matrix was converted into a crisp matrix. In this study, defuzzification was conducted before normalization, following common practice in Fuzzy DEMATEL applications (Wu et al., 2007).

The Center of Area (COA) method was used:

$$Z_{ij} = \frac{l_{ij} + m_{ij} + u_{ij}}{3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3.15]$$

The crisp direct-relation matrix is:

$$Z = \begin{bmatrix} 0 & \cdots & \tilde{z}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \cdots & 0 \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3.16]$$

This matrix represents the aggregated direct influence among all factors.

Step 3: Normalization of the fuzzy direct-relation matrix

By normalizing the average matrix Z, normalized direct-relation matrix X can be obtained in which this step ensures that all values lie between 0 and 1 (Fontela, 1972). (See Equations, 3.17 and 3.18), where S is the maximum value among the sum of direct relation matrix Z values in each row or column.

$$S = max\left(max_i \sum_{j=1}^{n} z_{ij}\ ,max_j \sum_{i=1}^{n} z_{ij}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3.17]$$

$$X = [x_{ij}] = \frac{1}{s} Z \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. [3.18]$$

Step 4: Computation of the total-relation matrix T.

The total relation matrix T is an (n x n) matrix incorporates both direct and indirect effects among the factors and is calculated by Eq.3.19, Where the matrix T = $[t_{ij}]$ reflects the overall influence that factor *i* exerts on factor *j* through all possible interaction paths. *I* is the identity matrix.

$$T = X\left(I - X\right)^{-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. [3.19]$$

Step 5: Determination of causal indicators

The sum of each row D of matrix *T* represents the total influence given by factor *i* (dispatching influence) and The sum of each column R of matrix *T* represents the total influence received by factor *I* (receiving influence) respectively (see Equations 3.20 and 3.21) respectively.

$$D_i = \sum_{j=1}^{n} t_{ij} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. [3.20]$$

$$R_i = \sum_{i=1}^{n} t_{ij} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. [3.21]$$

The overall importance (prominence) of each factor indicates the degree of influence.is determined by Eq.3.22.

$$D\,i + R\,i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. [3.22]$$

The net causal effect the relation vector which may divide factors into cause-and effect group is identified by Eq.3.23.

$$D\,i - R\,i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. [3.23]$$

If $D_i - R_i > 0$ a positive value of $D_i - R_i < 0$ indicates that the factor belongs to the cause group; whereas a negative value indicates that the factor is part of the effect group (Wu & Lee, 2007).

Step 6: Threshold value (α) and causal (a cause-and-effect relationship) diagram

The total relation matrix T represents the intensity of direct and indirect influences among the identified factors. However, not all relationships reflected in this matrix are meaningful for interpretation. Therefore, a threshold value (α) is introduced to remove negligible effects and to highlight only the most influential relationships when constructing the causal digraph.

In this study, the threshold value is objectively defined as the mean value of all elements in the total relation matrix T. This statistical measure provides a rational basis for separating significant interactions from weak ones and has been widely applied in DEMATEL-related research.

The threshold value is calculated using the following expression Eq (3.24).

$$\alpha = \frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. [3.24]$$

Where t_{ij} denotes the element in row i and column j of matrix T, and n is the total number of factors considered.

All matrix elements of T that are smaller than α; are set to zero (If t_{ij} < α then t_{ij}= 0) (Li & Tzeng, 2009). The remaining values were employed to construct the causal influence diagram, which graphically depicts the dominant relationships and the underlying structure of influence among the delay factors.

Thea cause-and-effect relationship diagram (causal diagram) is constructed using onto two planes,

Horizontal axis: $D\ i + R\ i$

Vertical axis: $D\ i - R\ i$

This diagram clearly distinguished the driving and dependent factors affecting change order approval delays.

3.7.5. Fuzzy Quality Function Deployment (FQFD)

Fuzzy Quality Function Deployment (Fuzzy QFD) was employed as the final analytical stage of this study to transform the prioritized and causally validated delay factors into practical managerial interventions. While the Fuzzy Analytic Hierarchy Process (FAHP) determines the relative importance of delay factors and Fuzzy DEMATEL reveals their causal relationships, these methods primarily provide diagnostic insights and do not explicitly identify which improvement strategies should be implemented. Therefore, Fuzzy QFD was adopted as a prescriptive decision-support tool that systematically links the critical delay factors with appropriate mitigation strategies.

Quality Function Deployment was originally introduced as a structured planning methodology for converting customer requirements into technical specifications through the House of Quality matrix (Akao, 1990). However, expert judgments in construction management are often uncertain and expressed linguistically rather than numerically. Consequently, fuzzy set theory was integrated into the QFD framework to accommodate this uncertainty by representing qualitative judgments with triangular fuzzy numbers (Zadeh, 1965; Kahraman & Büyüközkan, 2006) . This integration improves the reliability and realism of expert evaluations while preserving the ambiguity inherent in human reasoning.

The implementation of the Fuzzy QFD framework followed a systematic sequence. First, a simplified House of Quality relationship matrix was developed. The root-driver factors identified through the integrated FAHP–DEMATEL analysis were designated as the "WHATs", while the proposed mitigation strategies were treated as the "HOWs." The normalized importance weights obtained from the FAHP analysis were directly assigned to the corresponding delay factors. Since the objective of this research was strategic prioritization rather than product design, only the relationship matrix of the House of Quality was utilized.

The exclusion of the House of Quality roof (correlation matrix) was intentional and methodologically justified. First, the research focuses on managerial prioritization rather than technical product design; thus, the 'relationship wall' is the essential tool for linking root causes to solutions. Second, this streamlined approach ensures data reliability by preventing expert fatigue within the already complex triple-integrated framework of Fuzzy AHP, DEMATEL, and QFD. Third, the systemic interdependencies typically captured by the 'roof' were already rigorously mapped during the Fuzzy DEMATEL phase, making a secondary correlation analysis redundant. Finally, this focused model produces a clear Prioritization Index (PI), offering stakeholders in Addis Ababa a practical, high-impact roadmap that avoids unnecessary technical complexity.

After constructing the House of Quality, experts evaluated the strength of the relationship between each delay factor and each mitigation strategy using linguistic assessments. These qualitative judgments were subsequently converted into triangular fuzzy numbers and aggregated mathematically to ensure an objective prioritization process. The normalized importance weight of each delay factor, denoted by wi; is obtained from the FAHP results, while the relationship between delay driver i and mitigation strategy $j$is expressed as a fuzzy value$\tilde{R}_{ij}$; to capture the uncertainty inherent in human judgment, these relationships are modeled using triangular fuzzy numbers and organized into a fuzzy relationship matrix, where each element is defined as $\tilde{R}_{ij} = (l_{ij}, m_{ij}, u_{ij})$

Where l_{ij}, m_{ij} and u_{ij}denote the lower, most probable, and upper bounds of the expert assessment, respectively. All relationship values collectively form the fuzzy relationship matrix:

$$\tilde{R} = \begin{bmatrix} \tilde{R}_{11} & \tilde{R}_{12} & \cdots & \tilde{R}_{1n} \\ \tilde{R}_{21} & \tilde{R}_{22} & \cdots & \tilde{R}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{R}_{m1} & \tilde{R}_{m2} & \cdots & \tilde{R}_{mn} \end{bmatrix} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots [3.25]$$

Third, the overall significance of each mitigation strategy was determined by combining the weighted influence of all relevant delay factors. This was achieved through a weighted fuzzy aggregation process, which integrates the contributions of individual factors to produce a comprehensive priority score for each strategy. The fuzzy prioritization index for strategy

j was computed using:

$$\tilde{p}_{ij} = \sum_{i=1}^{m} \widetilde{W}_i \otimes \tilde{R}_{ij} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots [3.26]$$

Where $\widetilde{W}_i$denotes the fuzzy weight of factor i, $\otimes$ represents fuzzy multiplication, and m is the total number of delay factors (Huang, 2011).

For triangular fuzzy numbers, the multiplication is performed as:

$w_i \otimes (\widetilde{W}_i l_{ij}, m_{ij}, u_{ij})$=$(w_i l_{ij}, w_i m_{ij}, w_i u_{ij})$

Accordingly, the aggregated fuzzy score

Becomes $\tilde{p}_{ij} = (\sum w_i l_{ij}, \sum w_i m_{ij}, \sum w_i u_{ij})$

Fourth, to enable straightforward comparison among strategies, the fuzzy values are defuzzified using the Center of Area (COA) method:

$$S_j = \frac{l_j + m_j + u_j}{3} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..\dots\dots\dots\dots\dots\dots [3.27]$$

The resulting crisp score S_j represents the overall effectiveness of each mitigation strategy. Strategies are ranked in descending order of S_j , where higher values indicate greater potential to reduce change order approval delays.

Finally, mitigation strategies were ranked according to their defuzzified scores. Strategies with higher scores were interpreted as having greater potential to reduce change order approval delays and were therefore prioritized for implementation.

Through this structured procedure, Fuzzy QFD ensures that analytically identified root causes are directly translated into practical and evidence-based improvement actions, thereby enhancing the applicability of the integrated FAHP–DEMATEL–FQFD framework for complex construction decision problems.

To address the uncertainty and subjectivity inherent in expert evaluations during the Fuzzy QFD analysis, linguistic judgments describing the strength of relationships between change order approval delay factors and strategic mitigation actions were represented using triangular fuzzy numbers. Because experts naturally express their assessments through qualitative terms such as weak, medium, and strong rather than precise numerical values, fuzzy set theory was adopted to translate these linguistic expressions into measurable quantitative forms. This transformation preserves the ambiguity of human reasoning while enabling consistent mathematical computation within the House of Quality matrix. Following established practices in fuzzy multi-criteria decision-making and QFD applications, a standardized three-level linguistic scale was employed to convert each relationship strength into its corresponding triangular fuzzy number, thereby improving reliability, comparability, and aggregation of expert judgments (Zadeh, 1965; Siamak Noori, 2014; Akao, 1990) The linguistic scale adopted in this research is presented in the following.

In the Fuzzy QFD phase, experts evaluated the strength of relationships between root-driver factors (the “WHATs”) and proposed mitigation strategies (the “HOWs”) using a simple yet robust linguistic scale. This scale translates qualitative assessments into triangular fuzzy numbers, allowing the model to capture uncertainty while maintaining mathematical rigor.

- A Weak relationship (denoted as W) indicates minimal or indirect linkage, represented by the triangular fuzzy number (0, 0, 0.3)
- A Medium relationship (M) reflects a moderate but meaningful connection, captured by (0.3, 0.5, and 0.7).

- A Strong relationship (S) signifies a powerful, direct influence, expressed as (0.7, 1, 1)

Experts were instructed to assign one of these three linguistic terms (W, M, or S) to each intersection in the House of Quality matrix based on their professional experience. This fuzzy linguistic approach enabled nuanced aggregation across the fifteen experts and facilitated the computation of precise prioritization indices for each mitigation strategy. This scale allows qualitative managerial perceptions to be consistently transformed into quantitative fuzzy values suitable for mathematical aggregation.

Consistent with systems thinking principles (Sterman, 2000) , the Fuzzy QFD phase deliberately prioritizes the root-driver (cause-group) factors identified in the Fuzzy DEMATEL analysis (F8, F1, F3, F10, and F2). These factors exhibit positive net influence (D–R > 0) and function as fundamental leverage points within the system. Interventions targeting root drivers generate high-leverage, cascading improvements across the entire causal network, including prominent effect factors and bottlenecks such as F7 (poor logistics and material supply control, highest D+R prominence).

Focusing QFD exclusively on drivers avoids dilution of strategic focus and prevents symptomatic treatment that fails to address recurrence. Highly prominent effect factors (e.g., F7) represent critical operational bottlenecks but are downstream symptoms. Direct intervention on them yields limited sustainability without controlling upstream drivers. The causal-chain model (Section 4.6) and total-relation matrix confirm that strengthening root drivers naturally alleviates bottlenecks through propagated effects. This selective transfer aligns with established hybrid MCDM applications in complex project systems, where root-cause targeting maximizes impact (Huang, 2011; Wu & Lee, 2007). Prominent effect factors are indirectly addressed via the systemic improvements and are discussed in sensitivity analysis and practical implications sections.

3.7.6. Synthesis and Fuzzy QFD Prioritization Analysis

The final stage of the methodological framework involves the integration and synthesis of the Fuzzy Analytic Hierarchy Process (FAHP), Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL), and Fuzzy Quality Function Deployment (FQFD) to convert the analytical findings of the preceding stages into prioritized and implementable managerial interventions. While FAHP and FDEMATEL individually provide valuable diagnostic insights, they do not directly produce actionable solutions. FAHP primarily quantifies the relative importance of delay factors, whereas FDEMATEL reveals the structural interdependencies and causal mechanisms among them. However, effective project management requires not only identifying critical and causal factors but also determining which corrective actions should be implemented first. Therefore, a synthesis mechanism is required to transform analytical outputs into strategic decisions. For this reason, the present study employs Fuzzy QFD as a translation tool that links prioritized delay drivers with targeted mitigation strategies, thereby bridging the gap between diagnosis and implementation.

The synthesis begins with FAHP, where expert pairwise comparisons are expressed using triangular fuzzy numbers to capture ambiguity in human judgment. After aggregation and defuzzification, the normalized weight of each delay factor is computed as $w_i = W_i / \sum_i^n W_i$, representing its proportional contribution to overall delays. These weights are then incorporated into the FDEMATEL analysis to examine interdependencies among factors. Using the total-relation matrix, the influence dispatched and received by each factor is calculated as

$D_i = \sum_{j=1}^{n} t_{ij}$ And $R_i = \sum_{j=1}^{n} t_{ij}$ .while prominence and causality are determined from

$D\ i + R\ i$, and $D\ i - R\ i$ respectively, Factors with Positive $D\ i - R\ i$, distinguishes between drivers and dependent factors. Factors with positive causality values are classified as causal drivers, whereas negative values indicate effect factors.

Finally, the causal drivers are transferred to the Fuzzy Quality Function Deployment stage, where only the relationship wall of the House of Quality is constructed to directly link delay causes (WHATs) with mitigation strategies (HOWs). Consistent with systems thinking principles, this methodological decision prioritizes high-leverage interventions at the root causes of the problem rather than its symptoms. In complex systems such as public change order approval processes, addressing fundamental drivers generates cascading improvements across the entire system, including highly prominent effect factors that act as operational bottlenecks.

Although highly prominent effect factors (those with high prominence (D+R) but negative relation (D–R) values) play a significant role in day-to-day delays, they are largely downstream outcomes of the root drivers. Directly incorporating them into the QFD House of Quality as primary inputs could shift the focus toward reactive symptom management. By contrast, mapping mitigation strategies exclusively against the causal drivers ensures that the proposed solutions are strategic, systemic, and sustainable.

The prominent effect factors were not disregarded. They are explicitly visualized and discussed in the Influential Relation Map (Figure 4.3), the Cause-and-Effect diagram (Figure 4.2), and the proposed Causal-Chain Model (Figure 4.4). These factors serve as critical performance indicators for monitoring the effectiveness of the driver-focused mitigation strategies developed through Fuzzy QFD.

Recommendation for Future Enhancement While the current focused approach is appropriate for achieving strategic, systemic improvement. Future studies or implementation phases could adopt a two-tier QFD model: one tier focused on root drivers for long-term strategic solutions and a second tier addressing the most prominent effect factors for immediate operational improvements.

This methodological design choice strengthens the study's contribution by providing a causally grounded, high-leverage mitigation framework tailored to the complex realities of public building projects in Addis Ababa.

This focused approach maintains methodological coherence within the integrated FAHP–FDEMATEL–FQFD framework and aligns with the study's objective of developing a robust causal modeling and decision-support system for reducing change order approval delays in public building projects.

Experts assess the strength of each relationship using fuzzy linguistic scales to form the relationship matrix$\tilde{R}_{ij}$, and finally, the selected drivers and their FAHP weights are incorporated into the Fuzzy QFD model using the prioritization equation:

$\tilde{P}_{ij} = \sum_{i=1}^{m} \widetilde{W}_i \otimes \tilde{R}_{ij}$ Defuzzification using Sj= (l+m+u)/3, produces a crisp prioritization index that enables ranking of the interventions. After defuzzification and ranking, the resulting scores provide a clear and evidence-based ordering of mitigation strategies, thereby enabling decision makers to allocate resources toward the most impactful actions.

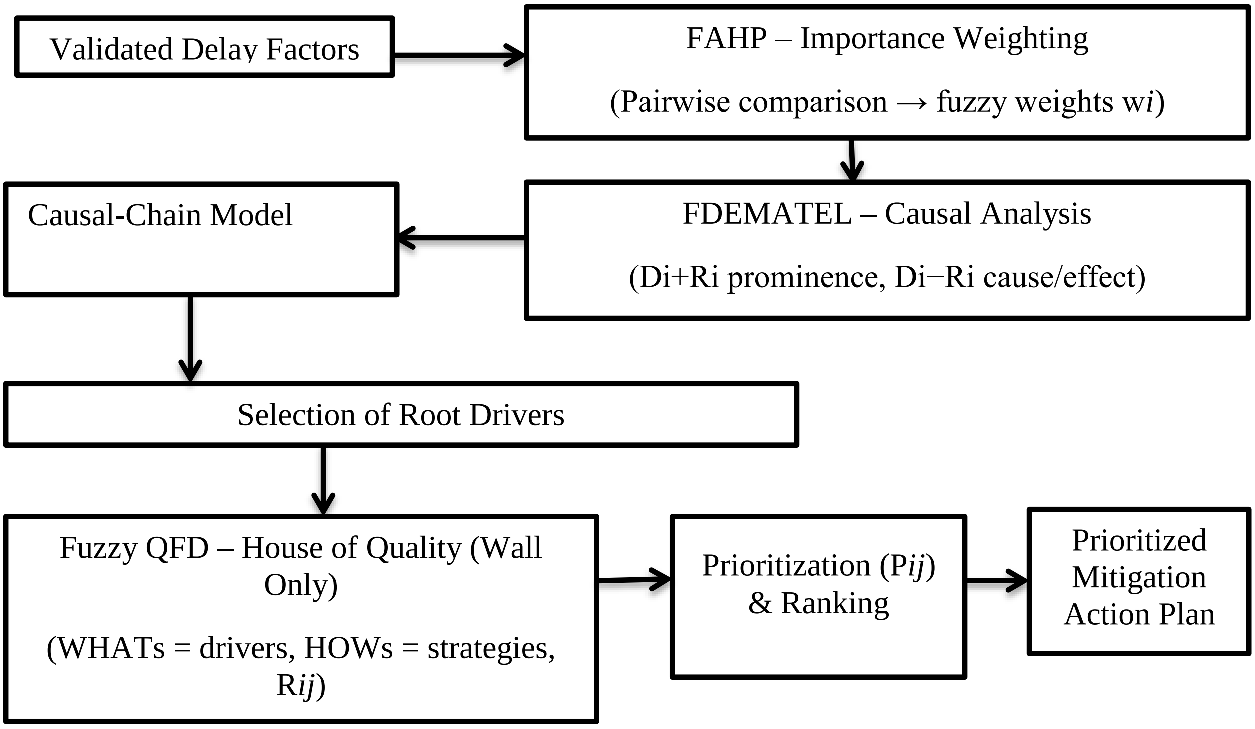

Figure 3.3 Hybrid FAHP–FDEMATEL–FQFD Synthesis Flowcharts

Table3.6 presents the structure of the Fuzzy QFD relationship matrix adopted in this study. The rows represent the five root-driver factors (WHATs) identified from the Fuzzy DEMATEL analysis (See Chapter Four). The columns represent the ten strategic mitigation interventions (HOWs) synthesized from expert suggestions and supporting literature. The FAHP weights (wi) of the root drivers are used to compute the weighted fuzzy relationship values, which are later defuzzified to obtain the Prioritization Index (PI) for each mitigation strategy.

Table 3.4: Fuzzy QFD Relationship Matrix and Prioritization Index for Mitigation Interventions

<table>
<tr><td rowspan="2">Root Driver Factors (WHATs) (From Fuzzy DEMATEL Analysis)</td><td colspan="10">HOWs (strategic mitigation)</td><td rowspan="2">FAHP-Normalized Weight (Wi)</td></tr>
<tr><td>S1</td><td>S2</td><td>S3</td><td>S4</td><td>S5</td><td>S6</td><td>S7</td><td>S8</td><td>S9</td><td>S10</td></tr>
<tr><td>Driver1</td><td colspan="10"></td><td></td></tr>
<tr><td>Driver2</td><td colspan="10" rowspan="4">Relationship Matrix</td><td></td></tr>
<tr><td>Driver3</td><td></td></tr>
<tr><td>Driver4</td><td></td></tr>
<tr><td>Driver5</td><td></td></tr>
<tr><td>Prioritization Index (PI)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>-</td></tr>
<tr><td>Priority Rank</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>-</td></tr>
</table>

- Where: - S1 to S10 = Strategic Mitigation Interventions (HOWs)
- Prioritization Index $=\sum_{i \in Cause\ Factors}(FAHP\ weight\ \times Relationship)$

(PI = ∑ (wi × Rij))

Strategic Mitigation Interventions (HOWs) Full List for Table 3.7

Code	Mitigation Strategy
S1	Establish a formal Change Control Committee with clear authority and strict timelines
S2	Implement strict scope freeze policy after design approval stage with robust front-end planning
S3	Create ring-fenced budgets, dedicated escrow accounts, and improved financial management mechanisms for variations
S4	Develop a one-stop digital approval portal with enforceable service level agreements (SLAs)
S5	Conduct mandatory value engineering workshops and joint stakeholder reviews

during planning phase

S6 Strengthen pre-contract geotechnical investigations and include clear contractual provisions for unforeseen conditions

S7 Implement continuous capacity building programs and foster more collaborative project delivery approaches among stakeholders

S8 Reduce unnecessary bureaucratic approval layers, appoint single focal persons, and promote policy-level reforms

S9 Adopt Building Information Modeling (BIM), digital tools, and full digitalization of approval and change management processes

S10 Introduce automatic CPI-linked price escalation clauses combined with quarterly price review mechanisms

Each cell in the relationship matrix reflects the strength of association between a given delay driver and a corresponding mitigation strategy. These relationships are assessed using linguistic terms, which are subsequently converted into triangular fuzzy numbers to accommodate uncertainty in expert judgment. Higher fuzzy values indicate stronger influence, suggesting that the associated strategy is more effective in addressing the respective delay factor. This structured evaluation supports decision-makers in identifying priority interventions by highlighting strategies that have the greatest overall impact on improving the approval process.

3.8. Data Reliability and Validity

To guarantee the integrity and dependability of the research findings, a rigorous assessment of data quality was performed through a multi-faceted strategy addressing both reliability and validity. Given the hybrid nature of the multi-criteria decision-making (MCDM) framework incorporating Fuzzy Analytic Hierarchy Process (FAHP) and Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL) specialized metrics were applied to align with the unique mathematical requirements of each method.

Reliability, which concerns the consistency and stability of the measurements, was a primary focus during the data analysis phase. Specifically, to ensure the reliability of the AHP judgments, the Consistency Ratio (CR) was calculated for each expert's completed pairwise comparison matrix. This step is critical as it quantitatively assesses the logical coherence of a respondent's judgments (Saaty, 2008). A CR value exceeding the acceptable threshold of 0.10

indicates a significant logical contradiction in the expert's responses. Any response set that failed this consistency test was handled by first contacting the respondent for potential clarification or revision. If clarification was not possible, the inconsistent data was excluded from the final aggregation to maintain the integrity and robustness of the calculated priority weights.

Regarding the FDEMATEL phase, reliability was established through the Reliability of Aggregated Expert Judgments. Unlike traditional metrics like Cronbach's Alpha, which are often unsuitable for small-sample expert panels, this approach focuses on the stability and convergence of the professional consensus. By analyzing the Aggregated Fuzzy Direct-Relation Matrix (Z), the study verified that the synthesized triangular fuzzy values (l, m, u) were convergent and free from significant individual bias. The pilot results confirmed that the data met all required reliability benchmarks, demonstrating that the responses were robust and suitable for the complex causal modeling required in the main research phase.

Validity was established through content, construct, and face validity, reinforced by triangulation.

Content validity was established through a two-stage process. First, an exhaustive literature review ensured that the initial pool of factors was comprehensive and theoretically grounded. Second, this initial list was subjected to a formal validation process by a panel of senior local experts. This panel reviewed each factor for its relevance, clarity, and applicability to the Ethiopian public construction context, thereby ensuring that the final variables used in the questionnaire were not only academically sound but also practically meaningful to the target population.

Construct validity was inherently strengthened by the selection of the analytical methodologies. The research aimed to measure the constructs of "perceived importance" and "causal influence." By employing well-established and scientifically validated techniques like the Analytic Hierarchy Process and DEMATEL, which were specifically designed to measure these exact constructs, the study ensured a strong alignment between the research goals and the analytical tools used.

Face validity was confirmed during the pilot study. Before the main data collection, the draft questionnaire was presented to a small group of representative experts. These individuals were asked to provide feedback on the clarity of the instructions, the comprehensibility of the questions, and the overall logical flow of the instrument. This step ensured that the questionnaire appeared credible and relevant to the participants, which in turn encouraged more thoughtful and accurate responses.

Finally, the overall credibility of the research was enhanced through triangulation. Methodological triangulation was achieved by combining different research methods a comprehensive literature review and an expert judgment survey to investigate the problem from multiple perspectives. Furthermore, data triangulation was accomplished by deliberately collecting data from the three distinct stakeholder groups (clients, consultants, and contractors). This approach provided a more balanced, holistic, and robust understanding of the change order approval phenomenon, mitigating the potential biases that could arise from relying on a single source of data.

3.9.Ethical Considerations

The highest ethical standards were rigorously maintained throughout the entire research process to protect the rights and welfare of all participants. Prior to their participation, all potential respondents were provided with a clear and comprehensive information sheet. This document detailed the research objectives, the procedures involved, the estimated time commitment, and the intended use of the findings, ensuring they could make a fully informed decision.

Formal informed consent was obtained from each participant before any data was collected. Participants were explicitly informed that their involvement was entirely voluntary and that they had the right to withdraw from the study at any point, or to decline to answer any specific question, without any negative consequences. To ensure confidentiality and anonymity, all collected data was coded, and the analysis was conducted on an aggregated basis. At no point were individual respondents or their affiliated organizations identified in the thesis or any subsequent publications, thereby safeguarding their personal privacy and professional standing. All data, both physical and digital, was stored securely on a password-protected device accessible only to the researcher and was used solely for the academic purposes of this research.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Introduction

This chapter presents and discusses the empirical findings obtained from the field data collected through expert surveys. It systematically reports the outcomes of the various analytical stages and interprets their implications for understanding and addressing change order approval delays in public building projects in Addis Ababa. The results provide evidence-based insights that directly respond to the research questions and contribute to the development of a practical decision-support framework for the Ethiopian construction industry.

Specifically, this chapter addresses four key specific objectives of the study: (i) identifying and reaching expert consensus on the critical factors influencing change order approval delays using the Delphi technique; (ii) prioritizing these factors according to their perceived importance through the Fuzzy Analytic Hierarchy Process (Fuzzy AHP); (iii) examining the causal interrelationships and influence structure among the factors using the Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL); and (iv) synthesizing the findings to develop a causal-chain model and prioritize strategic mitigation interventions via the integration with Fuzzy Quality Function Deployment (QFD).

The analysis followed a clear sequential hybrid approach. It commenced with a two-round Delphi process involving a panel of five senior experts to identify, validate, and refine the critical factors. The refined instrument was then tested in a pilot study before full deployment. In the main survey, questionnaires were distributed to 17 qualified construction professionals with extensive experience in public building projects. Fifteen experts returned fully completed questionnaires, yielding a response rate of 88.2%. These experts represented a balanced distribution across client, consultant, and contractor stakeholder groups, ensuring diverse and credible perspectives.

The chapter begins with the respondent profiles and Delphi results on factor identification and validation, followed by pilot study findings, Fuzzy AHP prioritization results, Fuzzy DEMATEL causal relationship analysis, the integrated causal-chain model, expert-suggested mitigation measures, and a comprehensive integrated discussion of the findings. All analyses were performed in strict accordance with the fuzzy multi-criteria decision-making procedures detailed in Chapter Three, incorporating consistency checks and appropriate defuzzification methods to ensure robustness and reliability of the results.

4.2. Profile of Respondents

A total of twenty senior construction professionals participated in this study. Five experts were involved in the Delphi panel and pilot study, while fifteen respondents completed the main survey questionnaire. All participants were purposively selected because of their direct involvement in public building projects in Addis Ababa and their rich practical knowledge of change order processes.

The combined demographic characteristics of all respondents are presented in Table 4.1 below. This table provides a clear overview and allows easy comparison between the Delphi/pilot group and the main survey participants.

Table 4.1: Demographic Characteristics of Delphi Panel, Pilot Study, and Main Survey Respondents (N=20)

Characteristic	**Delphi & Pilot** (n=5)		**Main Survey** (n=15)		**Total** (N=20)	
Stakeholder Group	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
Client Representative	2	40.0	5	33.3	7	35.0
Consultant	2	40.0	5	33.3	7	35.0
Contractor	1	20.0	5	33.3	6	30.0
Employment Status						
Permanent	4	80.0	12	80.0	16	80.0
Contractual	1	20.0	3	20.0	4	20.0
Experience in Public Building Projects (Years)						
10–14	1	20.0	3	20.0	4	20.0
15–20	2	40.0	8	53.3	10	50.0
>20	2	40.0	4	26.7	6	30.0

Number of Public Building Projects Involved						
6–10	1	20.0	2	13.3	3	15.0
11–15	2	40.0	6	40.0	8	40.0
More than 15	2	40.0	7	46.7	9	45.0
Highest Educational Qualification						
Bachelor’s Degree	2	40.0	6	40.0	8	40.0
Master’s Degree	3	60.0	8	53.3	11	55.0
PhD	0	0.0	1	6.7	1	5.0
Sex						
Male	4	80.0	13	86.7	17	85.0
Female	1	20.0	2	13.3	3	15.0

The respondent profile reveals a highly qualified and balanced expert panel, with strong representation across client representatives (35%), consultants (35%), and contractors (30%). The majorities (80%) were permanently employed, and over 80% possessed 15 or more years of experience in public building projects, with nearly half having participated in more than 15 such projects. Educational qualifications were robust, with 60% holding Master’s degrees or higher. This composition ensured diverse stakeholder perspectives while maintaining high expertise levels critical for reliable judgments in Fuzzy AHP, DEMATEL, and QFD analyses.

Discussion of these demographics highlights the suitability of the sample for complex multi-criteria decision-making in construction management. The balanced stakeholder distribution minimized bias and captured multifaceted views on change order approval delays. High experience levels (predominantly 15+ years) enhanced the validity of expert consensus, particularly in validating critical factors and assessing causal interrelationships. The gender distribution (85% male) reflects the industry norm in Ethiopia but suggests opportunities for greater inclusivity in future studies.

The expert profile strengthens the credibility and contextual relevance of the findings for Addis Ababa’s public building sector. Policymakers and project stakeholders can confidently apply the causal-chain model and prioritized mitigation strategies, knowing they are grounded in practical insights from seasoned professionals. This sample also underscores the value of purposive expert sampling in addressing systemic issues like bureaucratic delays and financial constraints in developing country contexts.

4.3. Identification and Validation of Critical Factors (Delphi Technique)

The Delphi technique was employed to systematically identify and validate the most critical factors influencing change order approval delays in public building projects in Addis Ababa. This iterative, expert-driven process helped refine an extensive list of factors drawn from the literature review into a concise, contextually relevant set (Appendix- I). Two rounds of consultation were conducted with a panel of five highly experienced professionals, achieving strong consensus while minimizing individual bias through anonymity and controlled feedback.

The preliminary list of factors was compiled from the broader change-order literature. During the Delphi process, experts evaluated each factor solely with respect to its influence on change-order approval delays. Factors that were not considered relevant to approval-delay mechanisms were excluded from subsequent analyses.

4.3.1. Delphi Technique Round 1 Result

In the first round, experts evaluated 54 potential factors grouped under six thematic categories (client-related, consultant/designer-related, contractor-related, third-party-related, political/economic, and environmental). Each factor was rated on a 5-point Likert scale for relevance (1 = Not Relevant to 5 = Highly Relevant) and experts indicated inclusion/exclusion with Yes or No votes, accompanied by brief justifications.

Responses were aggregated anonymously. Factors meeting the dual criteria of mean relevance score ≥ 4.0 and at least 80% Yes votes (i.e., 4 or 5 experts in agreement) were advanced. This process resulted in 31 prioritized factors. Several factors demonstrated exceptionally strong consensus, such as Change of plans or scope (mean = 4.6, 100% Yes) and Financial problems (mean = 4.8, 100% Yes), reflecting their prominence in public sector projects. Experts also nominated three additional context-specific factors: Bureaucratic approval layers in government (N1), Corruption in procurement (N2), and Labor shortages due to migration (N3). Feedback highlighted redundancies, particularly among design-related and site condition factors.

Table 4.2: Excerpt of Aggregated Round 1 Result

(Selected Prioritized Factors)

Original item No.	Factor	Mean Relevance	% Yes	Prioritized?
1	Change of plans or scope	4.6	100%	Yes
3	Change in specification	4.4	100%	Yes
4	Financial problems	4.8	100%	Yes
5	Poor decision making	4	80%	Yes
8	Additional orders	4.4	100%	Yes
11	Modifications to design	4.8	100%	Yes
12	Addition of new work	4.2	100%	Yes
13	Poor/incomplete drawings	4.6	100%	Yes
14	Errors and omissions	4.8	100%	Yes
16	Inconsistent site condition	4.8	100%	Yes
18	Inconsistent info in drawings	4.6	100%	Yes
19	Discrepancy between contracts	4.6	100%	Yes
20	Lack of geo-investigation	5	100%	Yes
21	Insufficient site details	4.4	100%	Yes
24	Design errors	5	100%	Yes
25	Poor quality of design	4.2	100%	Yes
29	Correct construction mistakes	4.8	100%	Yes

30	Improve quality of work	4	100%	Yes
31	Poor management skills	4.4	80%	Yes
34	Poor workmanship	4.6	100%	Yes
36	Poor logistics control	4.8	100%	Yes
37	3rd Party Regulations	4.6	100%	Yes
38	Government agencies	5	100%	Yes
40	Utility coordination	4.6	100%	Yes
43	Regulatory body request	4.8	100%	Yes
45	Material availability	5	100%	Yes
47	Economic conditions	5	100%	Yes
48	Law and policy changes	4.6	100%	Yes
49	Complex government regulations	4.8	100%	Yes
53	Geological uncertainty	4.8	100%	Yes
54	Unforeseen ground conditions	5	100%	Yes

(Note: Full list contained 31 prioritized factors meeting the thresholds.)

4.3.2. Round 2 Results, Consensus Achievement, and Factor Reduction and Merging Process

In Round 2, the 31 prioritized factors plus the three newly nominated ones (total 34) were re-evaluated using the same rating and voting mechanism. Experts received anonymized summaries of Round 1 results, including group means and key justifications, to facilitate convergence. This feedback loop strengthened agreement on most factors. For example, the mean relevance for financial problems rose to 5.0. While N1 (Bureaucratic approval layers) achieved strong support (mean = 4.8), N2 and N3 did not meet the thresholds and were excluded. Consensus was robust across the panel, with nearly all retained factors achieving 100% agreement on inclusion. The process demonstrated clear stability, rendering additional rounds unnecessary.

To eliminate redundancy and enhance analytical practicality, experts recommended merging conceptually overlapping items. Key merges included:

- Client scope-related factors (items 1, 8, 11, 12) → Client-initiated scope changes & additional orders.
- Design-related issues (items 13, 14, 18, 24, 25) → Design errors, omissions and poor/incomplete drawings.
- Site investigation and ground condition factors (items 16, 20, 21, 53, 54) → two consolidated site-related factors.
- Regulatory and bureaucratic items (37, 38, 43, 49 + N1) → Government agencies, regulatory bodies and bureaucratic approval layers.

This rigorous consolidation process produced a final set of 12 critical factors. Each factor was assigned a clear operational definition tailored to the Addis Ababa public building context.

Table 4.3: Final 12 Critical Factors Identified through Delphi Consensus

No.	Critical Factor (Merged)	Aggregated Mean (Round 2)	% Yes	Operational Definition (Contextualized)
1	Client-initiated scope changes & additional orders	4.55	100%	All client-driven modifications to plans, scope, and extra orders
2	Change in specification	4.4	100%	Requests for alternative or higher-quality materials/specifications
3	Financial problems of the client	5.0	100%	Budget shortfalls and delays in releasing public funds
4	Design errors, omissions	4.72	100%	Mistakes, inconsistencies, and

	and poor/incomplete drawings			sub-standard design documentation
5	Inconsistent site condition and insufficient site details	4.6	100%	Mismatches between design and actual site conditions
6	Lack of geotechnical investigation	5.0	100%	Absence or misinterpretation of soil/ground investigations
7	Unforeseen ground and geological conditions	5.0	100%	Unexpected site conditions discovered during execution
8	Poor workmanship and corrective construction mistakes	4.7	100%	Sub-standard execution requiring rework
9	Poor logistics and material supply control	5.0	100%	Supply chain failures and procurement inefficiencies
10	Government agencies, regulatory bodies and bureaucratic approval layers	4.68	100%	Multi-level administrative and regulatory delays
11	Material availability in the market	5.0	100%	Shortages of required construction materials
12	Economic conditions and price inflation	4.6	100%	Inflation, market volatility, and policy changes

Following the two-round Delphi process, an initial set of 12 critical factors achieved expert consensus. However, during the pilot study and main survey validation phases, two factors (“Unforeseen ground and geological conditions” and “Lack of geotechnical investigation”) were merged into F5: Site and geotechnical assessment inadequacies and unforeseen conditions due to significant conceptual overlap identified by the experts. This refinement resulted in a final streamlined list of ten critical factors that were used for the subsequent

Fuzzy AHP, Fuzzy DEMATEL, and Fuzzy QFD analyses. This consolidation improved the clarity and analytical efficiency of the model without losing important information.

The Delphi-derived factors align closely with previous Ethiopian studies while offering greater consolidation and contextual specificity. (Andualem, 2014) Andualem (2014) And (Andualem, 2016) highlighted client changes, design deficiencies, and inadequate drawings as major contributors. (Dejene, 2020) Emphasized errors/omissions in design, client scope modifications, and financial constraints, (Girum, 2022) similarly identified design errors, contractual conflicts, and site conditions as significant. (Mekonen, 2025) , Noted resource and contractual issues in road projects.

The current study advances beyond these descriptive works by achieving expert consensus on a streamlined set of 12 factors and incorporating unique public-sector challenges such as bureaucratic approval layers. The high consensus levels (predominantly 100%) and successful merging of overlapping items demonstrate the robustness of the validation process. This refined list provided a strong foundation for the subsequent Fuzzy AHP prioritization and Fuzzy DEMATEL causal modeling phases.

4.4. Pilot Study Results and Instrument Refinement

A pilot study was conducted following the Delphi validation phase to evaluate and refine the research instruments before full-scale deployment. The primary purpose was to assess the clarity, relevance, practicality, and overall effectiveness of the questionnaires designed for the Fuzzy Analytic Hierarchy Process (FAHP) and Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL) analyses. By administering the draft instruments to a small group of experienced professionals, the study aimed to identify potential ambiguities in factor descriptions, evaluate the feasibility of the pairwise comparison and influence-rating tasks, verify the logical flow and completion time, and ensure that the tools would yield reliable and consistent data in the main survey. This preparatory step was crucial for enhancing content validity, minimizing respondent burden, and strengthening the quality of the subsequent quantitative analyses.

The pilot study utilized the same five experts who participated in the Delphi panel, ensuring continuity and deep familiarity with the critical factors. These professional representing client (two), consultant (two), and contractor (one) perspectives possessed substantial experience in public building projects in Addis Ababa, with most having over 15 years in the field and advanced educational qualifications. Their involvement provided high-quality, contextually grounded feedback.

4.4.1. Validation of Critical Factors and Factor Refinement

One of the key objectives of the pilot was to confirm the relevance and clarity of the 12 critical factors identified through the Delphi process. Experts unanimously agreed that the factors accurately captured the primary drivers of change order approval delays in the local context. However, a strong consensus emerged regarding conceptual overlap among three site-related factors: inconsistent site conditions and insufficient site details, lack of geotechnical investigation, and unforeseen ground and geological conditions. Participants noted that these elements were closely interrelated in practice, often manifesting as interconnected issues stemming from inadequate pre-construction site evaluation.

In response to this feedback, the three factors were thoughtfully merged into a single comprehensive variable: “Inadequate site evaluation and unforeseen ground conditions.” This consolidation eliminated redundancy, improved conceptual clarity, and reduced the total number of factors from 12 to 10 for the main study. The refined definition emphasized the chain of problems arising from poor site investigation through to design mismatches and execution challenges. This adjustment enhanced the instrument’s focus and usability without sacrificing comprehensive coverage.

4.4.2. Feedback on Questionnaire Design and Usability

Experts found the overall questionnaire structure logical and well-organized, with clear instructions and appropriate use of linguistic scales for both FAHP and FDEMATEL components. The majority rated the instrument as easy to moderate in difficulty, and completion times were generally practical four experts finished within 30–60 minutes, while one required 60–90 minutes. Constructive suggestions included incorporating brief examples for pairwise comparisons, providing a quick reference for reciprocal values in the fuzzy scales, and minor formatting improvements for better readability. These recommendations were incorporated into the final version, resulting in a more user-friendly instrument that balanced analytical rigor with respondent accessibility.

4.4.3. Reliability Assessment

The reliability of the pilot study data was rigorously evaluated, with particular emphasis on the consistency of expert judgments in the Fuzzy AHP component. Each expert's pairwise comparison matrix was examined using the Consistency Ratio (CR) criterion. All five individual matrices achieved CR values well below the acceptable threshold of 0.10, indicating strong logical coherence in the experts' judgments.

The pilot study, conducted with five highly experienced professionals, confirmed the reliability of the Fuzzy AHP pairwise comparison instrument. All expert responses demonstrated strong internal consistency, with CR values ranging from 0.0361 to 0.0900. The average CR across the five experts was approximately 0.060.

Specifically, Expert 1 recorded a CR of 0.0404, Expert 2 recorded 0.0444, Expert 3 recorded 0.0361, Expert 4 recorded 0.0899, and Expert 5 recorded 0.0900. Consequently, all matrices were considered fully acceptable, and none required revision.

This consistently low level of inconsistency reflects the logical coherence of the experts' judgments. It also indicates that the questionnaire design, factor descriptions, and linguistic scales were clear and easy to follow. Overall, these results provided strong assurance regarding the instrument's readiness for the main survey.

Furthermore, the aggregated pairwise comparison matrix for the entire pilot panel demonstrated excellent overall consistency with a CR value of 0.0326**.** This low aggregated CR confirms the high level of logical coherence across the collective expert judgments and further strengthens confidence in the reliability of the data for subsequent analyses.

For the FDEMATEL component, reliability was assessed through the convergence and stability of the aggregated fuzzy direct-relation matrix. The narrow spreads in triangular fuzzy numbers and consistent application of the linguistic scale across experts demonstrated strong consensus and minimal individual bias.

4.4.4. Lessons Learned and Modifications for the Main Study

The pilot study provided valuable insights that directly informed improvements for the main survey. The successful merging of overlapping site-related factors streamlined the model while preserving its integrity. Questionnaire refinements such as added examples and clearer formatting were expected to reduce cognitive load and improve response quality. The uniformly acceptable consistency ratios, including the strong aggregated CR of 0.0326, validated the expert panel's capability and the suitability of the chosen scales.

Overall, the pilot confirmed that the research instruments were clear, relevant, and capable of producing reliable data. Minor adjustments enhanced usability without altering the core methodological framework. With these refinements, the instruments were deemed ready for distribution to the larger panel of 15 experts in the main study. This preparatory phase significantly strengthened the validity and practicality of the subsequent FAHP, FDEMATEL, and QFD analyses, ensuring that the full-scale results would rest on a solid and contextually appropriate foundation.

4.5. Validation and Practical Relevance of Critical Factors from the main survey (FAHP & FDEMATEL)

The main survey involved fifteen seasoned experts from client, consultant, and contractor backgrounds. It provided strong confirmation of the ten critical factors. All fifteen respondents unanimously agreed (100%) that the identified factors accurately reflect the real causes of change order approval delays in public building projects in Addis Ababa.

Similarly, every expert rated the overall relevance of the factor set to real-world conditions as "Very Relevant" (100%). Furthermore, no expert suggested any additional factors beyond the ten already included. This indicates that the list is both comprehensive and contextually appropriate.

The ten critical factors, initially derived from an extensive literature review, refined through two rounds of Delphi consensus, and further streamlined based on pilot study feedback, were subjected to final expert validation in the main survey. This complete consensus across all participants reinforces the practical validity of the factors and establishes a solid foundation for the subsequent Fuzzy AHP prioritization and Fuzzy DEMATEL causal modeling phases of the study.

4.5.1. Prioritization of Critical Factors Using Fuzzy AHP

Fuzzy Analytic Hierarchy Process (FAHP) was employed to elicit and synthesize expert judgments on the relative importance of the ten critical factors. This section details the aggregation process, consistency verification, computation of fuzzy synthetic extents, derivation of final weights, and ranking.

4.5.1.1. Aggregation of Expert Judgments

Fifteen individual fuzzy pairwise comparison matrices were obtained using the linguistic scale and corresponding triangular fuzzy numbers defined in Chapter Three. These matrices were synthesized into a group decision matrix using the geometric mean method. This aggregation technique effectively balances individual expert opinions while maintaining the fuzzy character of the judgments.

Table 4.4: Aggregated Fuzzy Pairwise Comparison Matrix

Factor	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	(1.0000, 1.0000, 1.0000)	(1.2944, 2.1277, 2.8948)	(1.1487, 1.7215, 2.2033)	(1.1016, 1.4741, 1.9851)	(1.7351, 2.4441, 3.1897)	(1.4473, 2.2636, 3.0209)	(1.5572, 2.6002, 3.6186)	(0.8154, 1.1487, 1.5806)	(1.5695, 2.5111, 3.3988)	(0.8414, 1.2125, 1.6874)
F2	(0.3455, 0.4700, 0.7725)	(1.0000, 1.0000, 1.0000)	(0.7875, 0.9294, 1.1055)	(0.7786, 1.1709, 1.6684)	(1.0194, 1.4310, 1.8523)	(0.9733, 1.4198, 1.8314)	(1.0968, 1.5277, 1.8669)	(0.5338, 0.7752, 1.0930)	(1.1487, 1.5695, 1.9031)	(0.6207, 0.9657, 1.3771)
F3	(0.4539, 0.5809, 0.8706)	(0.9046, 1.0760, 1.2699)	(1.0000, 1.0000, 1.0000)	(1.0921, 1.4730, 2.1819)	(1.9031, 2.6881, 3.4741)	(1.4869, 2.3075, 3.1724)	(1.4869, 2.3075, 3.0662)	(0.7435, 0.9922, 1.3138)	(1.5999, 2.4166, 3.1724)	(0.8254, 1.2030, 1.6801)
F4	(0.5037, 0.6784, 0.9077)	(0.5994, 0.8540, 1.2843)	(0.5027, 0.6789, 0.9157)	(1.0000, 1.0000, 1.0000)	(1.0882, 1.6567, 2.5357)	(0.9189, 1.3451, 1.8852)	(0.9053, 1.3819, 1.9744)	(0.5255, 0.8027, 1.2556)	(0.9624, 1.4473, 2.0677)	(0.7376, 1.1936, 1.7155)
F5	(0.3135, 0.4091, 0.5763)	(0.5399, 0.6988, 0.9810)	(0.2878, 0.3720, 0.5255)	(0.3944, 0.6036, 0.9189)	(1.0000, 1.0000, 1.0000)	(0.5566, 0.7579, 1.1578)	(0.6444, 0.8312, 1.1979)	(0.4098, 0.5057, 0.6988)	(0.5173, 0.7236, 1.1578)	(0.4037, 0.5196, 0.7572)

F6	(0.3310, 0.4418, 0.6910)	(0.5460, 0.7043, 1.0274)	(0.3152, 0.4334, 0.6725)	(0.5304, 0.7435, 1.0882)	(0.8637, 1.3195, 1.7967)	(1.0000, 1.0000, 1.0000)	(1.0473, 1.4869, 1.8314)	(0.4098, 0.5809, 0.8706)	(1.0000, 1.1487, 1.2457)	(0.5668, 0.7376, 0.9294)
F7	(0.2763, 0.3846, 0.6422)	(0.5356, 0.6546, 0.9117)	(0.3261, 0.4334, 0.6725)	(0.5065, 0.7236, 1.1046)	(0.8348, 1.2030, 1.5518)	(0.5460, 0.6725, 0.9548)	(1.0000, 1.0000, 1.0000)	(0.3839, 0.5654, 0.8706)	(1.0194, 1.3299, 1.6125)	(0.5127, 0.6910, 0.9474)
F8	(0.6327, 0.8706, 1.2263)	(0.9149, 1.2900, 1.8734)	(0.7611, 1.0079, 1.3451)	(0.7965, 1.2457, 1.9031)	(1.4310, 1.9775, 2.4403)	(1.1487, 1.7215, 2.4403)	(1.1487, 1.7687, 2.6052)	(1.0000, 1.0000, 1.0000)	(1.4310, 1.8882, 2.2679)	(1.0473, 1.4869, 1.8314)
F9	(0.2942, 0.3982, 0.6371)	(0.5255, 0.6371, 0.8706)	(0.3152, 0.4138, 0.6250)	(0.4836, 0.6910, 1.0391)	(0.8637, 1.3819, 1.9332)	(0.8027, 0.8706, 1.0000)	(0.6201, 0.7519, 0.9810)	(0.4409, 0.5296, 0.6988)	(1.0000, 1.0000, 1.0000)	(0.4895, 0.6132, 0.8027)
F10	(0.5926, 0.8247, 1.1885)	(0.7262, 1.0355, 1.6112)	(0.5952, 0.8312, 1.2115)	(0.5829, 0.8378, 1.3557)	(1.3206, 1.9247, 2.4768)	(1.0760, 1.3557, 1.7644)	(1.0556, 1.4473, 1.9505)	(0.5460, 0.6725, 0.9548)	(1.2457, 1.6309, 2.0427)	(1.0000, 1.0000, 1.0000)

4.5.1.2. Consistency Check of Pairwise Comparisons

All fifteen individual expert matrices demonstrated acceptable consistency (CR < 0.10), with values ranging from 0.0345 to 0.0923. The aggregated matrix also showed excellent consistency.

Table 4.5: Consistency Ratios of Individual Expert Matrices

Expert	Lambda max	CI	CR	Status (CR<0.1)
1	10.5266	0.0585	0.0393	Consistent
2	10.8454	0.0939	0.063	Consistent
3	10.7897	0.0877	0.0589	Consistent
4	11.2383	0.1376	0.0923	Consistent
5	10.78	0.0867	0.0582	Consistent
6	10.6208	0.069	0.0463	Consistent
7	10.7356	0.0817	0.0549	Consistent
8	10.7875	0.0875	0.0587	Consistent
9	11.1696	0.13	0.0872	Consistent
10	10.8184	0.0909	0.061	Consistent
11	10.8584	0.0954	0.064	Consistent
12	10.9548	0.1061	0.0712	Consistent
13	10.8842	0.0982	0.0659	Consistent
14	10.4632	0.0515	0.0345	Consistent
15	10.998	0.1109	0.0744	Consistent

Aggregated Matrix Consistency λ-max = 10.41981, CI = 0.046645, CR = 0.031306 (RI = 1.49 for n=10), Status: Acceptable

The strong consistency across individual and aggregated judgments reflects the shared professional experience of the panel and supports the reliability of the derived priorities.

4.5.1.3. Fuzzy Synthetic Extent Values, Defuzzification and Final Priority Ranking

Fuzzy synthetic extent values were calculated using Chang's extent analysis method, followed by normalization to obtain final weights.

Fuzzy synthetic extent values (Si) for each factor were calculated using Chang's extent analysis method. The lower (l), middle (m), and upper (u) bounds of the synthetic extents are shown below:

Table 4.6: Fuzzy Synthetic Extent Values (S)

Factor	L	M	U
F1	0.08326	0.16429	0.29771
F2	0.05527	0.09997	0.17527
F3	0.07651	0.14246	0.25679
F4	0.05154	0.09801	0.18824
F5	0.03372	0.05702	0.10866
F6	0.04399	0.07633	0.13509
F7	0.03954	0.06799	0.12437
F8	0.06863	0.12659	0.22932
F9	0.03884	0.0647	0.11613
F10	0.05817	0.10264	0.18842

Final Fuzzy AHP Normalized Weights, Ranking and description of Factors:

Factor	Description
F1	Client-initiated scope changes & additional orders
F2	Change in specification
F3	Financial problems of the client
F4	Design errors, omissions, and poor/incomplete drawings
F5	Site and geotechnical assessment inadequacies
F6	Poor workmanship and corrective construction mistakes
F7	Poor logistics and material supply control
F8	Government agencies, regulatory bodies & bureaucratic approval layers
F9	Material availability in the market
F10	Economic conditions and price inflation

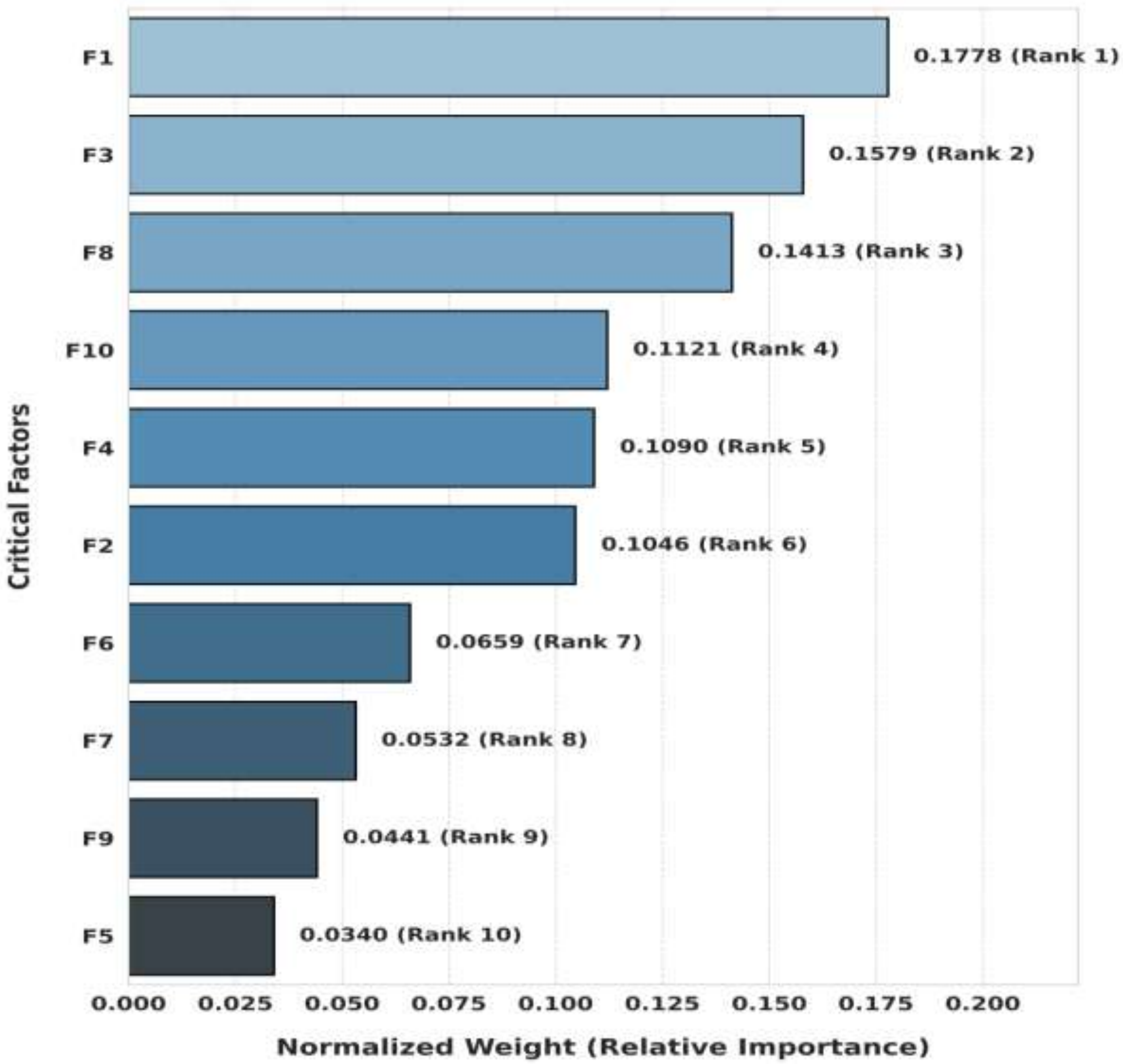

Figure 4.1: Bar Chart of Factor Priorities

The FAHP analysis identifies client-initiated scope changes and additional orders (F1) as the most influential factor contributing to change order approval delays in public building projects in Addis Ababa, with a normalized weight of 0.178. This dominant ranking indicates that shortcomings in early scope definition, frequent revision of client requirements, and late-stage functional adjustments remain persistent challenges in the public-sector project environment. Because such changes require multiple layers of administrative review, they significantly prolong the approval cycle.

The next most influential factors are client-related financial constraints (F3) and bureaucratic or regulatory procedures involving government bodies (F8). Together with F1, these factors account for nearly 48% of the total priority weight, underscoring that delays primarily stem from systemic managerial and institutional issues rather than from on-site technical problems.

The high weight assigned to financial constraints reflects continued dependence on annual budget releases and slow fund disbursement procedures, which often compel approval committees to postpone decisions until the financial impact of proposed changes is clarified. Similarly, the prominence of regulatory and bureaucratic processes points to lengthy authorization chains, overlapping responsibilities among government offices, and procedural redundancies that hinder timely decision-making.

These findings show strong alignment with previous Ethiopian studies by (Andualem, 2014; Andualem, 2016; Dejene, 2020; Tigist, 2017; Girum, 2022), all of which identify client-driven variations, funding limitations, and excessive bureaucracy as persistent obstacles. However, unlike the majority of these studies which primarily employed descriptive ranking tools such as the Relative Importance Index this research applies FAHP, enabling the incorporation of uncertainty in expert judgments and generating more defensible ratio-scale priorities. As a result, the present study provides stronger empirical clarification regarding which factors exert the greatest influence on approval delays.

An important observation is the relatively low weight assigned to site and geotechnical assessment deficiencies (F5). Although technical issues are not insignificant, experts viewed them as secondary in comparison to upstream managerial and institutional deficiencies. This suggests that many technical challenges encountered during construction may be symptoms of earlier planning problems, unstable funding environments, and inefficient administrative procedures rather than standalone causes of delay.

Overall, the FAHP results demonstrate that the most critical drivers of change order approval delays originate from client-side decisions, financial management practices, and institutional regulatory mechanisms. Strengthening pre-construction planning, improving budget reliability, and streamlining approval pathways are therefore essential priorities for enhancing change order administration in Addis Ababa's public building projects. While FAHP effectively establishes the relative importance of the factors, it does not reveal how these factors interact. The subsequent DEMATEL analysis addresses this by mapping causal relationships and distinguishing root drivers from dependent effects within the approval
Causal Interrelationships among Factors Using Fuzzy DEMATEL

4.5.2. Causal relationship using Fuzzy DEMATEL

4.5.2.1. Construction of the Fuzzy Direct-Relation Matrix

Experts rated the direct influence of each factor on every other factor using the 0–4 linguistic scale (converted to TFNs). Individual matrices were aggregated using the arithmetic mean to produce the fuzzy direct-relation matrix Z.

4.5.2.2. Defuzzification and Normalization

The aggregated fuzzy matrix was defuzzified using the Center of Area (COA) method to obtain the crisp direct-relation matrix. Normalization was performed by dividing by the maximum row/column sum (normalized constant using S = 6.9056.

Table 4.7: Crisp Direct-Relation Matrix

Factor	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.0833	0.6722	0.8611	0.8055	0.7167	0.7945	0.8167	0.3222	0.3111	0.5000
F2	0.3667	0.0833	0.6833	0.8722	0.6333	0.8055	0.7722	0.5000	0.2167	0.2389
F3	0.5889	0.4833	0.0833	0.7556	0.7389	0.7833	0.8722	0.6666	0.7334	0.8833
F4	0.5333	0.7500	0.2667	0.0833	0.6333	0.6222	0.7278	0.2778	0.3667	0.2556
F5	0.2556	0.4500	0.4833	0.5500	0.0833	0.5333	0.5667	0.4167	0.6889	0.3167
F6	0.2278	0.2889	0.2722	0.7722	0.2334	0.0833	0.6889	0.2556	0.2389	0.3389
F7	0.6333	0.5167	0.7278	0.5167	0.4833	0.8000	0.0833	0.4778	0.9055	0.5667
F8	0.7556	0.5000	0.9055	0.4667	0.7666	0.7278	0.7778	0.0833	0.4500	0.7111
F9	0.2722	0.3167	0.5000	0.3056	0.7666	0.2722	0.8278	0.2778	0.0833	0.5000
F10	0.4889	0.2500	0.8722	0.2722	0.6611	0.7556	0.7722	0.5167	0.7278	0.1111

4.5.2.3. Total-Relation Matrix and Causal Classification

The total-relation matrix T was calculated as T = X (I – X) ^ (-1), incorporating both direct and indirect influences.

Table 4.8: Total-Relation Matrix

Factor	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.211	0.298	0.3694	0.3668	0.3561	0.3959	0.4255	0.2287	0.2751	0.2774
F2	0.2279	0.1954	0.3148	0.3446	0.3136	0.3624	0.3814	0.2287	0.2341	0.2183
F3	0.3013	0.2933	0.2984	0.3813	0.3891	0.4229	0.467	0.2915	0.3558	0.3505
F4	0.2241	0.26	0.2353	0.2113	0.2844	0.3059	0.3398	0.1785	0.2259	0.1939
F5	0.184	0.2141	0.2556	0.2635	0.2061	0.2842	0.3126	0.1922	0.2641	0.2002
F6	0.1524	0.1647	0.1892	0.2544	0.1875	0.1827	0.2795	0.1433	0.1712	0.1698
F7	0.2769	0.2678	0.346	0.3174	0.3203	0.3828	0.3199	0.241	0.3422	0.2812
F8	0.3131	0.2856	0.3948	0.3359	0.3796	0.4038	0.4396	0.2061	0.3084	0.3205
F9	0.1827	0.1918	0.2555	0.225	0.2918	0.2463	0.3377	0.1725	0.1841	0.2211
F10	0.2529	0.2253	0.3569	0.2762	0.3332	0.3681	0.3993	0.2417	0.317	0.2155

Table 4.9: Prominence (D+R) and Relation (D–R) Values with Cause- Classification

Factor	D (Dispatched)	R (Received)	Prominence (D+R)	Relation (D-R)	Group
F1	3.2039	2.3262	5.5301	0.8777	Cause (Driver)
F2	2.8212	2.3961	5.2174	0.4251	Cause (Driver)
F3	3.551	3.0159	6.5669	0.5352	Cause (Driver)
F4	2.459	2.9765	5.4355	-0.5175	Effect
F5	2.3766	3.0616	5.4382	-0.685	Effect
F6	1.8948	3.3551	5.2499	-1.4604	Effect
F7	3.0955	3.7023	6.7978	-0.6068	Effect(Most Prominent)
F8	3.3874	2.124	5.5115	1.2634	Cause (Strongest Driver)
F9	2.3085	2.6779	4.9864	-0.3694	Effect

F10	2.9862	2.4485	5.4347	0.5376	Cause (Driver)

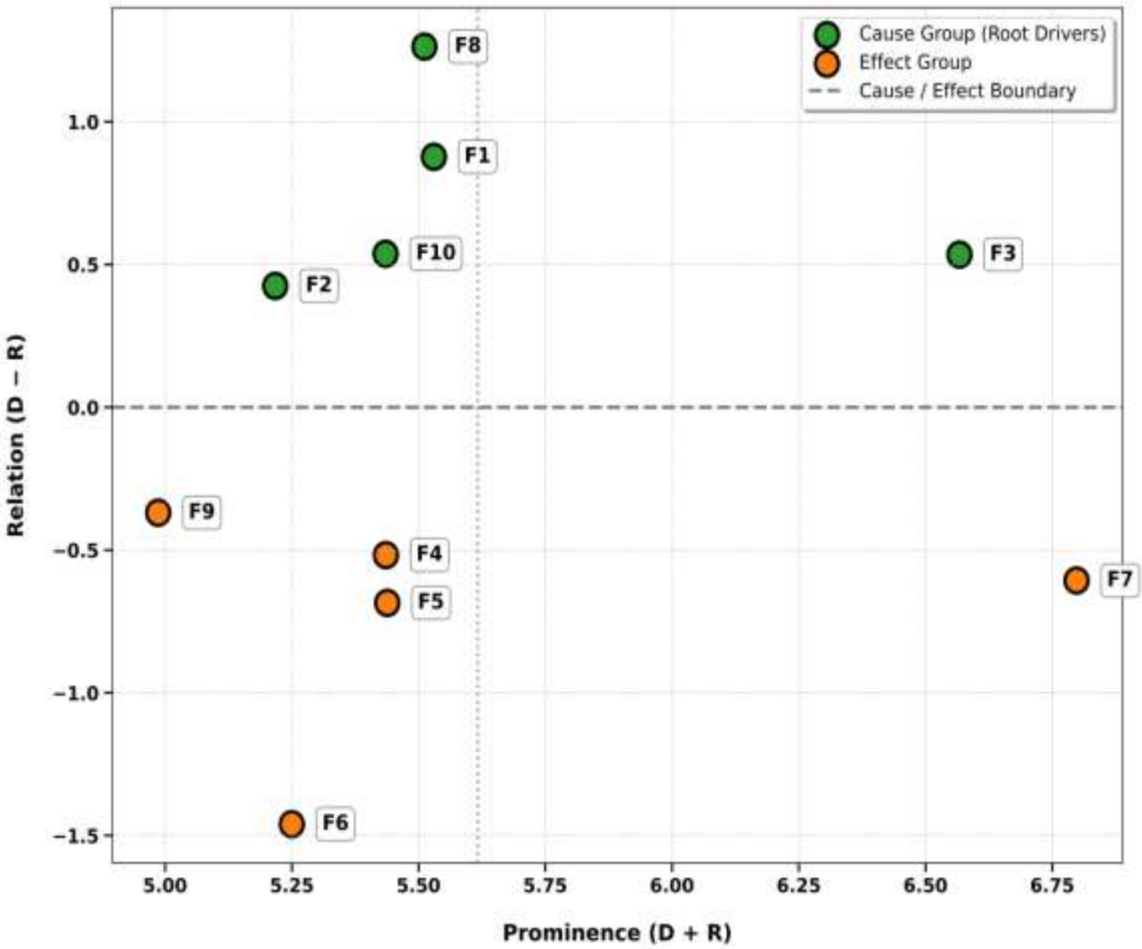

Figure 4.2: Cause-and-Effect Diagram Prominence (D+R) and Relation (D–R) Values

The analysis identifies five root cause (driver) factors: F8 (strongest driver), F1, F3, F10, and F2. These exert net positive influence on the system. Effect factors (F7, F6, F5, F4, and F9) are more dependent and receive greater influence from drivers. F7 (Poor logistics and material supply control) shows the highest prominence, indicating it is both heavily influenced and centrally embedded in the delay network.

The causal diagram (D+R vs. D–R) visually confirms a clear distinction between driving forces (primarily client, financial, regulatory, and economic) and resultant operational issues.

Threshold value (α) and Influential Relation Map: A threshold value of α = 0.28084 was determined (average of the total-relation matrix). The significant cause-and-effect relationships above this threshold are illustrated in the Influential Relation Map (Figure 4.3). The complete threshold matrix is provided in Appendix VIII.

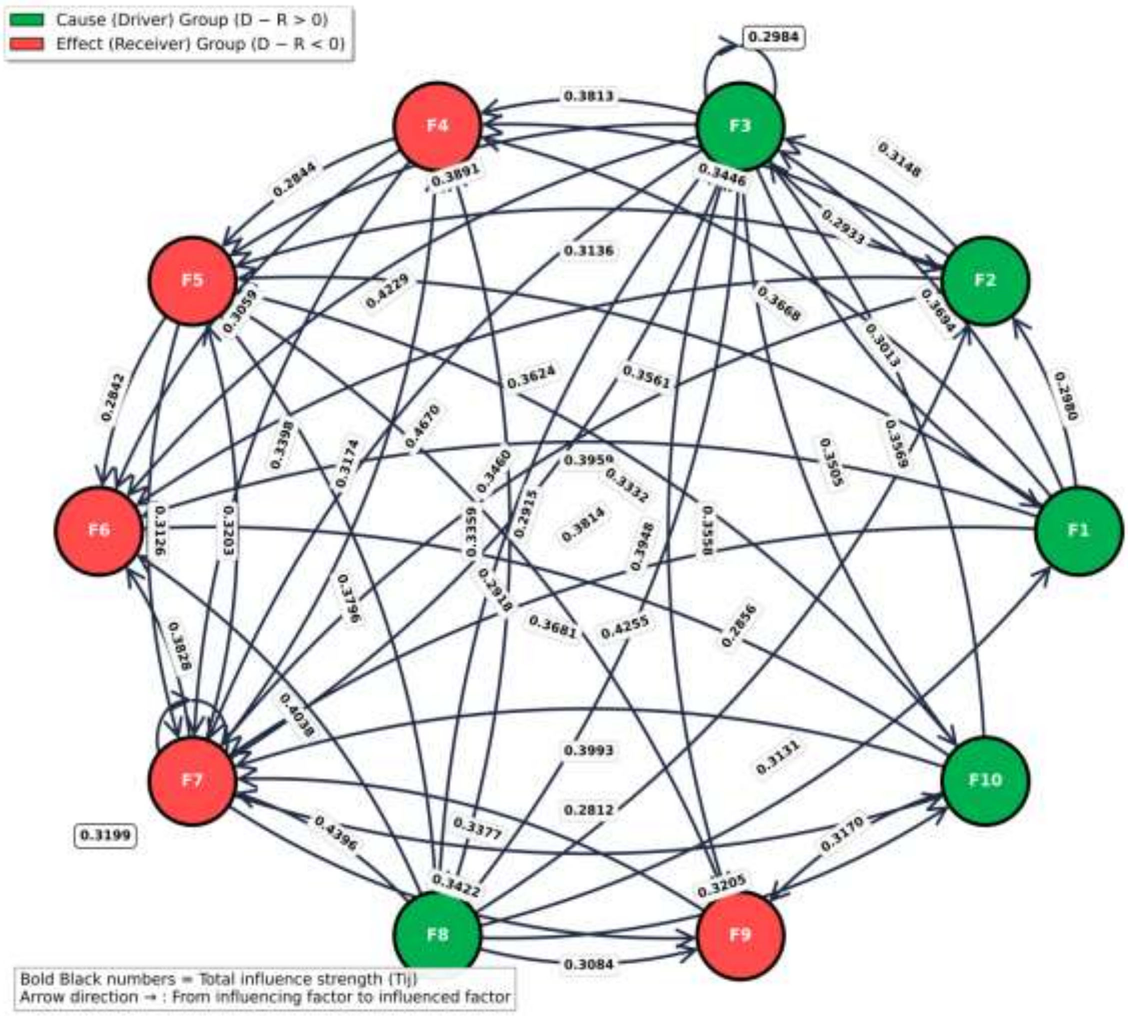

Figure 4.3: Influential Relation Map

(Threshold α = 0.28084, showing 49 significant relations)

The Fuzzy DEMATEL analysis provides a deeper systemic understanding by revealing the causal structure among the ten critical factors. The results identify five root cause (driver) factors: bureaucratic approval layers (F8 – strongest driver), client-initiated scope changes (F1), financial problems of the client (F3), economic conditions and price inflation (F10), and change in specification (F2). These factors dispatch more influence than they receive and therefore represent the fundamental leverage points for improvement.

In contrast, five factors were classified as effect factors, with poor logistics and material supply control (F7) emerging as the most prominent factor overall (highest D+R value). This indicates that logistics problems act as a critical bottleneck where upstream issues converge and intensify, ultimately prolonging change order approval times.

These causal patterns align with and extend the observations made in earlier Ethiopian studies. (Andualem, 2014; Andualem, 2016) , (Dejene, 2020), and (Girum, 2022)consistently noted the significance of client changes, financial difficulties, and government bureaucracy. However, those studies treated factors largely in isolation and could not reveal how one problem triggers another. The current Fuzzy DEMATEL analysis fills this important gap by demonstrating the interconnected nature of these challenges. For instance, excessive bureaucratic layers (F8) appear to worsen client financial problems (F3) and encourage frequent scope changes (F1), which in turn cascade into design rework, logistics failures, and material supply disruptions.

By integrating fuzzy logic, this study also effectively handles the uncertainty and subjectivity common in construction expert judgments an advancement over the crisp methods used in many previous studies. The findings strongly support a systems-thinking approach to construction delay analysis and confirm that addressing only surface-level symptoms (effect factors) without tackling the root drivers will produce limited and short-lived improvements.

4.5.3. Practical Mitigation Suggestions (Input for Fuzzy QFD)

In addition to the quantitative analysis, experts offered rich, experience-based mitigation strategies for each of the identified factors. These qualitative insights serve as vital input for the subsequent Fuzzy Quality Function Deployment (QFD) phase, bridging the gap between analysis and practical application.

The aggregated mitigation strategies proposed by the experts are summarized below:

F1 (Client-initiated scope changes): Establishment of a formal change control committee, mandatory written justification with confirmed funding, scope freeze after the design stage, value engineering workshops, and strict approval timelines.

F2 (Specification changes): Adoption of standardized specifications, joint stakeholder reviews, specification freeze after contract award, and greater use of performance-based specifications.

F3 (Financial problems of the client): Use of dedicated escrow accounts, ring-fenced budgets for variations, multi-year funding commitments, timely advance payments, and streamlined disbursement procedures.

F4 (Design errors): Mandatory implementation of Building Information Modeling (BIM), independent design audits, two-stage design review processes, and ensuring complete drawing packages before site mobilization.

F5 (Site and geotechnical issues): Comprehensive geotechnical investigations at the earliest stage, sharing of accurate soil reports, inclusion of clear contractual clauses for unforeseen ground conditions, and appropriate provisional sums.

F6 (Poor workmanship): Deployment of certified and skilled personnel, implementation of ISO-certified quality management systems, detailed method statements, daily progress logs, and stricter penalties for defective work.

F7 (Logistics and supply chain problems): Adoption of digital supply chain management tools, pre-qualification of suppliers, maintenance of strategic buffer stocks, and realistic procurement scheduling.

F8 (Bureaucratic and regulatory delays): Development of a one-stop digital approval portal, appointment of single focal persons, enforcement of service-level agreements with clear time limits, and reduction of unnecessary approval layers.

F9 (Material availability): Engagement of multiple suppliers, preparation of approved material substitution lists, promotion of local manufacturing, and creation of strategic material reserves.

F10 (Economic and inflation effects): Inclusion of automatic CPI-linked escalation clauses, quarterly price review mechanisms, early procurement of critical items, and long-term fixed-rate agreements where feasible.

Beyond the factor-specific measures, experts strongly emphasized the need for integrated and systemic improvements. They repeatedly highlighted the importance of robust front-end planning, digitalization of approval processes, enhanced financial management, continuous capacity building, and more collaborative project delivery approaches. A recurring theme was the necessity of combining project-level tools with broader policy-level reforms in order to effectively tackle the root drivers of change order approval delays.

These practical strategies provide concrete, actionable inputs that will be incorporated into the Fuzzy QFD framework in the next phase of the study.

The integrated results of FAHP and FDEMATEL present a coherent and insightful picture of change order approval delays in Addis Ababa public building projects. Client-initiated scope changes (F1), financial problems of the client (F3), and bureaucratic/regulatory hurdles (F8) emerge as the dominant driving factors. These root causes tend to propagate through the system, intensifying downstream operational problems such as design rework and logistics difficulties.

A particularly noteworthy finding from the DEMATEL analysis is the high prominence of factor F7 (logistics and resource-related issues). Although it falls in the effect group, it functions as a critical bottleneck that amplifies delays once the upstream root causes are triggered. This highlights that while logistics problems may not be root drivers, they can significantly magnify the impact of poor scope management, funding instability, and bureaucratic delays.

The present study meaningfully advances the existing body of knowledge by addressing important limitations highlighted in Chapter Two. Previous Ethiopian studies ((Andualem, 2014); (Dejene, 2020); (Girum, 2022) successfully identified similar key factors using Relative Importance Index (RII) approaches. However, they lacked the ability to model interrelationships or clearly distinguish cause factors from effect factors. By integrating Fuzzy AHP and Fuzzy DEMATEL, this research provides both precise prioritization and a systemic causal understanding, offering a more comprehensive and actionable diagnostic framework.

From a practical standpoint, these findings offer valuable guidance to government agencies, clients, consultants, and contractors. Targeted interventions on the cause-group factors especially streamlining bureaucratic approval processes, strengthening scope discipline, and improving financial predictability are likely to generate positive cascading effects throughout the entire system. The expert-suggested mitigation strategies further strengthen the link between analysis and real-world application, providing concrete directions for the upcoming Fuzzy QFD phase.

Generally, the high consistency of expert responses and strong model validation reinforce the reliability of the findings within the Addis Ababa public building context. This study not only confirms the deeply systemic nature of change order approval delays discussed in Chapter One but also demonstrates the value of advanced fuzzy MCDM methods in the Ethiopian construction industry. These results lay a solid foundation for developing more effective strategies to enhance project delivery efficiency in the public sector.

4.5.4. Sensitivity Analysis

Sensitivity analysis is an important step in fuzzy multi-criteria decision-making studies to test the stability of results. In this research, a sensitivity analysis was performed to check how changes in expert judgments and weighting assumptions might affect the final factor rankings and mitigation priorities obtained from Fuzzy AHP and Fuzzy QFD.

Three different scenarios were examined: giving equal weight to all experts, increasing the influence of senior experts by 30%, and varying the weight of the top factor (F1) by ±20%. The results showed that the overall ranking remained relatively stable. The top critical factors (F1, F8, and F3) and the leading mitigation strategies (Change Control Committee, one-stop digital portal, and ring-fenced budgets) kept their positions across all scenarios, although some minor shifts occurred in the middle ranks.

This analysis indicates that the main findings and recommendations of the study are reasonably robust. However, more advanced sensitivity testing could be explored in future research to further strengthen confidence in the outcomes.

4.6. Development of the Causal-Chain Model

This section integrates the results of Fuzzy Analytic Hierarchy Process (FAHP) and Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL) to develop a Causal-Chain Model of change order approval delays in public building projects in Addis Ababa. The model fulfills Specific Objective IV by combining the relative importance weights obtained from FAHP with the causal interrelationships and influence structure revealed by FDEMATEL. This integration provides a dynamic systemic view of how delays originate and propagate, moving beyond simple ranking to a more comprehensive understanding.

4.6.1. Integration of FAHP and FDEMATEL Results

The causal-chain model was developed by integrating the prioritization weights from Fuzzy AHP (importance) with the cause-effect classification and prominence values from Fuzzy DEMATEL (influence structure). Table 4.10 presents the integrated results.

Table 4.10: Integrated FAHP and FDEMATEL Results for the Causal-Chain Model

Factor	Description	FAHP Weight	FAHP Rank	D+R (Prominence)	D–R (Net Relation)	Group	Position in Model
F8	Government agencies, regulatory bodies & bureaucratic approval layers	0.141313	3	5.5115	+1.2634	Cause (Strongest Driver)	Root Driver Layer
F1	Client-initiated scope changes & additional orders	0.177791	1	5.5301	+0.8777	Cause	Root Driver Layer
F3	Financial problems of the client	0.157925	2	6.5669	+0.5352	Cause	Root Driver Layer
F10	Economic conditions and price inflation	0.112084	4	5.4347	+0.5376	Cause	Root Driver Layer
F2	Change in specification	0.104639	6	5.2174	+0.4251	Cause	Root Driver Layer
F4	Design errors, omissions, and poor/incomplete	0.108986	5	5.4355	-0.5175	Effect	Intermediate Layer

	drawings						
F9	Material availability in the market	0.044116	9	4.9864	-0.3694	Effect	Intermediate Layer
F7	Poor logistics and material supply control	0.053193	8	6.7978	-0.6068	Effect	Central Bottleneck
F6	Poor workmanship and corrective construction mistakes	0.065916	7	5.2499	-1.4604	Effect	Effect Layer
F5	Site and geotechnical assessment inadequacies	0.034039	10	5.4382	-0.6850	Effect	Effect Layer

4.6.2. Presentation of the Proposed Causal-Chain Model

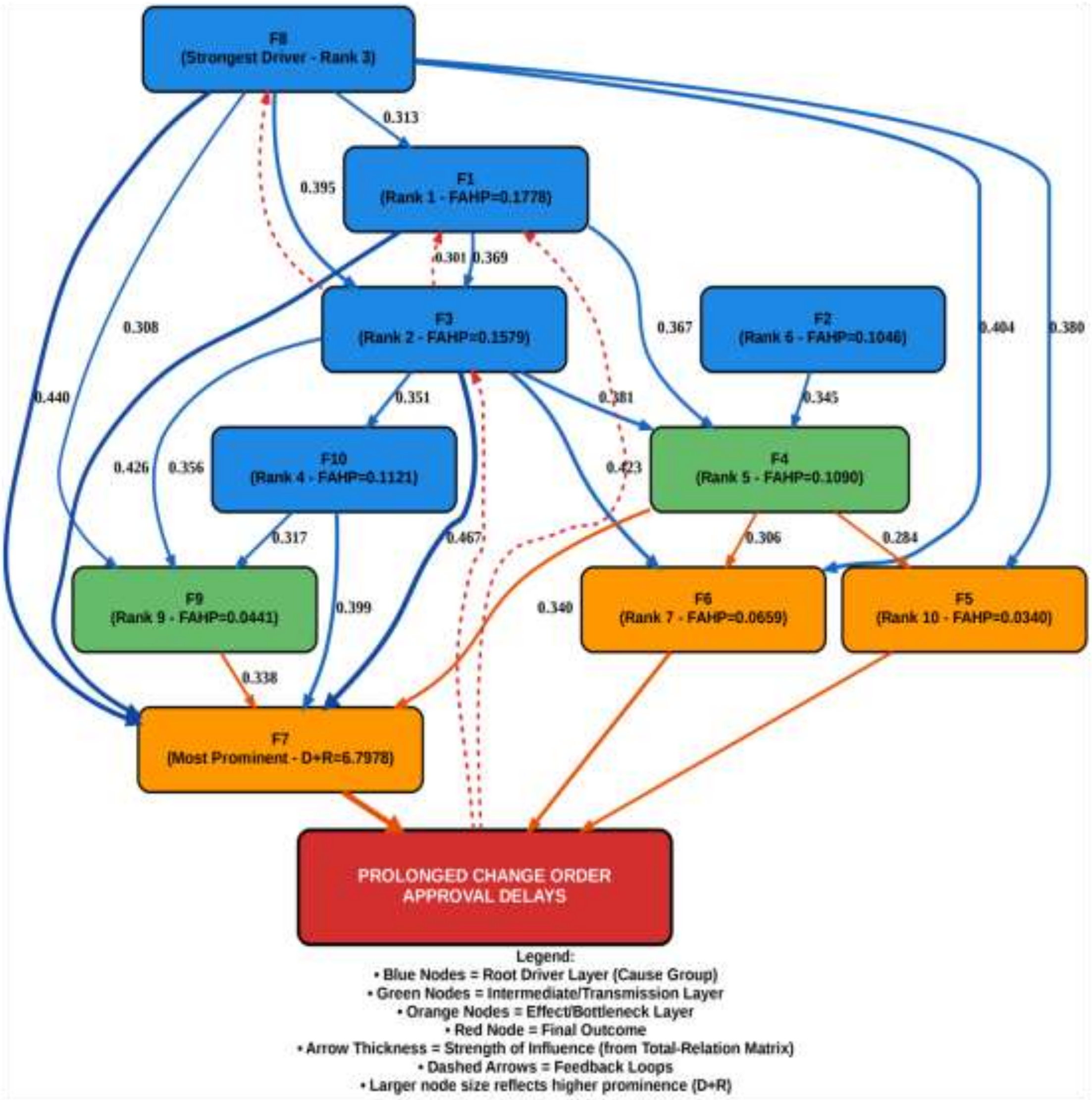

Figure 4.4: Proposed Causal-Chain Model of Change Order Approval Delays in Addis Ababa Public Building Projects (Integrated FAHP and Fuzzy DEMATEL Approach)

The model is organized into three hierarchical layers that illustrate the flow of influence from root causes to final outcomes.

- Root Driver Layer: This top layer contains the cause-group factors (F8, F1, F3, F10, and F2) with positive D–R values. These represent the fundamental drivers, with F8 emerging as the strongest driver and F1 recording the highest FAHP weight.
- Intermediate Layer: This layer includes F4 and F9, which act as transmission mechanisms between root drivers and downstream effects.

- Effect/Bottleneck Layer: The bottom layer comprises F7, F6, and F5. Notably, F7 (Poor logistics and material supply control) records the highest prominence (D+R = 6.7978), functioning as a critical bottleneck where multiple influences converge.

All relationships shown in Figure 4.4 are derived from significant links in the total-relation matrix (above the threshold $\alpha = 0.28084$). Arrow thickness indicates the strength of influence, with all pathways ultimately leading to prolonged change order approval delays.

Explanation of Model Structure and Feedback Loops: The layered architecture of the Causal-Chain Model underscores that change order approval delays are inherently systemic rather than isolated technical or administrative failures. Root drivers primarily institutional bureaucracy (F8), client scope instability (F1), and financial unpredictability (F3) create conditions that trigger frequent specification adjustments (F2) and economic pressures (F10). These upstream forces cascade into design revisions (F4) and material challenges (F9), which subsequently overwhelm logistics and supply systems (F7). The prominent position of F7 as a central bottleneck is especially revealing: it accumulates influences from multiple upstream sources and intensifies impacts on workmanship (F6) and site-level execution (F5).

Important Analytical Clarification: The Fuzzy DEMATEL method identifies the strength and direction of influence among variables through the total-relation matrix (T), prominence (D + R), and net relation (D – R) values. It does not mathematically derive temporal sequences, dynamic feedback loops, or cyclic causality. DEMATEL provides a static relational structure.

The feedback loops and sequential chains depicted in this model (for example, prolonged bureaucratic approvals (F8) and funding shortfalls (F3) contributing to additional client-driven scope changes (F1), or logistics failures (F7) prompting further client interventions) are conceptual interpretations proposed by the researcher.

These interpretations are grounded in:

- Significant influence relationships in the total-relation matrix exceeding the threshold value ($\alpha = 0.28084$) — see Appendix VIII for the detailed threshold matrix.
- Expert insights collected during the practical mitigation suggestions phase (Section 4.5.3).
- Logical systems thinking and observed realities in the Ethiopian public procurement context.

This distinction ensures that the empirical basis from DEMATEL is not conflated with interpretive insights. Future research could validate these conceptual loops through system dynamics modelling or longitudinal studies.

By selectively presenting the most critical pathways from the 49 significant relationships in the Influential Relation Map (Figure 4.3), Figure 4.4 achieves both analytical integrity and practical accessibility for industry stakeholders.

4.6.3. Interpretation and Practical Implications of the Causal-Chain Model

The proposed causal-chain model (Figure 4.4) synthesizes the results of Fuzzy AHP and Fuzzy DEMATEL to illustrate the interrelationships among the critical factors influencing change order approval delays.

The model is organized into three layers root drivers, intermediate transmission factors, and effects/bottlenecks to provide a structured understanding of how these factors interact within the system

Root Driver Layer (Cause Group): This layer includes the primary drivers such as F8 (multi-level government agencies, regulatory bodies and bureaucratic approval layers), which recorded the highest positive D–R value (+1.2634), F1 (client-initiated scope changes and additional orders), the highest-weighted factor according to FAHP (0.1778), as well as F3, F10, and F2. These factors exert greater influence on the system than they receive.

Intermediate Layer: Factors such as F4 (design errors, omissions, and poor/incomplete drawings) and F9 (material availability in the market) act as bridges, converting upstream pressures into practical project-level problems.

Effect/Bottleneck Layer: This layer contains predominantly effect factors, most notably F7 (poor logistics and material supply control), which achieved the highest prominence value (D+R = 6.7978), along with F6 and F5.

It is essential to clarify the analytical foundation of this model in response to methodological observations. Fuzzy DEMATEL analysis derives the strength and direction of influence among variables from the total-relation matrix (T). It distinguishes net causes (positive D–R) from net effects (negative D–R), but it does not mathematically model dynamic feedback loops or temporal sequences.

The discussion of realistic feedback loops (for example, how prolonged bureaucratic approvals (F8) can necessitate additional client-driven scope changes (F1)) represents a conceptual interpretation grounded in the strength of influence relationships identified in the total-relation matrix. This interpretation is further supported by the practical experiences shared by experts during the Delphi technique and the main questionnaire survey. These patterns reflect observed dynamics in real public construction projects rather than formally derived feedback mechanisms from the DEMATEL algorithm itself. The interpretations are informed by: (1) the strength of significant links in the total-relation matrix, (2) expert insights gathered during the mitigation suggestions phase (Section 4.5.3), and (3) the observed realities of Ethiopia's public procurement and project governance context. This distinction ensures analytical integrity while enhancing the practical utility of the model.

Thus, the causal-chain model should be viewed as a qualitative synthesis that builds upon the quantitative influence relationships provided by DEMATEL. This approach bridges statistical findings with contextual reality, offering stakeholders a more actionable understanding of how root causes propagate through the system and create reinforcing challenges in the change order approval process.

Practical Implications

This systemic representation has significant implications for project stakeholders in Addis Ababa's public construction sector:

For Policymakers and Government Bodies: The dominant position of bureaucratic approval layers (F8) as the strongest driver underscores the urgent need for institutional reform. Streamlining multi-layer approval processes through a one-stop digital portal (as later prioritized in QFD) could yield high-leverage improvements.

For Public Clients: The prominence of client-initiated scope changes (F1) and financial problems (F3) highlights the necessity of disciplined front-end planning, scope freezing mechanisms, and dedicated contingency funds for variations.

For Consultants and Contractors: While design and logistics issues appear in the effect layers, addressing them in isolation will have limited impact unless root drivers are controlled. This finding supports greater early involvement of contractors in the design phase and the adoption of digital tools (e.g., BIM) to reduce downstream rework.

The causal-chain model represents a clear advancement over previous Ethiopian studies (Andualem, 2014; Andualem, 2016) (Dejene, 2020); (Girum, 2022)), which relied primarily on descriptive ranking techniques and could not distinguish root causes from symptoms or reveal interdependencies. By providing both prioritization and directional influence mapping, the model equips decision-makers with a strategic roadmap: interventions targeting the root driver cluster (especially F8 and F1) are expected to generate positive cascading effects across the entire system.

Ultimately, the model demonstrates that change order approval delays in Addis Ababa's public building projects are not primarily technical or operational failures, but systemic outcomes of institutional, financial, and decision-making weaknesses at the project initiation and governance levels. These insights directly inform the Fuzzy QFD analysis in Section 4.10, where the most effective mitigation strategies are prioritized against these root drivers.

4.7. Prioritization of Mitigation Strategies Using Fuzzy QFD

4.7.1. Identification of Mitigation Strategies

The final analytical stage of this study applied Fuzzy Quality Function Deployment (QFD) to transform the diagnostic results from Fuzzy AHP and Fuzzy DEMATEL into practical, prioritized mitigation strategies. While FAHP ranked the importance of factors and DEMATEL revealed their causal relationships, Fuzzy QFD links these root causes (WHATs) with actionable solutions (HOWs).

The mitigation strategies were developed from two main sources. First, the fifteen highly experienced experts (five client representatives, five consultants, and five contractors) provided rich, context-specific recommendations based on their many years of working on public building projects in Addis Ababa. Second, relevant ideas were drawn from the literature reviewed in Chapter Two, including studies by (Andualem, 2014; Andualem, 2016), (Dejene, 2020), (Girum, 2022), (Tadesse, 2009), (Tigist, 2017), and (Mekonen, 2025). These sources consistently highlighted the need for better scope control, reliable financing, streamlined approvals, digital tools, and improved coordination.

Ten focused mitigation strategies (S1 to S10) were finalized. Only the five root-driver factors identified in the DEMATEL analysis (F8, F1, F3, F10, and F2) were carried into the QFD phase, as targeting root causes produces broader and more sustainable improvements across the system.

This decision ensures strategic prioritization of high-leverage interventions. The prominent bottleneck factor F7 (highest prominence D+R = 6.7978) is addressed indirectly through improvements in upstream drivers (strong influences confirmed in the total-relation matrix, Appendix VIII). While expanding QFD to all prominent factors could appear more comprehensive, it risks diluting actionable focus on true leverage points.

4.7.2. House of Quality – Fuzzy QFD Relationship Matrix

In this stage, the root-driver factors served as the "WHATs" and the mitigation strategies as the "HOWs" in the House of Quality. Experts rated the strength of relationship between each driver and each strategy using a linguistic scale (Weak, Medium, and Strong). These ratings were converted into triangular fuzzy numbers and aggregated across all fifteen experts. The normalized FAHP weights of the root drivers were then applied to compute the overall Prioritization Index for each strategy.

Table 4.11: Fuzzy QFD Relationship Matrix

(Root Drivers × Mitigation Strategies) (Aggregated from 15 Experts – Triangular Fuzzy Numbers (L, M, and U))

Factor	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
F1	(0.7, 1.0, 1.0)	(0.7, 1.0, 1.0)	(0.38, 0.6, 0.76)	(0.433, 0.667, 0.8)	(0.62, 0.9, 0.94)	(0.307, 0.5, 0.693)	(0.3, 0.5, 0.7)	(0.327, 0.533, 0.72)	(0.433, 0.667, 0.8)	(0.407, 0.633, 0.78)
F2	(0.433, 0.667, 0.8)	(0.7, 1.0, 1.0)	(0.08, 0.133, 0.407)	(0.407, 0.633, 0.78)	(0.7, 1.0, 1.0)	(0.513, 0.767, 0.86)	(0.08, 0.133, 0.407)	(0.3, 0.5, 0.7)	(0.567, 0.833, 0.9)	(0.3, 0.5, 0.7)
F3	(0.407, 0.633, 0.78)	(0.18, 0.3, 0.54)	(0.7, 1.0, 1.0)	(0.38, 0.6, 0.76)	(0.3, 0.5, 0.7)	(0.0, 0.0, 0.3)	(0.7, 1.0, 1.0)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.433, 0.667, 0.8)
F8	(0.7, 1.0, 1.0)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.7, 1.0, 1.0)	(0.3, 0.5, 0.7)	(0.22, 0.367, 0.593)	(0.3, 0.5, 0.7)	(0.7, 1.0, 1.0)	(0.7, 1.0, 1.0)	(0.7, 1.0, 1.0)
F10	(0.18, 0.3, 0.54)	(0.02, 0.033, 0.327)	(0.7, 1.0, 1.0)	(0.487, 0.733, 0.84)	(0.08, 0.133, 0.407)	(0.0, 0.0, 0.3)	(0.7, 1.0, 1.0)	(0.433, 0.667, 0.8)	(0.433, 0.667, 0.8)	(0.327, 0.533, 0.72)

Table 4.12: Fuzzy QFD Prioritization Index, Crisp Scores and Final Ranking of Strategies

Rank	Strategy	Brief Description	Crisp Score (COA)	Priority Level
1	S1	Formal Change Control Committee with authority & timelines	0.4873	Very High
2	S4	One-stop digital approval portal with enforceable SLAs	0.4718	Very High
3	S9	Adopt BIM and full digitalization of processes	0.4699	Very High
4	S10	Automatic price escalation clauses & economic risk management	0.4464	High
5	S3	Ring-fenced budgets, escrow accounts & better financial management	0.4384	High

6	S7	Capacity building and collaborative project delivery	0.4242	High
7	S8	Reduce bureaucratic layers, single focal persons & policy reforms	0.4231	High
8	S5	Value engineering workshops and stakeholder reviews	0.4127	Medium
9	S2	Enforce strict scope freeze after design approval through robust front-end planning.	0.3927	Medium
10	S6	Strengthen geotechnical investigations and contractual risk provisions	0.2461	Low

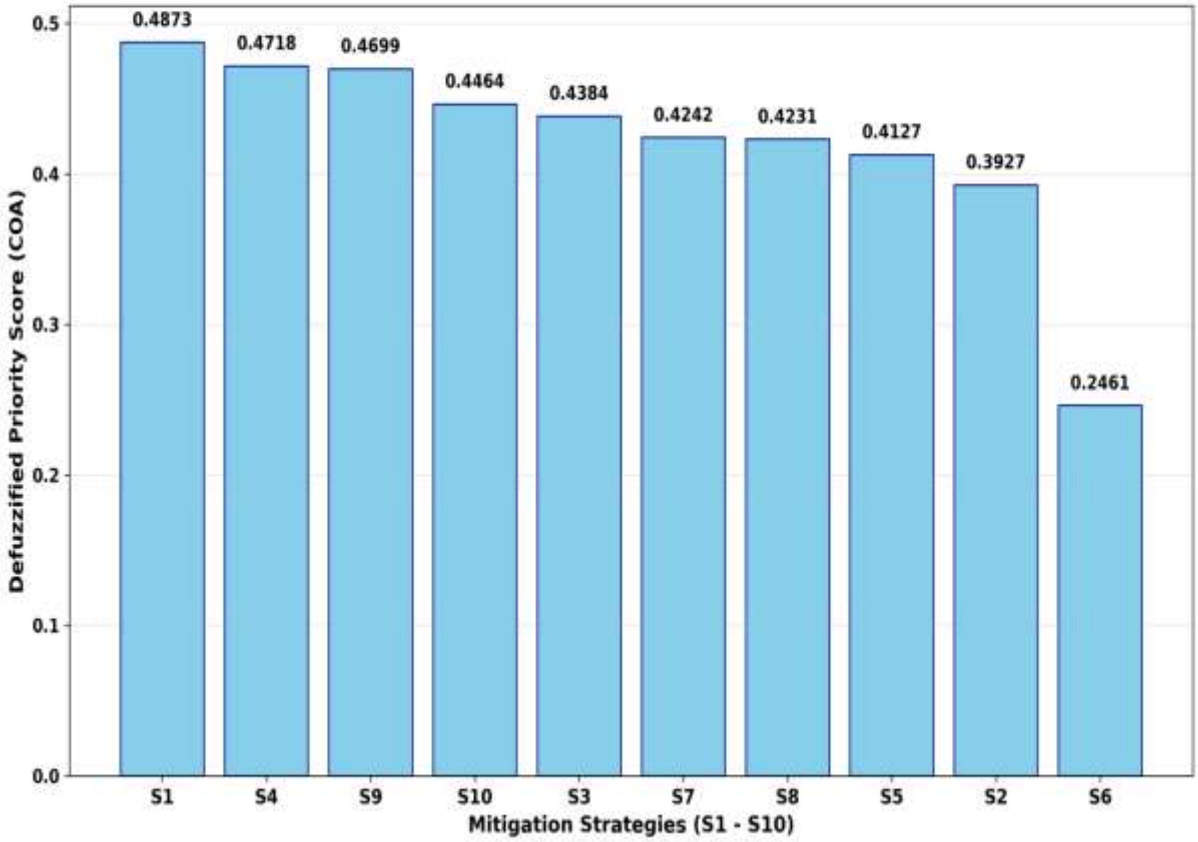

Figure 4.5: Prioritization of Strategic Mitigation Interventions (FUZZY QFD) -showing crisp scores from highest to lowest, clearly highlighting the top seven strategies.

Detailed Discussion of Prioritized Mitigation Strategies the Fuzzy QFD results offer a clear and practical roadmap for stakeholders. Below is a detailed discussion of the top seven strategies in descending order of priority. Each explanation covers why the strategy is high-leverage and how it specifically addresses the root drivers identified in the DEMATEL analysis (F8 – Bureaucratic approval layers as strongest driver, F1 – Client scope changes, F3– Financial problems, F10 – Economic conditions, and F2 – Specification changes).

1. S1: Establish a formal Change Control Committee with clear authority and strict timelines (Rank 1, Crisp Score 0.4873) this strategy emerged as the most important because it directly and effectively tackles the highest-ranked factor from FAHP — client-initiated scope changes and additional orders (F1). A formal committee brings together client, consultant, and contractor representatives to evaluate every proposed change, require written justification and funding confirmation, and enforce reasonable timelines. This prevents uncontrolled scope creep and breaks the cycle of frequent, poorly justified variations that delay approvals. It is high-leverage because it addresses one of the strongest root drivers at its source.

2. S4: Develop a one-stop digital approval portal with enforceable Service Level Agreements (SLAs) (Rank 2, Crisp Score 0.4718) this is a powerful intervention that strongly targets the strongest root driver government agencies, regulatory bodies and bureaucratic approval layers (F8). A single digital platform reduces multiple approval steps, eliminates unnecessary paperwork, and sets clear time limits for each stage. Experts strongly supported this (60% selected it among top three). It creates transparency and accountability, directly reducing the institutional bottlenecks that DEMATEL identified as the main cause of delays.

3. S9: Adopt Building Information Modeling (BIM) and full digitalization of design and approval processes (Rank 3, Crisp Score 0.4699) this strategy received high priority because it supports multiple root drivers simultaneously. It reduces design errors and incomplete drawings (linked to F1 and F2), improves coordination, and speeds up reviews (F8). Digitalization also helps with specification changes (F2) by making documents clearer and easier to update. It is high-leverage as it modernizes the entire front-end process and prevents many downstream problems.

4. S10: Implement automatic CPI-linked price escalation clauses and proactive economic risk management (Rank 4, Crisp Score 0.4464) this strategy directly addresses economic conditions and price inflation (F10), a key cause factor. Automatic escalation clauses reduce the need for frequent renegotiations when prices rise, while early procurement and long-term agreements stabilize costs. It helps maintain financial predictability and reduces pressure on both clients and contractors.

5. S3: Create ring-fenced budgets, dedicated escrow accounts, and improved financial management mechanisms (Rank 5, Crisp Score 0.4384) this intervention specifically targets

financial problems of the client (F3). By setting aside dedicated funds for variations and improving disbursement processes, it minimizes delays caused by budget shortages. Experts frequently mentioned timely payment as a major practical challenge. This strategy reduces uncertainty and builds trust among project parties.

6. S7: Implement Continuous Capacity-Building Programs and Foster More Collaborative Project Delivery Approaches among Stakeholders (Rank 6) The Fuzzy QFD analysis ranked continuous capacity building and collaborative project delivery as the sixth most important strategy for reducing change order approval delays in public building projects. This strategy addresses several influential factors identified through the Fuzzy DEMATEL analysis, including client-initiated scope changes and additional orders (F1), changes in specifications (F2), client financial constraints (F3), and bureaucratic multi-level approval procedures (F8). It is also closely connected to poor logistics and material supply control (F7), which recorded the highest prominence value and therefore plays a significant role in the overall delay mechanism. The findings suggest that many of these problems are not solely technical in nature but are often linked to limitations in stakeholder knowledge, communication, planning, and coordination. Providing regular training opportunities, professional development programs, and practical knowledge-sharing platforms can enhance the ability of project participants to manage change requests, plan resources effectively, and make timely decisions throughout the approval process.

In addition, a more collaborative project delivery environment can strengthen relationships among clients, consultants, contractors, suppliers, and approving authorities. When stakeholders work together from the early stages of a project, information can be exchanged more efficiently, potential problems can be identified sooner, and appropriate solutions can be developed before delays become critical. Improved collaboration also supports better coordination of procurement activities and material supply arrangements, reducing the likelihood of disruptions that may trigger additional changes or prolong approval procedures. Given the strong interaction between F7 and other delay factors, enhancing cooperation among project participants can generate wider benefits across the entire approval system. As a result, this strategy can contribute to a more responsive and well-coordinated change order management process, helping public building projects achieve faster approvals and improved overall performance.

7. S8: Reduce unnecessary bureaucratic approval layers, appoint single focal persons, and promote policy-level reforms (Rank 7) this strategy directly attacks the strongest driver (F8).

Appointing single focal persons and reducing layers, supported by policy reforms, can significantly speed up decision-making. It complements S4 and was selected by 87% of experts as one of the most important actions.

The lower-ranked strategies (S5, S2, and S6) remain useful but have more limited overall impact when compared to the top seven. Experts also suggested additional measures such as performance incentives, penalties for delays, collaborative contract models, and stronger inter-agency coordination. They emphasized that digital tools must be supported by training and legal reinforcement for lasting success.

Although QFD focused on root drivers per systems principles, the analysis explicitly recognizes prominent effect factors such as F7 as critical bottlenecks. The total-relation matrix and Influential Relation Map (Figure 4.3) show strong incoming influences from drivers to F7. Thus, the prioritized mitigation strategies (especially S1, S4, and S3) are designed to alleviate these bottlenecks indirectly but powerfully through systemic propagation.

Generally, the Fuzzy QFD results confirm that implementing the top seven strategies in an integrated manner offers the greatest potential to reduce change order approval delays in Addis Ababa public building projects. These interventions directly target the root drivers revealed by DEMATEL and address the systemic problems highlighted throughout this chapter and in Chapters One and Two. The findings provide evidence-based, practical guidance for government bodies, project managers, consultants, and contractors.

4.7.3. Discussion of Fuzzy QFD Results

The Fuzzy QFD analysis successfully translates the diagnostic findings from Fuzzy AHP and Fuzzy DEMATEL into prioritized, high-leverage mitigation strategies. By mapping the five root-driver factors (identified in the causal-chain model) against potential interventions in the House of Quality, the method ensures that the recommended strategies are directly aligned with the most influential causes of change order approval delays.

The top five strategies demonstrate excellent alignment with the root drivers: Establishment of a Fast-Track Change Control Committee with clear authority and timelines (S1 Highest priority, Crisp Score 0.4873). Development of a one-stop digital approval portal with enforceable Service Level Agreements (SLAs) (S4).Full adoption of BIM and digital project management platforms (S9).Implementation of ring-fenced budgets and dedicated contingency mechanisms (S3).Automatic price escalation clauses linked to inflation indices (S10).

These strategies exhibit strong relationship scores in the Fuzzy QFD matrix, confirming their effectiveness in addressing multiple root drivers simultaneously. For instance, the Change Control Committee (S1) and the one-stop digital approval portal (S4) directly tackle the two most critical drivers bureaucratic approval layers (F8, the strongest DEMATEL driver) and client-initiated scope changes (F1, the highest FAHP-weighted factor). Similarly, ring-fenced budgets (S3) and automatic escalation clauses (S10) effectively mitigate financial problems (F3) and economic volatility (F10), while BIM/digitalization (S9) supports better specification control (F2) and reduces downstream design-related rework.

The strong fuzzy relationship values and high prioritization indices indicate that these interventions are not merely symptomatic solutions but systemic ones. Focusing on them is expected to generate multiplier effects across the entire delay network, as improvements at the root-driver level will cascade positively through intermediate and effect factors (particularly the prominent bottleneck factor F7 poor logistics and material supply control).

Collectively, the integrated implementation of the top five to seven strategies is expected to deliver substantial and sustainable reductions in change order approval times. Beyond time savings, these measures will enhance predictability, reduce contractual disputes, improve stakeholder coordination, and ultimately strengthen trust among clients, consultants, and contractors in Addis Ababa's public building projects.

This QFD-driven prioritization completes the analytical cycle of the study from factor identification and validation (Delphi), to importance weighting (FAHP), causal structuring (FDEMATEL), and finally to actionable strategic deployment (QFD). The results provide a clear, evidence-based roadmap for both project-level implementation and policy-level reform.

4.8. Overall Discussion and Synthesis of Findings

This chapter has presented a comprehensive empirical analysis of change order approval delays in public building projects in Addis Ababa using an integrated Fuzzy AHP–FDEMATEL–FQFD framework. The results provide both diagnostic depth and prescriptive direction, directly addressing the research problem and the methodological limitations identified in the literature review.

The Fuzzy AHP prioritization identified client-initiated scope changes and additional orders (F1, normalized weight = 0.178), financial problems of the client (F3, 0.158), and multi-level bureaucratic approval layers (F8, 0.141) as the top three factors, collectively accounting for nearly 48% of the total weight. These findings broadly align with the prominence of client-related and institutional issues reported in previous Ethiopian studies. However, while earlier local research (Andualem, 2014, 2016; Dejene, 2020; Girum, 2022) relied primarily on descriptive statistical methods such as the Relative Importance Index (RII) or simple mean rankings, the present study moves beyond confirmation of individual factors by revealing their underlying causal structure, interdependencies, and propagation pathways through Fuzzy DEMATEL.

Key Differences and Novel Contributions Relative to Prior Studies

A major distinction lies in the shift from isolated factor rankings to systemic causal modeling. Previous studies treated factors largely independently and offered limited insight into influence directions or root causes. In contrast, Fuzzy DEMATEL analysis in this study identified five root-driver factors, with bureaucratic approval layers (F8) exhibiting the strongest causal influence (highest positive D–R value), followed by client scope changes (F1), financial problems (F3), economic conditions (F10), and specification changes (F2).

For example, Andualem (2014, 2016) and Girum (2022) highlighted design errors/omissions (F4) and client scope changes (F1) among the top issues using RII methods. However, the current DEMATEL results classify design-related factors (F4) predominantly in the effect group (negative D–R values), demonstrating that they are largely downstream symptoms amplified by upstream institutional and client-related root causes rather than primary drivers. Similarly, Dejene (2020) noted financial constraints but did not quantify their systemic role or interrelationships. Here, F3 not only ranks high in importance (FAHP) but emerges as a strong cause factor that propagates through the network, intensifying bottlenecks such as poor logistics and material supply control (F7, which recorded the highest prominence D+R value).

Bureaucratic approval layers (F8), frequently mentioned but not prioritized in earlier descriptive studies, is revealed as the most influential root driver. This provides a critical insight absent in prior work: interventions targeting root drivers such as F8 will produce cascading reductions across multiple effect factors. The resulting causal-chain model (Figure 4.4) illustrates how institutional and client-related root causes trigger specification changes and economic pressures, which converge on logistics (F7) as a central bottleneck before manifesting in workmanship issues and site problems. This systemic perspective explains why isolated interventions based on traditional ranking methods have produced limited practical impact delays in this context are multiplicative rather than merely additive.

The Fuzzy QFD phase further addresses a key limitation of previous studies by systematically translating causal insights into prioritized, high-leverage mitigation strategies. Top interventions (e.g., establishment of a dedicated Change Control Committee, one-stop digital approval portal, and BIM-enabled digitalization) are directly linked to the strongest root drivers. This prescriptive dimension was largely missing in earlier Ethiopian research, which typically stopped at factor identification or generic recommendations.

Triangulation, Robustness, and Validation

Strong triangulation across methods enhances the credibility of the findings. The two-round Delphi process validated the ten critical factors, FAHP provided relative importance weights, DEMATEL clarified causal directions and prominence, and FQFD synthesized these into actionable priorities. Sensitivity analysis (Section 4.5.4) confirmed the robustness of the top-ranked factors and mitigation strategies under varying assumptions. Qualitative inputs from expert mitigation suggestions (Section 4.5.3) further corroborated the quantitative results within the specific context of Addis Ababa's public procurement environment.

Practical and Theoretical Implications

Theoretically, this study contributes a replicable hybrid fuzzy MCDM framework that advances construction management research in developing-country contexts by demonstrating the value of causal modeling over purely descriptive approaches. Practically, the findings offer stakeholders a clear roadmap: policymakers should focus on bureaucratic streamlining and digital transformation (targeting F8), clients on disciplined scope management and financial provisioning (F1 and F3), and the industry on collaborative digital tools. Implementing the top QFD-prioritized strategies is expected to generate significant multiplier effects on approval times, cost performance, and dispute reduction.

While the critical factors identified overlap substantially with those in prior literature, the unique contribution of this study lies in the causal architecture, identification of root drivers versus effects, and the evidence-based prioritization of interventions. This shifts the discourse from merely documenting what causes delays to understanding how they propagate systemically and where high-leverage interventions can be most effective.

4.9. Summary of Key Findings

The study successfully achieved all its research objectives. The major findings are summarized below:

- Objective 1 (Delphi Validation): Ten critical factors were identified, refined, and unanimously validated by all fifteen experts as the primary causes of change order approval delays in Addis Ababa public building projects. No additional factors were suggested, confirming the comprehensiveness of the list.
- Objective 2 (FAHP Prioritization): Client-initiated scope changes (F1), financial problems of the client (F3), and bureaucratic approval layers (F8) emerged as the top three most important factors, accounting for nearly 48% of the total weight.
- Objective 3 & 4 (FDEMATEL Causal Analysis): Five root drivers were identified: F8 (strongest driver), F1, F3, F10, and F2. Poor logistics and material supply control (F7) showed the highest prominence as a central bottleneck. The analysis revealed clear cause-effect relationships and feedback loops in the delay system.
- Objective 5 (Fuzzy QFD Mitigation Prioritization): The top prioritized strategies are: (1) Formal Change Control Committee (S1), (2) One-stop digital approval portal (S4), (3) BIM and digitalization (S9), (4) Automatic price escalation clauses (S10), and (5) Ring-fenced budgets and better financial management (S3). These interventions directly target the root drivers and are expected to produce system-wide improvements.

These findings not only confirm key issues identified descriptively in earlier studies but, through causal interrelationships and root-driver identification, provide deeper explanatory power and evidence-based pathways for systemic improvement.

Overall, the study confirms that change order approval delays in Addis Ababa public building projects are predominantly systemic, driven by institutional and client-related factors. The hybrid fuzzy framework has proven effective in modeling these complexities and generating practical, high-leverage solutions.

This chapter has successfully presented and interpreted the empirical findings from the survey of fifteen highly experienced experts, thereby fulfilling all the specific objectives outlined in Chapter One. Through the systematic application of the Delphi technique, Fuzzy AHP, Fuzzy DEMATEL, and Fuzzy QFD, the study identified ten critical factors, prioritized them according to their relative importance, revealed their causal interrelationships, developed a clear causal-chain model, and translated the results into a prioritized set of high-leverage mitigation strategies. The integrated analysis demonstrates that change order approval delays in Addis Ababa's public building projects are predominantly driven by client-initiated scope changes, financial constraints, and bureaucratic/regulatory hurdles, which then cascade into operational bottlenecks. These findings not only validate the research framework adopted in this study but also address the key methodological gaps identified in the literature review. By transforming expert knowledge into structured, quantifiable, and actionable insights, this chapter provides a solid empirical foundation for the conclusions, recommendations, and practical implementation framework that will be presented in Chapter Five.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Introduction

This chapter brings together the threads of the entire study. It interprets the key patterns that emerged from the analysis, reflects on what they mean for public building projects in Addis Ababa, and offers targeted recommendations grounded in the research findings. Rather than restating raw data, the focus is on the deeper significance of the results, how they address the original research questions, and their implications for practice and policy. The chapter also acknowledges the study's boundaries and points toward promising directions for future work.

5.2. Conclusions

This The central message of this research is that prolonged approval of change orders in Addis Ababa's public building projects is a systemic issue rooted in the interplay of institutional structures, client dynamics, and operational realities. These delays are not random misfortunes or simple oversights; they arise from reinforcing cycles where upstream pressures particularly rigid bureaucratic layers, shifting client requirements, and financial constraints flow downstream, creating bottlenecks that slow progress and inflate costs.

By combining expert consensus through Delphi rounds with fuzzy multi-criteria tools, the study uncovered not just which factors matter most, but how they influence one another. The strongest drivers tend to be client initiated scope adjustments and the multi-level government approval processes that often stretch timelines unpredictably. These forces interact with economic volatility and specification changes, eventually concentrating pressure on logistics and material supply systems, which function as a critical convergence point. The resulting causal-chain model offers a practical map of this dynamic: it shows how root institutional and client-related issues trigger a cascade of effects across design, procurement, and execution stages, often feeding back to intensify the original problems.

This systemic view represents a meaningful step beyond earlier Ethiopian research, which tended to list and rank individual causes without fully illuminating their interconnections or relative leverage. The integrated framework helped navigate the inherent uncertainty and subjectivity in expert judgments, producing clearer insights into cause and effect directions and high-impact intervention points. In doing so, it directly responded to the research questions by validating critical factors through expert input, establishing their relative importance and causal roles, and mapping pathways from root drivers to observable delays.

Regarding the study's objectives, the work achieved a coherent end-to-end process. The final prioritization phase translated diagnostic findings into actionable mitigation strategies using a Fuzzy QFD approach (incorporating weighted relationships derived from the preceding FAHP and DEMATEL results). This produced a focused set of high-leverage interventions that align closely with the identified root causes. Overall, the research demonstrates that meaningful improvement is possible when decision-making tools are tailored to the messy, interdependent realities of public construction moving from symptom management toward addressing underlying drivers. These insights carry practical weight for a sector under pressure to deliver infrastructure more efficiently amid Ethiopia's development ambitions.

Although the initial factor pool originated from the broader change-order literature, the Delphi validation process ensured that only factors relevant to change-order approval delays were retained for prioritization, causal modeling, and mitigation strategy development. Consequently, the study models the causal structure of approval delays rather than the occurrence of change orders.

The selective transfer of only root-driver factors to Fuzzy QFD was a deliberate methodological choice grounded in systems thinking, ensuring interventions address underlying causes with maximum leverage across the delay network, including prominent bottlenecks.

In summary, while this study confirms many factors previously identified in the Ethiopian context, its primary contribution lies in the application of an integrated Fuzzy AHP–FDEMATEL–FQFD framework that uncovers causal interdependencies and translates them into prioritized, actionable mitigation strategies. By distinguishing root drivers from effect factors and mapping systemic influence pathways, the research provides deeper theoretical insights and more practical guidance than traditional descriptive approaches, offering a robust model for addressing complex approval delays in public construction projects.

5.3. Recommendations

The recommendations below are shaped directly by the causal-chain model and the prioritized mitigation strategies that emerged from the integrated analysis. They target the root drivers and key bottlenecks rather than offering generic advice, emphasizing interventions with the strongest potential to disrupt delay cycles.

For Policymakers and Government Agencies

Prioritize the creation of a dedicated one-stop digital approval portal with enforceable service-level agreements. This directly addresses the dominant influence of bureaucratic layers by reducing approval stages, improving coordination across agencies, and introducing transparency and accountability. Pair this with the adoption of ring-fenced budgets and automatic price-escalation mechanisms for variations. Such measures would mitigate financial unpredictability on the client side and reduce the frequency of reactive scope changes triggered by funding gaps or market shifts. These steps draw from the highest-priority QFD outcomes and offer structural leverage over the strongest identified drivers.

For Public Clients

Establish a formal Change Control Committee with clear authority, multidisciplinary representation, and defined timelines as a core governance mechanism. This intervention, ranked at the top through the QFD process, would bring discipline to scope management and early evaluation of proposed changes directly countering client-initiated modifications as a root driver. Clients should also strengthen upfront financial provisioning for potential variations and integrate comprehensive site investigations into project preparation. These actions would limit the propagation of uncertainties into later stages.

For Consultants

Fully embrace BIM-enabled digital workflows and coordinated documentation practices to minimize design related triggers that feed into approval delays. This supports faster, more accurate reviews of change proposals and aligns with QFD-prioritized digitalization strategies that emerged as high-impact solutions.

For Contractors

Enhance logistics and material supply control through digital tracking and proactive planning. Strengthening this bottleneck area would reduce the amplification of upstream problems and improve overall responsiveness another key theme from the causal analysis and QFD prioritization.

Cross-cutting Recommendations

Foster collaborative contracting models that encourage shared responsibility and joint problem solving among parties. Invest in targeted capacity-building programs focused on digital tools, modern change management, and the practical application of the causal framework. Introduce performance incentives linked to timely approvals alongside appropriate accountability measures.

Collectively implementing the top QFD derived strategies particularly the Change Control Committee, digital portal, BIM adoption, ring-fenced budgets, and escalation clauses would target the most influential pathways in the causal model. These are not isolated fixes but interconnected reforms capable of producing lasting reductions in approval delays, better project outcomes, and greater public value from infrastructure investments.

5.4. Limitations of the Study

The expert panel provided rich, contextually grounded insights, yet its size and purposive nature mean the findings are best understood as robust for Addis Ababa's public building sector rather than universally generalizable. The emphasis remained on the approval phase, though interconnections with other project stages were acknowledged. Contextual factors specific to Ethiopia's public procurement environment also shape the results.

5.5. Suggestions for Future Research

Subsequent studies could apply and refine this framework in private projects, infrastructure works, or other regions to test its broader relevance. Longitudinal or simulation-based research (for example, using system dynamics) could evaluate the real-world impact of the recommended interventions over time. Piloting the proposed digital portal or Change Control Committee mechanisms would generate valuable implementation lessons, while further exploration of collaborative contracting in the Ethiopian context could complement the current findings.

This research highlights both the challenges and the opportunities within Ethiopia's public construction sector. By focusing on systemic causes and evidence-based leverage points, it contributes a practical foundation for stakeholders seeking timelier, cost-effective, and successful project delivery.

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Appendix I

Comprehensive List of factors from literature in Causes of Change Orders approval delay

Thematic Group	**Factor**	**Original Definition of Factor**	**Key References**
Client-Related Factors	Change of plans or scope	Rework /Change in project plans or scope initiated by the client, often due to evolving needs in public sector priorities (e.g., budget reallocations).	(Muhammad, et al., 2015; Mohamad K. Alaryan, 2012; Tigist, 2017).
Client-Related Factors	Inadequate objectives	Inadequate/incomprehensive project objectives by the client (Unclear project goals).	(Ayman, 2016; Mohamad K. Alaryan, 2012; Ogunlana, Promkuntong, & Jearkjirm, 1996).
Client-Related Factors	Change in specification	Change in specification by the client often due to desire to use better specification (Quality/material changes).	(Tadesse, 2009; Mohamad K. Alaryan, 2012).
Client-Related Factors	Financial problems	Financial constraints of the client, including budget shortfalls or delays in releasing funds under Ethiopian public finance laws.	(Muhammad, et al., 2015; Andualem, 2016).
Client-Related Factors	Poor decision making	Weakness in motivating the decision making by the client leading to impediment in prompt decision making (Administrative bottlenecks).	(Tadesse, 2009; Chao-Hui Wu, 2005).

Client-Related Factors	Replacement of materials	The research conveyed that replacement of materials by the client was the most likely cause of change (Material substitution).	(Muhammad, et al., 2015; Mohamad K. Alaryan, 2012; Andualem, 2016).
Client-Related Factors	Obstinate nature	Obstinate nature of the client (Behavioral resistance).	(Tadesse, 2009).
Client-Related Factors	Additional orders	Contributing factors of the client to variations... are mostly client's changes and extra orders (Additional work requests).	(Tadesse, 2009; Mohamad K. Alaryan, 2012; Andualem, 2016; Tigist, 2017).
Client-Related Factors	Bad choice of method	Initial flawed selection of materials or methods by the client, necessitating later changes.	(Tadesse, 2009; Muhammad, et al., 2015; Mikael Hygum Thyssen, 2010).
Client-Related Factors	Wrong information	Wrong information or Inaccurate project data [provided by the client].	(Tadesse, 2009; Muhammad, et al., 2015; Ayman, 2016).
Client-Related Factors	Modifications to design	Change orders are mainly requested by the clients often for modifications to the original design (Design scope changes).	(Andualem, 2016; Mohamad K. Alaryan, 2012; Ijaola, 2012).
Consultant/Designer-Related Factors	Poor/incomplete drawings	Caused by poor/incomplete drawings.	(Tadesse, 2009; Peter E. D. Love, 2004; Mohamad K. Alaryan, 2012; Andualem, 2016).

Consultant/Designer-Related Factors	Errors and omissions	Caused by design errors and omissions (Mistakes in design docs).	(Hsieh, Lu, & Tzeng, 2004; Abebit, 2013; Hamzah, Khoiry, Arshad, Badaruzzaman, & Tawil, 2012; Mendelsohn, 1997).
Consultant/Designer-Related Factors	Poor brief change orders	Change orders due to poor brief (Unclear project brief).	(Ijaola, 2012; Mohamad K. Alaryan, 2012; Ogunlana, Promkuntong, & Jearkjirm, 1996; Chao-Hui Wu, 2005).
Consultant/Designer-Related Factors	Inconsistent site condition	Inconsistent site condition - found during execution compared to design (Incorrect site data).	(Andualem, 2016; Mohamad K. Alaryan, 2012; Hamzah, Khoiry, Arshad, Badaruzzaman, & Tawil, 2012; Peter E. D. Love, 2004).
Consultant/Designer-Related Factors	Improper design improvement	Design revisions for improvements that were inadequately planned initially.	(Tadesse, 2009; Mohamad K. Alaryan, 2012; Abebit, 2013; Hsieh, Lu, & Tzeng, 2004).
Consultant/Designer-Related Factors	Inconsistent info in drawings	Caused by inconsistent information in drawings (Discrepant information).	(Andualem, 2016; Mohamad K. Alaryan, 2012; Peter E. D. Love, 2004).
Consultant/Designer-Related Factors	Discrepancy between contracts	Caused by the discrepancy between contracts (Legal/Contractual conflicts).	(Hsieh, Lu, & Tzeng, 2004; Tadesse, 2009; Mohamad K. Alaryan, 2012; Hamzah, Khoiry,

			Arshad, Badaruzzaman, & Tawil, 2012).
Consultant/Designer-Related Factors	Lack of geo-investigation	Lack of geotechnical investigation/ wrong interpretation of findings (Poor soil analysis).	(Andualem, 2016; Abebit, 2013; Chao-Hui Wu, 2005).
Consultant/Designer-Related Factors	Insufficient site details	Insufficient detail of existing site condition (Missing site info).	(Hamzah, Khoiry, Arshad, Badaruzzaman, & Tawil, 2012; Mohamad K. Alaryan, 2012; Peter E. D. Love, 2004).
Consultant/Designer-Related Factors	Designer's omission	Designer's omission in tender documents (Missing items in tender).	(Tadesse, 2009; Mendelsohn, 1997; Hsieh, Lu, & Tzeng, 2004; Andualem, 2016).
Consultant/Designer-Related Factors	Coordination defects	Coordination defects in tender documents (Poor internal coordination).	(Tadesse, 2009; Mohamad K. Alaryan, 2012; Abebit, 2013; Peter E. D. Love, 2004).
Consultant/Designer-Related Factors	Design errors	Caused by design errors and omissions (Technical design flaws).	(Hsieh, Lu, & Tzeng, 2004; Abebit, 2013; Chao-Hui Wu, 2005).
Consultant/Designer-Related Factors	Poor quality of design	Poor quality of design and specification (Sub-standard drafting).	(Chao-Hui Wu, 2005; Andualem, 2016; Mendelsohn, 1997).
Contractor-Related Factors	Request to use available material	Caused by contractor's request to use the available material (Material substitution).	(Chao-Hui Wu, 2005; Girum, 2022; Mohamad K. Alaryan, 2012; Rahel,

			2016).
Contractor-Related Factors	Save time (Alt. Method)	To use alternative construction method to save time (Process modification).	(Chao-Hui Wu, 2005; Mohamad K. Alaryan, 2012; Andualem, 2016; Rahel, 2016).
Contractor-Related Factors	Save money (Alt. Method)	To use alternative construction methods to money (Process modification).	(Andualem, 2016; Girum, 2022; Chao-Hui Wu, 2005).
Contractor-Related Factors	Correct construction mistakes	To rectify construction mistakes and human errors causing on-site repair work (Corrective rework).	(Girum, 2022; Chao-Hui Wu, 2005; Mohamad K. Alaryan, 2012).
Contractor-Related Factors	Improve quality of work	To improve the quality of works at site (Quality enhancement).	(Andualem, 2016; Girum, 2022; Chao-Hui Wu, 2005; Mohamad K. Alaryan, 2012).
Contractor-Related Factors	Poor management skills	Poor site/project management skills (Operational inefficiency).	(Andualem, 2016; Girum, 2022; Chao-Hui Wu, 2005; Rahel, 2016).
Contractor-Related Factors	Late sub appointment	Delays in appointing subcontractors (Procurement delay).	(Andualem, 2016; Mohamad K. Alaryan, 2012; Girum, 2022; Rahel, 2016).
Contractor-Related Factors	Delay of sub's work	Delays of sub-contractors work (Partner performance issue).	(Chao-Hui Wu, 2005; Girum, 2022; Mohamad K. Alaryan, 2012; Rahel, 2016).

Contractor-Related Factors	Poor workmanship	Poor workmanship (Sub-standard construction).	(Andualem, 2016; Chao-Hui Wu, 2005; Girum, 2022; Rahel, 2016).
Contractor-Related Factors	Low productivity	Low productivity (Labor inefficiency).	(Andualem, 2016; Girum, 2022; Mohamad K. Alaryan, 2012; Rahel, 2016).
Contractor-Related Factors	Poor logistics control	Poor logistic control as a major factor of change order (Supply chain failure).	(Andualem, 2016; Chao-Hui Wu, 2005; Girum, 2022; Rahel, 2016).
Third-Party Related	3rd Party Regulations	Regulation imposed by the third parties(External legal constraints)	(Hsieh, Lu, & Tzeng, 2004; Love & Peter Edwards, 2002; Mekonen, 2025; Sambasivan & Yau, 2007).
Third-Party Related	Government agencies	Change order happens by the cause of government agencies (Regulatory body impact).	(Andualem, 2014; Getachew, 2009; Chao-Hui Wu, 2005; Hsieh, Lu, & Tzeng, 2004).
Third-Party Related	Neighborhood communities	Change order happens by the cause of neighborhood communities (Social environment impact).	(Tadesse, 2009; Hsieh, Lu, & Tzeng, 2004; Love & Peter Edwards, 2002; Sambasivan & Yau, 2007).
Third-Party Related	Utility coordination	Change order happens by the cause of... coordinating with utility systems (Infrastructure interference).	(Andualem, 2016; Chao-Hui Wu, 2005; Getachew, 2009).

Third-Party Related	Neighborhood complaint	The complaint from the neighborhood (Local opposition).	(Andualem, 2014; Hsieh, Lu, & Tzeng, 2004; Sambasivan & Yau, 2007).
Third-Party Related	End user request	The request made by end user.	(Chao-Hui Wu, 2005; Getachew, 2009; Mekonen, 2025; Tadesse, 2009).
Third-Party Related	Regulatory body request	The request from regulatory bodies.	(Andualem, 2016; Hsieh, Lu, & Tzeng, 2004; Sambasivan & Yau, 2007; Tadesse, 2009).
Third-Party Related	Public agency design change	Design change due to public agencies (roads, utilities, and public services).	(Andualem, 2016; Hsieh, Lu, & Tzeng, 2004; Love & Peter Edwards, 2002; Mekonen, 2025).
Political & Economic Factors	Material availability	Materials on the market availability (Market supply shortages).	(Andualem, 2016; Jamal, 2015; Matusala Bassa, 2019; Tadesse, 2009).
Political & Economic Factors	Equipment availability	Equipment and tools on the market availability (Rental market shortages).	(Andualem, 2016; Chao-Hui Wu, 2005; Tadesse, 2009).
Political & Economic Factors	Economic conditions	Economic conditions including inflationary pressure on construction inputs (Price inflation).	(Andualem, 2016; Hsieh, Lu, & Tzeng, 2004; Jamal, 2015; Tadesse, 2009).
Political &	Law and policy	Law and regulation (change in	(Getachew, 2009; Chao-

Economic Factors	changes	Changes in Ethiopian laws or policies affecting public projects), interpretation and understanding of rules and regulations/ Regulatory shifts/.	Hui Wu, 2005; Muhammad, et al., 2015; Ting-ya Hsieh, 2004).
Political & Economic Factors	Complex government regulations	Complex and confusing government regulations	(Andualem, 2016; Jamal, 2015; Matusala Bassa, 2019).
Political & Economic Factors	Changes in policies	Changes in laws and policies [important influences to project change order].	(Getachew, 2009; Tadesse, 2009; Ting-ya Hsieh, 2004).
Environmental Related Factors	Weather conditions	Variations and change order due to severe weather conditions (Adverse climate impact).	(Tigist, 2017; Jamal, 2015; Olawale & Sun, 2010).
Environmental Related Factors	Natural disasters	Occurrence of natural disaster such as flood, earthquake.	(Tigist, 2017) , (Andualem, 2014; Mohamad K. Alaryan, 2012).
Environmental Related Factors	Geological uncertainty	Change order happens by the cause of geological uncertainty (Unforeseen soil issues).	(Getachew, 2009; Jamal, 2015; Olawale & Sun, 2010).
Environmental Related Factors	Unforeseen ground conditions	Variation orders due to unforeseen ground conditions (Unexpected site condition).	(Andualem, 2014; Getachew, 2009; Mohamad K. Alaryan, 2012).

Appendix II

Delphi technique Questionnaire Round One

Date: February 20, 2026

Dear Expert Panel Member,

My name is Ayenew Melese, MSc candidate in Construction Technology and Management at the Federal Technical and Vocational Training Institute. This questionnaire is part of my thesis on “Modeling the Causal Factors of Change Order Approval Delays in Public Building Projects in Addis Ababa: A Fuzzy AHP, DEMATEL and QFD Approach”.

You have been selected as one of 5 experts based on your ≥10 years of experience in public building projects in Addis Ababa. Your input is essential for identifying and reaching consensus on critical factors from literature, as per the multi-round Delphi technique in my methodology. This is **Round 1**. Responses are anonymous, aggregated, and used solely for this academic thesis.

Participation is voluntary.

Estimated time: 20-30 minutes. Submission deadline: February 24, 2026. Aggregated results (means, comments) will be shared in Round 2 for refinement.

Thank you sincerely for your valuable time and expertise.

Please complete this questionnaire carefully and truthfully. If you have questions, contact me at: Addresses of the researcher Phone+251924267686

Email: -AYENEWMELESEZELEKE@gmail.com

With Regards, Ayenew Melese

SECTION 1: Respondent Background (For Validation and Grouping—Anonymous)

1. Condition of worker employment(Employment Status): ☐permanent ☐ contractual ☐ Temporary /daily
2. Respondents designation (Current Position): ☐Client representative ☐ Consultant ☐Contractor ☐ Other-----------------------
3. Relevant working experience in in Public Building Projects (Years):☐ <10Yr ☐ 10-14Yrs ☐15-20Yrs ☐>20Yrs
4. Number of public building projects involved in: ☐<1-5 ☐ 6-10 ☐ 11-15 ☐More than 15
5. Highest Educational Qualification : ☐ Diploma ☐ Bachelor's Degree ☐ Master's Degree ☐PHD ☐others specify
6. Sex : ☐ Male ☐ Female

Section 2: Identification of Critical Factors

Purpose: Reach consensus on critical factors influencing change order approval delays, drawn from literature

Instructions:

Rate the relevance of each factor to change order approval delays in public building projects in Addis Ababa using a 5-point scale (Rate each factor using the following scale):

1 = Not Relevant

2 = Slightly Relevant

3 = Moderately Relevant

4 = Very Relevant

5 = Highly Relevant

Indicate 'Yes' if you believe the factor should be included in the final distilled list of approximately 10–15 critical factors (provide brief justification); otherwise, 'No'.

Prioritization Rule (for researcher use): Factors with average relevance score mean ≥4.0 across the panel and ≥80% majority 'Yes' votes will be prioritized for the final 10–15 list.

At the end, you may nominate additional factors if any are missing from the long-list.

No.	Factor	Original Definition of factor	Relevance (1-5)					Select for Final List(Yes / No) If yes justify /comments
			1	**2**	**3**	**4**	**5**	
I.	**Client-Related Factors**							
1.	Change of plans or scope	Rework /Change in project plans or scope initiated by the client, often due to evolving needs in public sector priorities (e.g., budget reallocations).						
2.	Inadequate objectives	Inadequate/incomprehensive project objectives by the client (Unclear project goals).						
3.	Change in specification	Change in specification by the client often due to desire to use better specification (Quality/material changes).						
4.	Financial problems	Financial constraints of the client, including budget shortfalls or delays in releasing funds under Ethiopian public finance laws.						

5.	Poor decision making	Weakness in motivating the decision making by the client leading to impediment in prompt decision making (Administrative bottlenecks).						
6.	Replacement of materials	The research conveyed that replacement of materials by the client was the most likely cause of change (Material substitution).						
7.	Obstinate nature	Obstinate nature of the client (Behavioral resistance).						
8.	Additional orders	Contributing factors of the client to variations... are mostly client's changes and extra orders (Additional work requests).						
9.	Bad choice of method	Initial flawed selection of materials or methods by the client, necessitating later changes.						
10.	Wrong information	Wrong information or Inaccurate project data [provided by the client].						
11.	Modifications to design	Change orders are mainly requested by the clients often for modifications to the original design (Design scope changes).						
12.	Addition of new work	Addition of new work/scope (Scope expansion) [requested by the client].						
II.	**Consultant/Designer-Related Factors**							
13.	Poor/incomplete drawings	Caused by						

		poor/incomplete drawings.						
14.	Errors and omissions	Caused by design errors and omissions (Mistakes in design docs).						
15.	Poor brief change orders	Change orders due to poor brief (Unclear project brief).						
16.	Inconsistent site condition	Inconsistent site condition - found during execution compared to design (Incorrect site data).						
17.	Improper design improvement	Design revisions for improvements that were inadequately planned initially.						
18.	Inconsistent info in drawings	Caused by inconsistent information in drawings (Discrepant information).						
19.	Discrepancy between contracts	Caused by the discrepancy between contracts (Legal/Contractual conflicts).						
20.	Lack of geo-investigation	Lack of geotechnical investigation/ wrong						

		interpretation of findings (Poor soil analysis).						
21.	Insufficient site details	Insufficient detail of existing site condition (Missing site info).						
22.	Designer's omission	Designer's omission in tender documents (Missing items in tender).						
23.	Coordination defects	Coordination defects in tender documents (Poor internal coordination).						
24.	Design errors	Caused by design errors and omissions (Technical design flaws).						
25.	Poor quality of design	Poor quality of design and specification (Sub-standard drafting).						
III.	**Contractor-Related Factors**							
26.	Request to use available material	Caused by contractor's request to use the available material (Material substitution).						
27.	Save time (Alt. Method)	To use alternative construction method to						

		save time (Process modification).						
28.	Save money (Alt. Method)	To use alternative construction methods to money (Process modification).						
29.	Correct construction mistakes	To rectify construction mistakes and human errors causing on-site repair work (Corrective rework).						
30.	Improve quality of work	To improve the quality of works at site (Quality enhancement).						
31.	Poor management skills	Poor site/project management skills (Operational inefficiency).						
32.	Late sub appointment	Delays in appointing subcontractors (Procurement delay).						
33.	Delay of sub's work	Delays of sub-contractors work (Partner performance issue).						
34.	Poor workmanship	Poor workmanship (Sub-standard construction).						

35.	Low productivity	Low productivity (Labor inefficiency).						
36.	Poor logistics control	Poor logistic control as a major factor of change order (Supply chain failure).						
IV.	**Third-Party Related**							
37.	3rd Party Regulations	Regulation imposed by the third parties(External legal constraints)						
38.	Government agencies	Change order happens by the cause of government agencies (Regulatory body impact).						
39.	Neighborhood communities	Change order happens by the cause of neighborhood communities (Social environment impact).						
40.	Utility coordination	Change order happens by the cause of... coordinating with utility systems (Infrastructure interference).						
41.	Neighborhood complaint	The complaint from the neighborhood						

		(Local opposition).							
42.	End user request	The request made by end user.							
43.	Regulatory body request	The request from regulatory bodies.							
44.	Public agency design change	Design change due to public agencies (roads, utilities, and public services).							
V.	**Political & Economic Factors**								
45.	Material availability	Materials on the market availability (Market supply shortages).							
46.	Equipment availability	Equipment and tools on the market availability (Rental market shortages).							
47.	Economic conditions	Economic conditions including inflationary pressure on construction inputs (Price inflation).							
48.	Law and policy changes	Law and regulation (change in Changes in Ethiopian laws or policies affecting public projects),							

		interpretation and understanding of rules and regulations / Regulatory shifts/.						
49.	Complex government regulations	Complex and confusing government regulations						
50.	Changes in policies	Changes in laws and policies [important influences to project change order].						
VI.	**Environmental Related Factors**							
51.	Weather conditions	Variations and change order due to severe weather conditions (Adverse climate impact).						
52.	Natural disasters	Occurrence of natural disaster such as flood, earthquake.						
53.	Geological uncertainty	Change order happens by the cause of geological uncertainty (Unforeseen soil issues).						
54.	Unforeseen ground conditions	Variation orders due to unforeseen ground conditions (Unexpected site						

		condition).						

SECTION 3: Overall Feedback

1. Are any important factors missing?

   ☐ Yes (If yes, please specify):- ☐ No

2. Are any factors redundant or irrelevant?

   ☐ Yes (If yes, please specify):- ☐ No

3. General suggestions:-----------------------

Appendix III

Delphi technique Questionnaire Round Two

Date: February 28, 2026

Dear Expert Panel Member,

My name is Ayenew Melese, MSc candidate in Construction Technology and Management at the Federal Technical and Vocational Training Institute. This questionnaire is part of my thesis on "Modeling the Causal Factors of Change Order Approval Delays in Public Building Projects in Addis Ababa: A Fuzzy AHP and DEMATEL Approach".

Thank you for your participation in Round One. Based on your collective input, we have aggregated the results (means, % agreement on inclusion, and anonymized comments) to refine the list toward consensus on 10-15 critical factors. This is **Round Two**. Responses remain anonymous, aggregated, and used solely for this academic thesis.

Participation is voluntary.

Estimated time: 15-25 minutes. Submission deadline: March 4, 2026.

After this round, the final distilled list will be confirmed for my analysis.

Thank you again for your expertise in helping shape this study. Please complete this questionnaire carefully and truthfully. If you have questions, contact me at: Addresses of the researcher

Phone+251924267686 Email: -AYENEWMELESEZELEKE@gmail.com

With Regards, Ayenew Melese

SECTION 1: Respondent Background (For Validation and Grouping - Anonymous)

1. Condition of worker employment(Employment Status): ☐permanent ☐ contractual ☐ Temporary /daily
2. Respondents designation (Current Position): ☐Client representative ☐ Consultant ☐Contractor ☐ Other-----------------------
3. Relevant working experience in in Public Building Projects (Years):☐ <10Yr ☐ 10-14Yrs ☐15-20Yrs ☐>20Yrs
4. Number of public building projects involved in: ☐<1-5 ☐ 6-10 ☐ 11-15 ☐More than 15
5. Highest Educational Qualification : ☐ Diploma ☐ Bachelor's Degree ☐ Master's Degree ☐PHD ☐others specify
6. Sex : ☐ Male ☐ Female

SECTION 2: Refinement of Critical Factors

Purpose: Build consensus on the final 10-15 critical factors by reviewing Round One aggregates and re-evaluating.

Round One Summary: From the 54 factors, 31 met the prioritization rule (average relevance mean ≥4.0 and ≥80% "Yes" votes for inclusion). Aggregated comments (anonymized and summarized from panel) are provided to inform your refinement. Three new factors were nominated by the panel and are added for initial rating.

Instructions:

Review each prioritized factor's Round One mean relevance, % "Yes" for inclusion, and summarized comments.

Re-rate the relevance on the 5-point scale only if your opinion has changed based on the group feedback (otherwise, leave as is or note "No change").

1 = Not Relevant, 2 = Slightly Relevant, 3 = Moderately Relevant, 4 = Very Relevant, 5 = Highly Relevant

Indicate 'Yes' if the factor should be in the final 10-15 list (provide brief justification if changed from Round One); otherwise, 'No'.

Suggest any merges (e.g., "Merge with Factor X due to overlap") or redundancies in the comments column.

For the three new nominated factors (at the end), rate relevance and select for inclusion as in Round One.

Prioritization Rule for Final List (researcher use): Factors with revised mean ≥4.0 and ≥80% "Yes" will be included; merges will be applied based on majority suggestions to reach 10-15.

No.	Factor	Original Definition of factor	Round One Mean Relevance	Round One % Yes	Aggregated Comments (Anonymized)	Your Re-Rate (1-5, if changed)	Select for Final List (Yes/No	Your Comments/Merge Suggestions
I.	**Client-Related Factors**							
1.	Change of plans or scope	Rework /Change in project plans or scope initiated by the client, often due to evolving needs in public sector priorities (e.g., budget reallocations).	4.6	100 %	Common in budget shifts; evolving public needs force tweaks; frequently alters plans mid-project; seen in designs needing updates; delays site work massively.			
3.	Change in specification	Change in specification by the client often due to desire to use better specification	4.4	100 %	Quality upgrades typical but slow; material changes for standards; direct impact on timelines;			

		(Quality/material changes).			common in public tenders; forces re-bidding.			
4.	Financial problems	Financial constraints of the client, including budget shortfalls or delays in releasing funds under Ethiopian public finance laws.	4.8	100 %	Funding delays rampant in public sector; budget laws cause lags; affects decisions; key bottleneck in Ethiopia; stops work until release.			
5.	Poor decision making	Weakness in motivating the decision making by the client leading to impediment in prompt decision making (Administrative bottlenecks).	4	80 %	Administrative layers slow approvals; bureaucracy major source; often multi-level reviews; client indecision halts progress.			
8.	Additional orders	Contributing factors of the client to variations... are mostly client's changes and extra orders (Additional work	4.4	100 %	Extra work requests common; adds to scope creep; leads to extended reviews; frequent in public buildings; increases			

		requests).			approval time.			
11.	Modifications to design	Change orders are mainly requested by the clients often for modifications to the original design (Design scope changes).	4.8	100 %	Design changes core delays; often client-driven; impacts approval chain; key in adaptive projects; always needs re-approval.			
12.	Addition of new work	Addition of new work/scope (Scope expansion) [requested by the client].	4.2	100 %	Scope expansion frequent; public priorities shift; adds complexity; common addition; delays timelines.			
II. **Consultant/Designer-Related Factors**								
13.	Poor/incomplete drawings	Caused by poor/incomplete drawings.	4.6	100 %	Incomplete doc's slow reviews; leads to clarifications; major design flaw; core issue in approvals; causes site stoppages.			
14.	Errors and omissions	Caused by design errors and omissions	4.8	100 %	Common in rushed designs; triggers change			

		(Mistakes in design docs).			orders; high relevance; essential to fix early; affects construction.			
16.	Inconsistent site condition	Inconsistent site condition - found during execution compared to design (Incorrect site data).	4.8	100 %	Site mismatches common; unexpected findings; key delay factor; requires geo-checks; major on-ground issue.			
18.	Inconsistent info in drawings	Caused by inconsistent information in drawings (Discrepant information).	4.6	100 %	Discrepancies slow; causes confusion; high impact; technical errors; leads to reworks.			
19.	Discrepancy between contracts	Caused by the discrepancy between contracts (Legal/Contractual conflicts).	4.6	100 %	Legal conflicts delay; common in public contracts; affects approvals; key contractual issue; disputes arise.			
20.	Lack of geo-investigation	Lack of geotechnical investigation/ wrong interpretation of	5	100 %	Poor soil analysis critical; unforeseen issues; essential pre-design;			

		findings (Poor soil analysis).			major in Addis terrain; always a risk.			
21.	Insufficient site details	Insufficient detail of existing site condition (Missing site info).	4.4	100 %	Missing info delays; site surveys lacking; direct cause; common oversight; affects planning.			
24.	Design errors	Caused by design errors and omissions (Technical design flaws).	5	100 %	Technical flaws major; overlaps with errors; high relevance; core problem; causes changes.			
25.	Poor quality of design	Poor quality of design and specification (Sub-standard drafting).	4.2	100 %	Sub-standard work; drafting issues; impacts overall; key quality factor; leads to delays.			
III. **Contractor-Related Factors**								
29.	Correct construction mistakes	To rectify construction mistakes and human errors causing on-site repair work (Corrective	4.8	100 %	Reworks necessary; human errors; on-site fixes; common; always happens.			

		rework).						
30.	Improve quality of work	To improve the quality of works at site (Quality enhancement).	4	100 %	Quality enhancements; site improvements; relevant; upgrades; essential.			
31.	Poor managemen t skills	Poor site/project management skills (Operational inefficiency).	4.4	80 %	Operational issues; inefficiency delays; management flaws; key contractor issue.			
34.	Poor workmanshi p	Poor workmanship (Sub-standard construction).	4.6	100 %	Sub-standard work; construction quality; impacts approvals; triggers changes; occasional issue.			
36.	Poor logistics control	Poor logistic control as a major factor of change order (Supply chain failure).	4.8	100 %	Supply chain failures; logistics key; major factor; in Addis context; critical for materials.			
IV. **Third-Party Related**								
37.	3rd Party	Regulation	4.6	100	External			

	Regulations	imposed by the third parties(External legal constraints)		%	constraints; legal impacts; regulations delay; common.			
38.	Government agencies	Change order happens by the cause of government agencies (Regulatory body impact).	5	100 %	Regulatory body impact; govt interference; high relevance; key in public; delays approvals.			
40.	Utility coordination	Change order happens by the cause of coordinating with utility systems (Infrastructure interference).	4.6	100 %	Infrastructure interference; utility clashes; common in urban; essential; major site issue.			
43.	Regulatory body request	The request from regulatory bodies.	4.8	100 %	Requests from bodies; compliance; high impact; core; frequent.			
V. **Political & Economic Factors**								
45.	Material availability	Materials on the market availability (Market supply shortages).	5	100 %	Market shortages; supply issues; economic factor; key in Ethiopia; critical.			
47.	Economic conditions	Economic conditions	5	100 %	Price inflation; inflationary			

		including inflationary pressure on construction inputs (Price inflation).			pressure; high impact; economic shifts; affects budgets.			
48.	Law and policy changes	Law and regulation (change in Changes in Ethiopian laws or policies affecting public projects), interpretation and understanding of rules and regulations / Regulatory shifts/.	4.6	100 %	Regulatory shifts; changes in laws; interpretation issues; major; policy impacts.			
49.	Complex government regulations	Complex and confusing government regulations	4.8	100 %	Confusing rules; gov't complexity; delays approvals; key bottleneck; always present.			
VI. **Environmental Related Factors**								
53.	Geological uncertainty	Change order happens by the cause of geological	4.8	100 %	Unforeseen soil; geo issues; high relevance; Addis terrain; critical.			

		uncertainty (Unforeseen soil issues).						
54.	Unforeseen ground conditions	Variation orders due to unforeseen ground conditions (Unexpected site condition).	5	100 %	Unexpected site; overlaps with geological; key; common; always a risk.			
New Nominated Factors (From Round One Panel Suggestions)								
N1	Bureaucratic approval layers	Multi-level government approval processes causing delays in decision-making.	N/A (New)	N/A	Nominated as missing: Often ties into administrative bottlenecks in Ethiopian public projects.			
N2	Corruption in procurement	Irregularities in bidding or material selection processes leading to revisions.	N/A (New)	N/A	Nominated as missing: Common issue affecting fair approvals and changes.			
N3	Labor shortages due to migration	Shortages in skilled labor from workforce migration,	N/A (New)	N/A	Nominated as missing: Affects productivity and on-site			

		impacting execution and necessitating changes.			adjustments in Addis Ababa context.			

Note:- In the previous Round one response **,** factors of item number 2,6,7,9,10,15,17,22,23,26,27,28,32,33,35,39,41,42,44,46,50,51,52 are not satisfy aggregation rule therefore it also not include in Round two checklist.

SECTION 3: Overall Feedback

1. After reviewing aggregates, are any important factors still missing?

   ☐ Yes (If yes, please specify):- ☐ No

2. Are any factors redundant or irrelevant now? (Suggest merges if applicable)

   ☐Yes (If yes, please specify) ☐No

3. General suggestions for the final list or process:-

Appendix IV

Pilot study

Date: March 15, 2026

Dear Respondent,

My name is Ayenew Melese, MSc candidate in Construction Technology and Management at the Federal Technical and Vocational Training Institute. This pilot questionnaire is part of an academic research; I am conducting research on modeling the Causal Factors of Change Order Approval Delays in Public Building Projects in Addis Ababa: A Fuzzy AHP, DEMATEL and QFD Approach. This **pilot study** is conducted to validate and refine the research instrument before the main data collection. Specifically, it seeks to:

- Confirm the clarity and relevance of the identified critical factors.
- Evaluate the practicality of the FAHP pairwise comparison structure.
- Evaluate the clarity of the DEMATEL causal influence assessment.
- Identify ambiguous wording, structural weaknesses, or technical difficulties and usability of the questionnaire.
- Improve the overall reliability and validity of the research instrument

The critical factors presented in this instrument were identified through an extensive literature review and finalized using a **two-round Delphi method involving expert consultation**, where consensus was achieved among professionals. Your expert judgment is highly appreciated. All responses will remain confidential and used solely for academic purposes. Estimated time completion: 45–60 minutes. Submission deadline: March 28, 2026

Thank you for your valuable time and cooperation.

Addresses of the researcher Phone +251 924267686

Email: ------ AYENEWMELESEZELEKE@gmail.com

With Regards, Ayenew Melese

SECTION A — GENERAL ORGANIZATION (Respondent Background) Information (Please tick ✓ or fill where appropriate) two client representative, two consultants, and one contractors

1. Condition of worker employment (Employment Status): ☐permanent ☐ contractual ☐ Temporary /daily

2. Respondents designation (Current Position): ☐Client representative ☐ Consultant ☐Contractor ☐ Other-----------------------

3. Relevant working experience in in Public Building Projects (Years):☐ <10Yr ☐10-14Yrs ☐15-20Yrs ☐>20Yrs

4. Number of public building projects involved in: ☐<1-5 ☐ 6-10 ☐ 11-15 ☐ More than 15

5. Highest Educational Qualification: ☐ Diploma ☐ Bachelor's Degree ☐Master's Degree ☐PHD ☐others specify

6. Sex: ☐ Male ☐ Female

Code	Critical Factor	Description
F1	Client-initiated scope changes & additional orders	All client-driven changes in plans, scope, additions and extra orders
F2	Change in specification	Client requests for better quality or material specifications
F3	Financial problems of the client	Budget shortfalls and delays in releasing public funds
F4	Design errors, omissions and poor/incomplete drawings	Mistakes, inconsistencies and sub-standard design documents

F5	Inconsistent site condition and insufficient site details	Mismatches or missing information between design and actual site
F6	Lack of geotechnical investigation	Absence or wrong interpretation of soil investigations
F7	Unforeseen ground and geological conditions	Unexpected soil or geological issues discovered on site
F8	Poor workmanship and corrective construction mistakes	Sub-standard work and on-site errors requiring rework
F9	Poor logistics and material supply control	Supply chain failures and poor logistics management
F10	Government agencies, regulatory bodies and bureaucratic approval layers	All government interference, requests and multi-level approval delays
F11	Material availability in the market	Shortages of construction materials in the local market
F12	Economic conditions and price inflation	Inflation, economic shifts and changes in laws/policies affecting costs

SECTION B: VALIDATION OF CRITICAL FACTORS (Finalized Through Two-Round Delphi Method)

The following critical factors were refined and finalized through a structured two-round Delphi process involving experienced professionals in public building projects. Expert consensus was achieved before inclusion in this study.

Validation Questions:-Although these factors were finalized through the Delphi method, your feedback is essential to confirm their clarity and practical relevance before the main survey.

1. Are the above factors clearly described and understandable? ☐Very Clear ☐ Clear ☐ Moderately Clear ☐Unclear
2. Do these factors adequately represent the main causes of change order approval delays in Addis Ababa public building projects?
   ☐ yes ☐No (Please specify): -
3. Are any factors overlapping, ambiguous, or requiring refinement?

SECTION C — FAHP Pairwise Comparison (Assessment of Relative Importance)

- **Objective: -** To evaluate/ determine the relative importance of each identified factor contributing to change order approval delays.
- **Instruction:** Compare two factors at a time (compare each pair of factors) and indicate which factor has greater importance and to what extent using the provided 1–9 scale.
- **Recording Judgments:** Fill only the upper triangular part of the matrix.
  - **Diagonal values** are pre-set to 1 (a factor is equally important to itself).
  - **Consistency Check:** Please ensure your comparisons are transitive. If F1>F2 and F2>F3, then F1 must be rated as more important than F3. Consistent responses are critical for the Mathematical Consistency Ratio (CR) validation.
  - Reciprocal values and Consistency Ratio (CR) will be calculated during analysis.
  - You are not required to perform any calculations.

Use the scale below:

Scale	Degree of influence/ Linguistic Judgment	Triangular Fuzzy Number
1	Equally important	(1,1,1)
2	Weakly more important	(1, 2, 3)
3	Moderately more important	(2,3,4)
4	Moderately strong important	(3, 4, 5)
5	Strongly more important	(4,5,6)
6	Strong to very strong important	(5, 6, 7)
7	Very strongly more important	(6,7,8)
8	Very to extremely strong important	(7, 8, 9)
9	Extremely more important	(8,9,9)

R.M:- (Even numbers 2,4,6,8 may be used for intermediate judgments. Fill the upper triangular part of the matrix may be you using or fill Reciprocal value (1/2, 1/3, 1/4, 1/5, 1/6,1/7.1/8,1/9)Are indicate that row factors less important than column factors.

Pairwise Comparison Matrix (Fuzzy AHP):- Only upper triangular part to be completed and Fill only one judgment for each comparison.

Factor	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
F1	1											
F2		1										
F3			1									
F4				1								
F5					1							
F6						1						
F7							1					
F8								1				
F9									1			
F10										1		
F11											1	
F12												1

SECTION D — Fuzzy DEMATEL Influence Assessment (Causal Relationship Analysis)

Objective: - to determine the degree of influence among the critical factors and identify cause–effect relationships.

Instruction:-

- Indicate how much the row factor influences the column factor.
- Row factor → influences → Column factor Instruction Indicate how much the row factor influences the column factor.
- Use the 0–4 scale.
- Diagonal values must be rated as 0 (no self-influence).
- No mathematical calculations required.

Scale	Degree of influence/Influence Level	Triangular fuzzy number (l, m, u)
0	No Influence:	(0, 0, 0.25)
1	Low Influence:	(0, 0.25, 0.50)
2	Medium Influence:	(0.25, 0.50, 0.75)
3	High Influence:	(0.50, 0.75, 1.00)
4	Very High Influence:	(0.75, 1.00, 1.00)

Direct Influence Matrix (Fuzzy DEMATEL)

Influencing Factor →	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
F1	0											
F2		0										
F3			0									
F4				0								
F5					0							
F6						0						
F7							0					
F8								0				
F9									0			
F10										0		
F11											0	
F12												0

1. The instructions were clear and easy to understand.

   ☐Strongly Agree ☐ Agree ☐Neutral ☐Disagree

2. The structure of the questionnaire was logical and organized.

   ☐Strongly Agree ☐ Agree ☐Neutral ☐Disagree

3. The overall difficulty level was:

   ☐Easy ☐Moderate ☐Difficult

4. Approximate time required to complete the questionnaire: ☐Less than 30 minute’s
   ☐30–60 minutes ☐ 60-90minutes ☐More than 90 minutes

5. Suggestions for improvement of this questionnaire

   ☐No ☐ Yes (please specify):-

Appendix V

SHORT SEMI-STRUCTURED INTERVIEW OF PILOT SURVEY

(Conducted after Questionnaire Completion) Duration: 10–15 minutes.

Interview Question 1:-Based on your professional experience, do the finalized Delphi factors adequately reflect the primary causes of change order approval delays in Addis Ababa public building projects? Please explain.

Interview Question 2:-Was the FAHP pairwise comparison process clear and manageable? What challenges did you face or as experienced?

Interview Question 3:- Did you clearly understand the DEMATEL causal influence assessment (row influencing column)? Were any relationships difficult to evaluate?

Appendix VI

Main questionnaire

Dear respondents

My name is Ayenew Melese, an MSc candidate pursuing research on modeling the causal factors contributing to delays in change order approvals for public building projects in Addis Ababa. This main questionnaire forms a core part of my thesis, employing a hybrid approach with Fuzzy Analytic Hierarchy Process (FAHP), Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL), and Quality Function Deployment (QFD) to analyze these factors and propose mitigation strategies.

Insights from a pilot study helped refine the instrument and consolidate overlapping site-related issues. This results in a streamlined list of ten critical factors, derived from an extensive literature review and a two-round Delphi consensus. The survey now asks you to:

1. Confirm the practical relevance of these factors in your experience.
2. Compare their relative importance using FAHP pairwise comparisons.
3. Assess direct influence relationships among them using FDEMATEL.
4. Provide brief comments on mitigation suggestions to inform the QFD phase for strategic mitigation.

All information you provide will remain confidential and will be used solely for academic purposes. The estimated time to complete the questionnaire is 30–90 minutes (refined based on pilot feedback).

For any questions, please contact me at: - Phone+251924267686

Email: AYENEWMELESEZELEKE@gmail.com

Thank you for taking the time to share your professional experience

With Regards

Ayenew Melese

SECTION 1: GENERAL ORGANIZATION (Respondent Background) Information

(Please tick √ or fill where appropriate. The responses fill by stakeholder group such as client representatives, consultants, or contractors.)

1. Condition of worker employment(Employment Status): ☐ permanent ☐Contractual ☐Temporary /daily
2. Respondents designation (Current Position): ☐Client representative ☐ Consultant ☐Contractor ☐Other-----------------------
3. Relevant working experience in Public Building Projects (Years): ☐ <10Yr ☐ 10-14Yrs ☐ 15-20Yrs ☐ >20Yrs
4. Number of public building projects you have been involved in: ☐ <1-5 ☐6-10 ☐11-15 ☐ More than 15
5. Highest Educational Qualification : ☐Diploma ☐Bachelor's Degree ☐Master's Degree ☐ PHD☐ others specify
6. Sex : ☐Male ☐Female

SECTION 2: Validation and Practical Confirmation of Critical Factors

The following ten critical factors were identified through a comprehensive review of relevant literature and subsequently refined using a two-round Delphi process involving experienced professionals. The pilot study further helped to improve clarity, remove overlaps, and ensure that the factors are understandable and applicable to real project conditions.

This section is designed to both validate these factors and confirm their practical relevance based on your professional experience in public building projects in Addis Ababa. Your responses will ensure that the selected factors accurately reflect the real causes of change order approval delays and are suitable for the subsequent FAHP and FDEMATEL analyses.

Code	Critical Factor	Description
F1	Client-initiated scope changes & additional orders	Client-driven alterations to project plans, scope expansions, or extra requirements.
F2	Change in specification	Client demands for upgraded quality, materials, or standards.
F3	Financial problems of the client	Budget constraints, funding shortages, or delays in disbursing public funds.

F4	Design errors, omissions, and poor/incomplete drawings	Flaws (mistakes), inconsistencies, or inadequate details in design documents.
F5	Site and geotechnical assessment inadequacies and unforeseen conditions	Inadequate pre-construction site evaluation (including insufficient details, lack of geotechnical investigation, and misinterpretation) leading to design mismatches and unexpected geological issues.
F6	Poor workmanship and corrective construction mistakes	Substandard execution and on-site errors necessitating rework.
F7	Poor logistics and material supply control	Failures in supply chain management and material procurement.
F8	Government agencies, regulatory bodies and bureaucratic approval layers	Interventions (interference), requirements, or delays from government entities and multi-tier (level) approvals.
F9	Material availability in the market	Shortages or unavailability of construction materials locally.
F10	Economic conditions and price inflation	Fluctuations in economy, inflation, or policy changes impacting costs.

Note: Scope changes (F1) refer to modifications in the extent or quantity of work, while specification changes (F2) refer to adjustments in technical standards or material quality without altering the overall scope.

Validation and Relevance Assessment

Based on your experience, please evaluate the following:

1. Do these factors practically reflect the key causes of change order approval delays? ☐ Yes ☐ No (If no, please explain):-----------
2. Rate the overall relevance of this list to real-world delays: ☐ Very Relevant ☐ Relevant ☐ Moderately Relevant ☐ Not Relevant

3. Any additional factors you believe should be included? (Optional)________

SECTION 3: FAHP Pairwise Comparison (Assessment of Relative Importance)

Objective: To determine the relative importance of each factor in contributing to change order approval delays.

Instructions: Compare factors pairwise (row vs. column) and indicate which is more important and by how much, using the 1-9 scale below. Fill only the upper triangular part of the matrix (diagonal is preset to 1). Ensure transitivity (e.g., if A > B and B > C, then A > C). Use even numbers (2, 4, 6, and 8) for intermediates if needed. Reciprocals (e.g., 1/3) indicate the row factor is less important than the column. No calculations are required from respondents; consistency will be checked during analysis. (Pilot feedback: A brief example is provided below for clarity.)

Example: If Factor A is moderately more important than Factor B, enter 3. If Factor B is moderately more important than Factor A, enter 1/3.

Scale:

Scale	Degree of Importance / Linguistic Judgment	Triangular Fuzzy Number
1	Equally important	(1,1,1)
2	Weakly more important	(1,2,3)
3	Moderately more important	(2,3,4)
4	Moderately strong important	(3,4,5)
5	Strongly more important	(4,5,6)
6	Strong to very strong important	(5,6,7)
7	Very strongly more important	(6,7,8)
8	Very to extremely strong important	(7,8,9)
9	Extremely more important	(8,9,9)

Pairwise Comparison Matrix (Fuzzy AHP):-

Please fill only one judgment for each comparison.

Factor	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
F1	1											
F2		1										
F3			1									
F4				1								
F5					1							
F6						1						
F7							1					
F8								1				
F9									1			
F10										1		
F11											1	
F12												1

SECTION 4: Fuzzy DEMATEL Influence Assessment (Causal Relationship Analysis)

Objective: To identify cause-effect relationships by assessing how much one factor influences another.

Instructions: For each pair, rate how strongly the row factor influences the column factor using the 0-4 scale. Diagonal is preset to 0 (no self-influence). Focus on direct influences. No calculations needed. (**Pilot feedback:** Please remember that the direction of influence matters. Each entry should reflect how much the factor in the row affects the factor in the column. Focus only on direct relationships based on your practical experience.)

Example:-

(Pilot feedback):- Suppose you are assessing how one factor influences another. If you believe that F1 (Client-initiated scope changes) has a strong effect on F4 (Design errors, omissions, and poor drawings), you may assign a value of 3 (high influence) in the cell where row F1 intersects with column F4. On the other hand, if you think that F4 has only a minor effect on F1, you may assign a value of 1 (low influence) in the corresponding cell. If you consider that there is no direct influence between two factors, you should assign a value of 0.

Scale:-

Scale	Degree of influence / Influence Level	Triangular Fuzzy Number
0	No Influence:	(0, 0, 0.25)
1	Low Influence:	(0, 0.25, 0.50)
2	Medium Influence:	(0.25, 0.50, 0.75)
3	High Influence:	(0.50, 0.75, 1.00)
4	Very High Influence:	(0.75, 1.00, 1.00)

Direct Influence Matrix (Fuzzy DEMATEL)

Influencing Factor →	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0									
F2		0								
F3			0							
F4				0						
F5					0					
F6						0				
F7							0			
F8								0		
F9									0	
F10										0

SECTION 5: PRACTICAL MITIGATION SUGGESTIONS (QFD INPUT)

Objective: To gather practical insights on addressing these factors, informing the QFD phase for strategic mitigation recommendations.

Instructions: For each factor, briefly suggest 1-2 mitigation strategies based on your experience (e.g., processes, tools, or policies). Keep responses concise (1-2 sentences per factor) this will help translate causal analysis into actionable project improvements.

F1 (Client-initiated scope changes & additional orders): ___________________________

F2 (Change in specification): ____

F3 (Financial problems of the client): _________________________

F4 (Design errors, omissions, and poor/incomplete drawings): _______________________

F5 (Site and geotechnical assessment inadequacies and unforeseen conditions): ___________

F6 (Poor workmanship and corrective construction mistakes): _________________________

F7 (Poor logistics and material supply control): _________________________

F8 (Government agencies, regulatory bodies, and bureaucratic approval layers): __________

F9 (Material availability in the market): _________________________

F10 (Economic conditions and price inflation): _________________________

Overall Comments (Optional): Any general thoughts on mitigating change order delays in Addis Ababa public projects? _________________________

Feedback on Questionnaire

1. The instructions were clear and easy to understand: ☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree
2. The structure was logical and organized: ☐ Strongly Agree ☐ Agree

   ☐ Neutral ☐ Disagree
3. Overall difficulty level: ☐ Easy ☐ Moderate ☐ Difficult
4. Approximate completion time: ☐ <30 minutes ☐ 30-45 minutes ☐ >45 minutes
5. Suggestions for improvement:

   ☐ No ☐ Yes (specify): _________________________

Thank you for your time and insights. Your input will directly contribute to better practices in public building projects. Please return the completed questionnaire via email.

Appendix VII

SECTION 5: PRIORITIZATION OF STRATEGIC MITIGATION INTERVENTIONS

Fuzzy Quality Function Deployment (FQFD) – Relationship Matrix

Dear Respondent,

Thank you for your continued valuable contribution to this research.

This final section aims to translate the research findings into practical, actionable solutions. Using the Fuzzy Quality Function Deployment (FQFD) approach, we kindly request your expert judgment on how effectively various strategic mitigation interventions can address the root-driver factors (WHATs) identified through the Fuzzy DEMATEL analysis.

Your professional insights will help develop a prioritized roadmap for reducing change order approval delays in public building projects in Addis Ababa.

Instructions:

1. The WHATs (left column) are the five root-driver factors with the strongest influence on change order approval delays.
2. The HOWs (top row) are strategic mitigation interventions synthesized from expert suggestions and literature
3. For each cell, evaluate the strength of the relationship between each mitigation strategy and each root-driver factor using the following linguistic scale:

Linguistic Scale for Relationship Strength

Symbol	Linguistic Term	Triangular Fuzzy Number
W	Weak Relationship	(0, 0, 0.3)
M	Medium Relationship	(0.3, 0.5, 0.7)
S	Strong Relationship	(0.7, 1.0, 1.0)

Please based your assessment on your practical experience in public building projects in Addis Ababa.

Root-Driver Factors (WHATs)

Code	Root-Driver Factor	Operational Definition
F1	Client-initiated scope changes & additional orders	Client-driven modifications to project plans, scope expansions, or extra orders
F2	Change in specification	Requests for alternative or higher-quality materials/specifications
F3	Financial problems of the client	Budget shortfalls and delays in releasing public funds
F8	Government agencies, regulatory bodies & bureaucratic approval layers	Multi-level administrative and regulatory approval bottlenecks
F10	Economic conditions and price inflation	Market volatility, inflation, and related policy changes

Strategic Mitigation Interventions (HOWs)

Code	Mitigation Strategy
S1	Establish a formal Change Control Committee with clear authority and strict timelines
S2	Implement strict scope freeze policy after design approval stage with robust front-end planning
S3	Create ring-fenced budgets, dedicated escrow accounts, and improved financial management mechanisms for variations
S4	Develop a one-stop digital approval portal with enforceable service level agreements (SLAs)
S5	Conduct mandatory value engineering workshops and joint stakeholder reviews during planning phase

S6	Strengthen pre-contract geotechnical investigations and include clear contractual provisions for unforeseen conditions
S7	Implement continuous capacity building programs and foster more collaborative project delivery approaches among stakeholders
S8	Reduce unnecessary bureaucratic approval layers, appoint single focal persons, and promote policy-level reforms
S9	Adopt Building Information Modeling (BIM), digital tools, and full digitalization of approval and change management processes
S10	Introduce automatic CPI-linked price escalation clauses combined with quarterly price review mechanisms

Fuzzy QFD Relationship Matrix

Please indicate the strength of relationship by placing W, M, or S in each cell.

Root Drivers (WHATs) ↓	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
F1 – Client-initiated scope changes										
F2 – Change in specification										
F3 – Financial problems of the client										
F8 – Bureaucratic & regulatory delays										
F10 – Economic conditions & price inflation										

Additional Comments (Optional)

1. Do you recommend any other important mitigation strategies?
2. Which three strategies do you believe would have the greatest overall impact?
3. Any general remarks on improving change order approval processes in Addis Ababa public building projects?

Thank you very much for completing this questionnaire!

Your expert input is highly valuable and will contribute directly to practical recommendations for the Ethiopian construction industry.

Appendix VIII

DETAILED THRESHOLD MATRIX (α) AND SIGNIFICANT CAUSE-AND-EFFECT RELATIONSHIPS FROM FUZZY DEMATEL ANALYSIS

Table show: Threshold value (α) and causal (a cause-and-effect relationship) matrix ($\alpha = 0.28084$).

This table presents the filtered total-relation matrix after applying the threshold value ($\alpha = 0.28084$). Only relationships equal to or greater than the threshold are shown. Zeros indicate relationships below the threshold.

Factor	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0	0.298	0.3694	0.3668	0.3561	0.3959	0.4255	0	0	0
F2	0	0	0.3148	0.3446	0.3136	0.3624	0.3814	0	0	0
F3	0.3013	0.2933	0.2984	0.3813	0.3891	0.4229	0.467	0.2915	0.3558	0.3505
F4	0	0	0	0	0.2844	0.3059	0.3398	0	0	0
F5	0	0	0	0	0	0.2842	0.3126	0	0	0
F6	0	0	0	0	0	0	0	0	0	0
F7	0	0	0.346	0.3174	0.3203	0.3828	0.3199	0	0.3422	0.2812
F8	0.3131	0.2856	0.3948	0.3359	0.3796	0.4038	0.4396	0	0.3084	0.3205
F9	0	0	0	0	0.2918	0	0.3377	0	0	0
F10	0	0	0.3569	0	0.3332	0.3681	0.3993	0	0.317	0